# Lithium-ion battery: a review

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**Abstract:** Lithium-Ion Batteries (LIBs) play a crucial role in electric vehicles and energy storage systems, and their importance continues to grow as their utilisation is increasing day-by-day with a greater number of battery-powered vehicles on the road. In this paper, an extensive literature review has been discussed in the domain of LIBs. Research papers published during the last 12 years, from 2010 to 2022 are critically reviewed. The literature review is classified into five sections: types of batteries, battery technologies, opportunities and challenges, mechanical recycling techniques and adoption of proper recycling techniques, sustainability impact, product life cycle analysis and comparison of the lithium-ion batteries with presently available battery techniques. Several models have been studied to simulate and replicate the dynamic behaviours of Li-ion batteries. This comprehensive review serves as a valuable resource for researchers, in understanding the current state of LIBs and their implications.

**Keywords:** LIBs; lithium-ion batteries; mechanical recycling techniques; sustainability; product life cycle analysis.

**Reference** to this paper should be made as follows: Bidwe, M.M. and Kulkarni, S.G. (2024) 'Lithium-ion battery: a review', *Int. J. Vehicle Information and Communication Systems,* Vol. 9, No. 2, pp.135–163.

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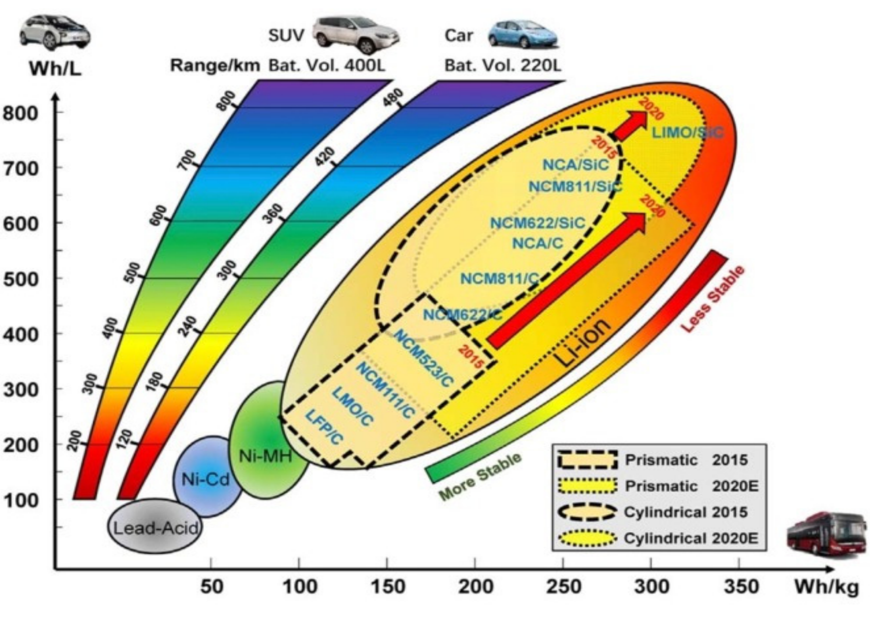
## 1 Introduction

Electric Vehicles (EVs) are an effective way to reduce greenhouse gas emissions. EVs reduce reliance on fossil fuels, minimise ozone-depleting substances and facilitate large-scale renewable deployment (Chen et al., 2015; Asef et al., 2021). EV production and network modelling continue to evolve and be constrained, despite substantial studies on the features and attributes of EVs and the nature of their charging infrastructure (Ceder, 2010; Chen et al., 2020; Barraza and Estrada, 2021). EVs can help lessen climate change's effects. EVs are also designed to help with decarbonisation and construct a more sustainable world. Administrations all across the planet are supporting the usage of EVs. The number of EVs worldwide increased tremendously from 2010 to 2022. Such movements correspond to increased demand for high-performance EV batteries, such as Li-Ion Batteries (LIBs), which are considered the most promising interaction for EVs due to their inherent properties and significant cost reduction in the recent period. Figure 1 illustrates the tremendous use of EV batteries on roadmap.

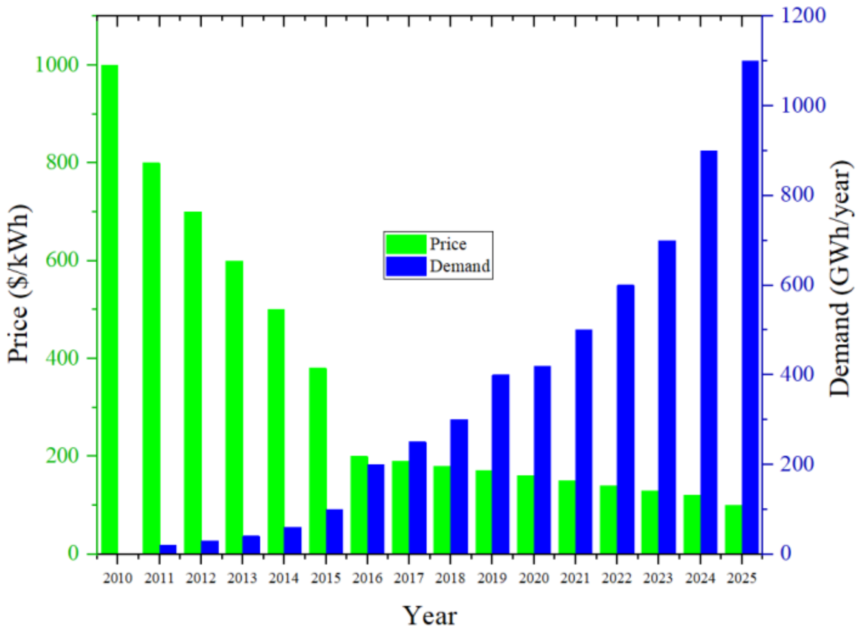
**Figure 1** Application of EV batteries on roadmap (see online version for colours)




*Source*: Shahid and Agelin-Chaab (2022)

The environmental consequences of electric vehicles are partly influenced by the settings in which they operate. The usual driving habits of different geographic areas vary, and EV energy usage is also influenced by how heating and cooling are used locally. EVs have an influence on the environment when these attributes are combined with the local electrical mix (Jaguemont et al., 2016). As a result, while performing an ecological evaluation, these affecting elements must be taken into account. For quantitative ecological evaluations, Life Cycle Analysis (LCA) and Product Life Cycle Analysis (PLA) methodologies should be utilised. These strategies can be utilised as a decision-making aid in automotive engineering. In addition, as illustrated in Figure 2, the remarkable drop in the cost of LIB storage systems over the last decade has accelerated grid-scale energy storage system installations.

**Figure 2** Li-ion battery pack-level price and demand trend (see online version for colours)



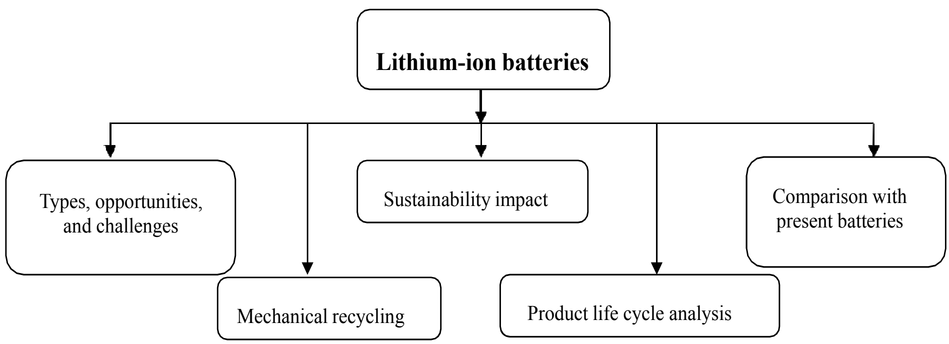

*Source*: Observed and projected

The research work published in the past 12 years, from 2010 to 2022, is considered for the present literature review. Thus, reviewed papers are categorised into six classes: types of batteries, battery technologies, opportunities and challenges, mechanical recycling techniques and proper recycling technique, sustainability impact, product life cycle analysis and comparison of the lithium-ion batteries with presently available battery techniques. The publications mentioned in this review are from prestigious publishers, including Emerald, Elsevier, Taylor & Francis, Springer, etc. Following is a list of research gaps found and discussed as a result of the thorough review.

## 2 Methodology of literature review

Literature related to the domain of LIBs is classified into: (i) Types of batteries, battery technologies, opportunities and challenges, (ii) Mechanical recycling techniques and adoption of proper recycling techniques, (iii) Sustainability impact, (iv) Product life cycle analysis and (v) Comparison of the LIBs with currently available battery techniques concerning power, energy, heat dissipation rate, packing, fuel cell, life, cost and safety is done. Figure 3 shows the classification of a literature review on LIBs.

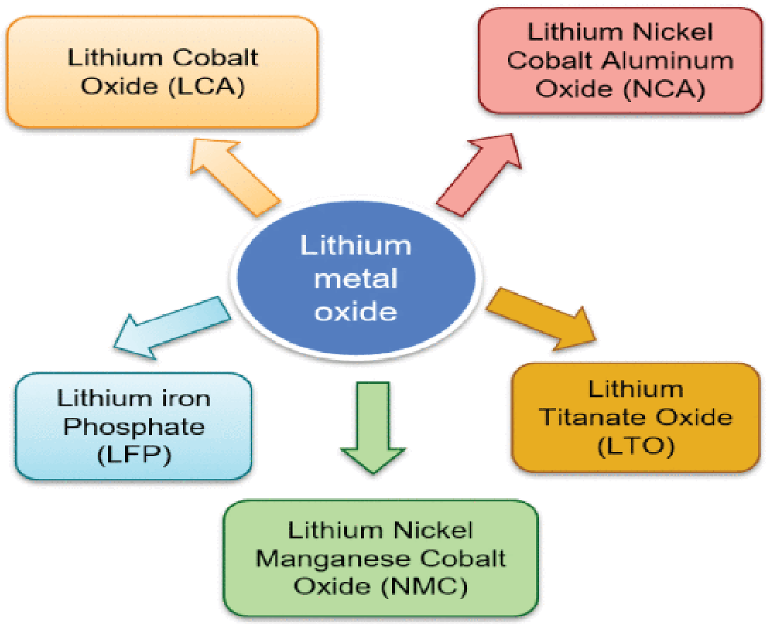
**Figure 3** Classification of literature review on LIBs




### *2.1 Types of batteries, battery technologies, opportunities and challenges*

Finding and implementing cost-efficient and sustainable energy storage and conversion systems is crucial because as more renewable energy is produced, energy storage – particularly grid-scale electrical energy storage – becomes increasingly pertinent and alluring (Xie and Lu, 2020). One of the best methods for storing energy is through the use of batteries, which come in a variety of shapes and sizes. A lot of study has been done on different battery technologies and uses. Exceptionally high energy densities are possible with metal-air batteries. Lead-acid, Nickel-metal hydride (NiMH), LI, redox flow and Sodium-Sulphur (NaS) batteries are the current commercial utility-scale battery technologies. These technologies frequently exhibit various technical and economic characteristics in terms of energy density, power density, energy efficiency, lifetime, safety and cost. Because of these distinctions, one technology is particularly well suited to a specific energy storage application due to technological and economic advantages. As a result, there is a variety of battery technologies in the energy storage industry worldwide. Several researchers studied types of batteries, battery technologies, opportunities and challenges. Figure 4 Illustrate the various types of lithium metal oxides are available to manufacture the battery.

**Figure 4** Types of lithium metal oxide (see online version for colours)




*Source*: Elmahallawy et al. (2022)

Materials in Li-ion batteries have distinct properties that affect their performance. Some commonly used lithium-metal oxides include Lithium Cobalt Oxide ($LiCoO_2$), Lithium Iron Phosphate ($LiFePO_4$) and Lithium Manganese Oxide ($LiMn_2O_4$). $LiCoO_2$ is widely used in commercial Li-ion batteries due to its high-energy density, which allows for longer-lasting battery life. However, it has some drawbacks such as lower thermal stability and limited availability of cobalt resources. $LiFePO_4$, on the other hand, offers better thermal stability, enhanced safety and a longer cycle life compared to $LiCoO_2$. It has become popular for applications where safety is a critical concern, such as electric vehicles and power tools. Additionally, lithium iron phosphate is more environmentally friendly due to its lower toxicity.

$LiMn_2O_4$, also known as lithium manganese oxide or LMO, is another cathode material used in Li-ion batteries. It has a lower energy density compared to $LiCoO_2$ but offers better thermal stability and improved safety. $LiMn_2O_4$ batteries are often used in power tools, medical devices and other applications where safety and stability are paramount. Other lithium-metal oxides, such as lithium Nickel Manganese Cobalt oxide (NMC), lithium Nickel Cobalt Aluminium oxide (NCA) and Lithium Vanadium Oxide (LVO), are also being researched and developed to improve the performance of Li-ion batteries. These materials aim to strike a balance between energy density, safety, stability and cost-effectiveness. Overall, the choice of lithium-metal oxide in Li-ion batteries depends on the specific requirements of the application, considering factors such as energy density, safety, thermal stability, cycle life and cost. Ongoing research and development continue to explore new materials and improve the performance of Li-ion batteries for various industries and applications (Dehghani-Sanij et al., 2019; Wang and Yang, 2021).

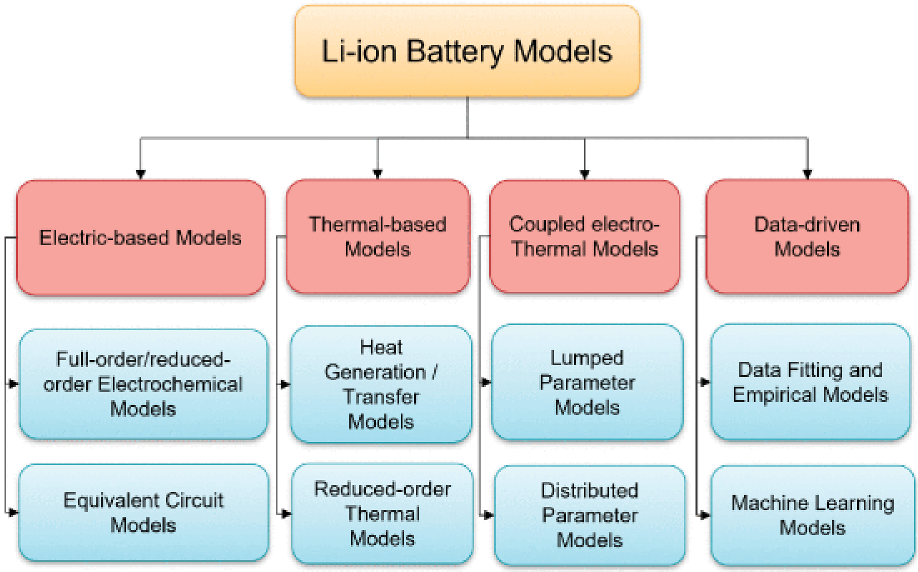
### *2.2 Lithium battery models*

Several models have been studied to simulate and replicate the dynamic behaviours of Li-ion batteries, each offering a different level of accuracy and complexity (Elmahallawy et al., 2022). These models aim to provide insights into battery performance, optimise battery management systems and improve battery design and operation. Here are a few commonly used battery models:

- *Equivalent circuit models (ECMs)*: ECMs are widely employed due to their simplicity and computational efficiency. They represent the battery as an electrical circuit consisting of resistors, capacitors and voltage/current sources. ECMs can accurately capture the transient behaviour of batteries but may lack the ability to capture detailed electrochemical processes.
- *Single particle models (SPMs)*: SPMs simulate the behaviour of individual particles within the battery electrode. They are more complex than ECMs and account for electrochemical reactions, mass transport and diffusion phenomena. SPMs offer higher accuracy in predicting battery performance but can be computationally expensive.
- *Pseudo-2D models*: Pseudo-2D models combine the simplicity of ECMs with some aspects of SPMs. They divide the battery electrode into small regions or 'pseudo particles' to account for electrochemical reactions and transport phenomena within the electrode. Pseudo-2D models strike a balance between accuracy and computational complexity.
- *Three-dimensional models (3D)*: 3D models provide the highest level of accuracy by considering the full geometry and structure of the battery. They simulate the electrochemical processes in all three dimensions within the battery electrode. 3D models can provide detailed insights into complex phenomena but require significant computational resources.

Each model has its strengths and limitations, and the choice depends on the specific requirements of the analysis or simulation. Researchers and engineers select the appropriate model based on factors such as the desired level of accuracy, computational resources available and the specific phenomena or behaviour being investigated. It's worth noting that ongoing research is focused on developing more advanced and accurate battery models, including multiscale models that integrate different modelling approaches, machine learning-based models that learn from experimental data and models that incorporate thermal effects and aging mechanisms. These advancements aim to enhance the understanding and optimisation of Li-ion batteries for various applications.

**Figure 5** Lithium-ion battery models (see online version for colours)




*Source*: Elmahallawy et al. (2022)

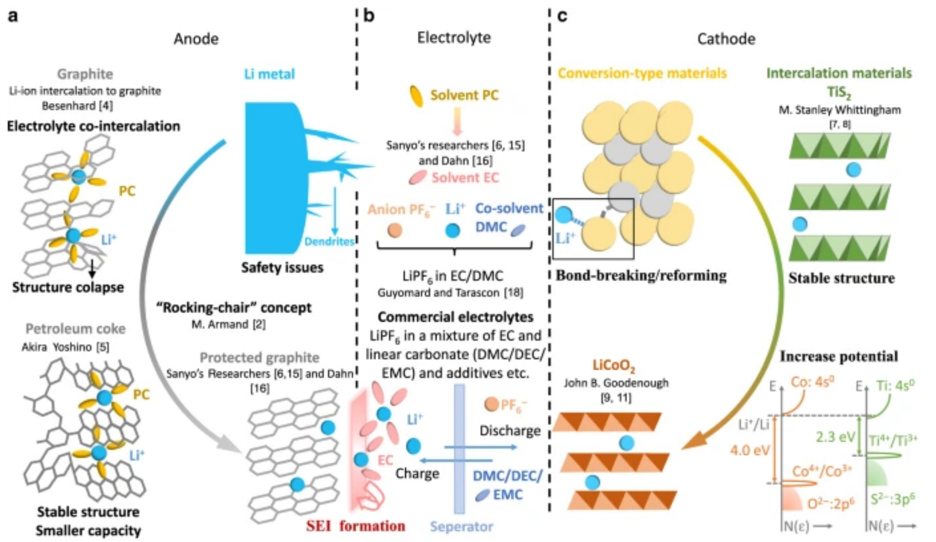
## 2.3 *Modern lithium-ion battery*

Lithium metal is indeed the lightest metal, and its unique properties make it an ideal for anode materials in high-voltage and high-energy batteries. Lithium metal has a high specific capacity of 3.86 Ah $g^{-1}$ (Ahmad et al., 2020; Yang et al., 2021). This means that it can store a significant amount of energy per unit weight, making it an attractive choice for energy-dense battery applications. The high specific capacity allows lithium-based batteries to deliver more energy compared to other traditional battery chemistries (Gurung et al., 2018; Goikolea et al., 2020).

*Low Electrode Potential*: Lithium metal exhibits an extremely low electrode potential of –3.04 V versus the Standard Hydrogen Electrode (SHE). This low potential indicates that lithium has a strong tendency to donate electrons and undergo oxidation, enabling it to serve as an efficient anode material. The low electrode potential of lithium contributes to the high voltage and energy density achievable in lithium-based batteries. Advantage of lithium metal as an anode material is its excellent voltage stability during charge and discharge cycles (Ahmadi et al., 2014; Chen et al., 2021). Lithium-based batteries can maintain a relatively stable voltage profile, resulting in consistent and reliable power output. This characteristic is crucial for applications that require stable voltage levels, such as electric vehicles and portable electronics.

*Low Equivalent Weight*: The lightweight nature of lithium metal is advantageous for battery applications, particularly in industries where weight reduction is a critical factor. The low equivalent weight of lithium allows for the design of lightweight battery systems, enhancing overall energy efficiency and portability. Lithium metal's properties, such as its high specific capacity and low electrode potential, make it compatible with various high-energy cathode materials. This compatibility enables the development of high-performance battery systems with excellent energy storage capabilities. However, it's important to note that the use of lithium metal as an anode material faces challenges such as dendrite formation, which can cause safety hazards and reduce the lifespan of batteries. Extensive research is being conducted to address these challenges and develop new approaches for utilising lithium metal effectively in advanced battery technologies. Figure 6 elaborates the modern lithium-ion battery.

**Figure 6** Modern lithium-ion battery: (a) Anode material used for lithium-ion battery, (b) Electrodes with many additives and (c) cathode material used in lithium-ion battery (see online version for colours)




*Source*: Xie and Lu (2020)

To cater to the high capacity of lithium metal, conversion-type cathodes were initially considered, which involved the use of metal fluorides, sulphides or oxides. These materials have the ability to undergo chemical reactions and change their structures and compositions during battery operation (Wu et al., 2017; Tian et al., 2021).

## 2.4 *Charging and discharging of lithium-ion battery*

Charging and discharging processes in lithium-ion batteries are fundamental to their operation and involve the movement of lithium ions between the battery's cathode and anode (Harting et al., 2012; Hu et al., 2017).

1 *Charging process*

- *Lithium-ion intercalation*: During the charging process, an external power source is connected to the battery, causing a flow of electrons from the cathode to the anode. Simultaneously, lithium ions are extracted from the cathode material, typically a lithium-metal oxide, and intercalated into the anode material, which is typically graphite. This intercalation process involves the reversible insertion of lithium ions into the host lattice structure of the anode material.

- *Electrolyte role*: The electrolyte in a lithium-ion battery plays a crucial role during charging. It acts as a medium for lithium-ion transport between the anode and cathode. The electrolyte typically consists of lithium salts dissolved in an organic solvent, which enables the movement of lithium ions while preventing direct contact between the cathode and anode.
- *Voltage and current control*: During charging, the voltage and current applied to the battery are controlled by the charging system or charger. Initially, the charging current is typically higher, and as the battery approaches its maximum capacity, the charging current decreases. The charger monitors the battery's voltage and adjusts the charging parameters accordingly to ensure safe and efficient charging.

$$Li_{2O_2} \rightarrow 2Li^{+} + 2^{e-} + O_2 \quad \text{(Charging)}$$

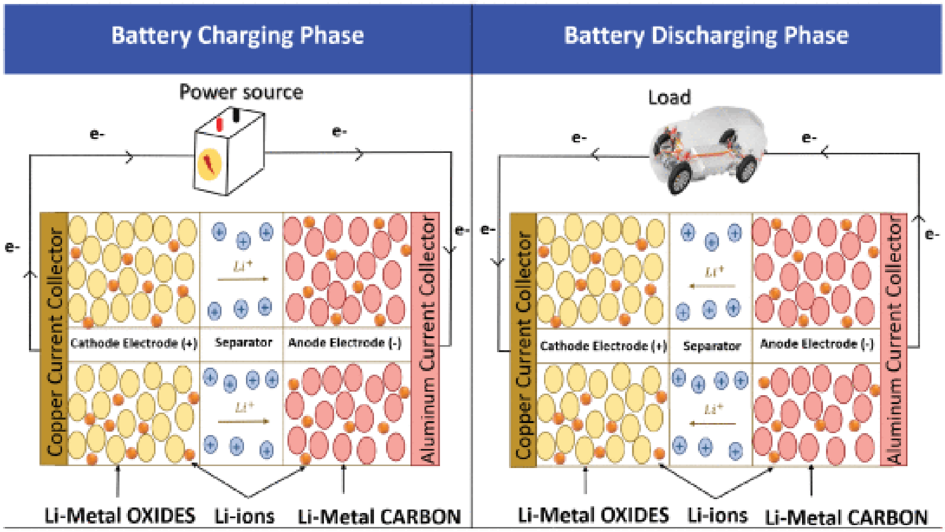
2 *Discharging process*

- *Lithium-ion deintercalation*: During the discharging process, the battery delivers electrical energy to an external device or system. Electrons flow from the anode to the cathode through the external circuit, while lithium ions are released from the anode material and move through the electrolyte to the cathode material. This deintercalation process involves the reversible extraction of lithium-ions from the anode material.
- *Voltage and capacity*: The battery's voltage gradually decreases during discharging as the available capacity diminishes. The discharge capacity, often measured in Ampere-Hours (Ah), represents the total amount of charge that the battery can deliver before reaching a specified endpoint voltage.
- *Discharge rate*: The rate at which a battery is discharged affects its overall performance. High discharge rates can result in a voltage drop and reduced capacity due to limitations in ion diffusion and electrode kinetics. Battery systems designed for high-power applications must consider the discharge rate to ensure optimal performance.
- *State of charge (SOC)*: The state of charge represents the remaining capacity of the battery as a percentage of its maximum capacity. Monitoring the SOC is important for battery management and accurate energy estimation.

It's important to note that the charging and discharging processes in lithium-ion batteries are reversible, allowing for multiple cycles of energy storage and release. Proper charging and discharging protocols, along with appropriate battery management systems, are essential for maximising the performance, lifespan, and safety of lithium-ion batteries. Figures 7 and 8 gives the information of charging and discharging of lithium-ion battery, and Charge Discharge curve over the time, respectively.

$$2Li^{+} + 2^{e-} + O_2 \rightarrow Li_{2O_2} \quad \text{(Discharging)}$$

**Figure 7** Charging and discharging of lithium-ion battery (see online version for colours)




*Source*: Elmahallawy et al. (2022)

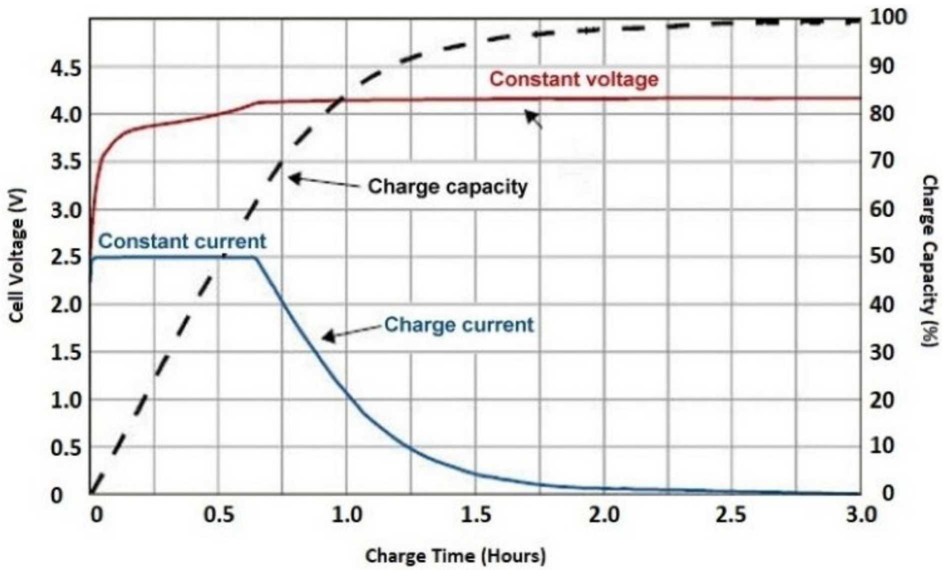
The charge-discharge curve of a lithium-ion battery represents the relationship between the battery's voltage and its State of Charge (SOC) over time. It's important to note that the charge-discharge curve may vary depending on factors such as the battery's chemistry, design, operating conditions and the specific charging and discharging protocols employed. Battery manufacturers often provide specific charge-discharge curves and guidelines to ensure safe and optimal performance of their lithium-ion batteries.

*Constant current charge*: In the initial stage of charging, the battery is typically charged with a Constant Current (CC). During this phase, the charging current remains relatively high, and the battery voltage gradually increases. The voltage initially rises slowly, and then it starts to increase more rapidly as the battery approaches its maximum voltage.

*Constant voltage charge*: After reaching the maximum voltage, the charging process enters the Constant Voltage (CV) phase. In this phase, the charger maintains a constant voltage while reducing the charging current. The battery continues to charge, but at a slower rate. The voltage remains relatively stable during this phase, with a small voltage drop due to internal resistance.

During discharge, the battery's voltage gradually decreases over time as the stored energy is released. The voltage decay is typically gradual, with a relatively constant discharge voltage during most of the discharge cycle (Tarascon et al., 2011; Perner et al., 2015). As the discharge progresses, the voltage may exhibit a relatively flat region where the battery maintains a relatively stable voltage before entering the end-of-discharge voltage range (Zeng et al., 2015; Yang et al., 2019). This flat voltage region often represents the majority of the battery's usable capacity, where the voltage remains relatively constant before dropping more significantly. The end-of-discharge voltage is the minimum voltage at which the battery is considered fully discharged. It represents the cutoff point where the battery can no longer provide the desired voltage or power required for a specific application. Discharging the battery below this voltage can potentially damage the battery or reduce its lifespan (Feng et al., 2020).

**Figure 8** Charge discharge curve over the time (see online version for colours)




*Source*: Bollini (2022)

## 3 Mechanical recycling techniques and adoption of proper recycling technique

Several efforts are being made to develop electrode materials, electrolytes, and separators for energy storage devices in order to meet the demands of EVs, decarbonised electricity, and electrochemical energy storage (Etacheri et al., 2011; Geng et al., 2016). On the other hand, there hasn't been much discussion on the long-term viability of LIBs and the next-generation of rechargeable batteries. The sustainability of batteries as a whole depends on recycling, which is determined by battery properties including environmental risks and the worth of their resource constituents (Kuang et al., 2019; Nair et al., 2019). As a result, recycling should be taken into account when developing battery systems. With the ever-increasing demand for LIBs, notably in the electric transportation industry, a substantial number of batteries will be phased out shortly, posing serious disposal issues and negative environmental and energy conservation consequences. Commercial LIBs contain hazardous lithium salts in organic electrolytes, aluminium, copper, graphite, polymer separators, transition metal oxides or phosphates and plastic or metallic enclosures. The improper disposal of expended LIBs is likely to have serious repercussions, including pollution and resource waste. As a result, the recycling of expended LIBs has gotten much interest in recent years. Studies have been performed in this direction. Zhu et al. (2011) recovered copper from spent LIBs. They adopted dismantling mechanical pulverisation and sieving processes for anode separation.

Further, fluidised bed technology is applied. Gaines and Dunn (2014) discussed the environmental impacts of the production of automobile Li-ion batteries and ways to reduce them using recycling. They found that including recycled materials (such as cathode, aluminium and copper) into Li-ion minimised energy consumption by 50%. Also, they found that batteries contributed about 20% of EV life-cycle $SO_x$ emissions. Further, they discussed problems that affect battery recycling, such as design, economic and regulatory factors. He and Xu (2014) reviewed treatment techniques for recycling Waste Electrical and Electronic Equipment (WEEE). Also, they proposed an environment-friendly and efficient technique of recycling. Sonoc and Jeswiet (2014) reviewed the role of lithium in electronics and vehicles and its reserves, projected mining capacity and forecasted demand. They also demonstrated a preliminary experiment for recovering materials. Sonoc et al. (2015) analysed current industrial processes to recover lithium from LIBs. They proposed that LIBs can be disassembled using automation to recover valuable electronics, after which their cells can be discharged to recover residual energy.

Kushnir (2015) summarised key results and references to state-of-the-art literature and data on the LIB recycling process. To lessen the cohesiveness of coated material particles, Hanisch et al. (2015) used a battery recycling technique including the heat breakdown of the polyvinylidene fluoride binder. Then, jet separators detach the coating powder from the collector foil and reduce the remaining particles. They found that 97.1% w/w of electrode coating was regained with aluminium impurities of only 0.1% w/w and 30% times purer than the mechanical recycling process. Diouf and Pode (2015) presented a review on LIBs. They found longer lifespan, environmentally friendly, higher energy density and power density as strength points while weak points as cost and safety. They concluded that recycling technologies should be improved as lithium reserves are limited. Zhang and Xu (2016) focused on the recycling of metals from WEEE. They summarised recycling principles, separated processes and optimised operating parameters of existing technologies. They found that pyrometallurgical technology and mild extracting reagents can effectively recycle materials. Further, they applied various recycling techniques such as electrochemical technology, supercritical technology, vacuum metallurgical technology, ultrasound technology, mechanochemical technology and molten salt oxidation technology.

Zhao (2017) described EVs' basic concepts, general management, and tendencies. Also, they introduced sorting methods, prediction techniques of cycle life, performance analysis and diagnostic methods for the reuse of batteries. Further, they discussed progress related to resource utilisation, its harmless disposal, prevention of secondary pollution and reuse and recycling of batteries. Li et al. (2017) proposed a theory to design the e-waste recycling process and summarised the indicators and tools regarding resource dimensions, environmental dimensions and economic experience. Zhao et al. (2019) described various recycling technologies and principles of spent LIB. Arshad et al. (2020) reviewed articles related to the recycling of LIB components such as cathode, anode and electrolyte. Initially, they presented a brief overview of recycling. Later, they looked over laboratory research and commercial anode and electrolyte recovery investigations. Additionally, they discussed the constraints of end-of-life Li-ion battery recycling as well as upcoming initiatives to extract and separate metals in order to recycle used LIBs sustainably.

Fan et al. (2020) provided an overview of the sustainability of rechargeable batteries. They also analysed the market competitiveness of various batteries in terms of economy, environment and policy. They evaluated battery utilisation and recycling from the perspective of economic feasibility, environmental impact, technology and safety. Further, they discussed the sustainability of batteries concerning life-cycle assessment and highlighted challenges with prospects. Werner et al. (2020) studied several recycling techniques for spent LIBs and classified them into waste management technologies. Xu et al. (2020) reported a benign Li-ion battery generation method based on defect- targeted healing. They successfully regenerated spent cathodes using re-lithiation and post-annealing. Life-cycle analysis of different LIBs found that the proposed approach significantly minimises energy usage and greenhouse gas emissions. Costa et al. (2021) provided an overview of relevant recycling LIBs and their impact on the environment. They focused largely on lithium while literature in cobalt and nickel is also discussed. They listed the advantages and limitations of various recycling methods.

Makuza et al. (2021) gave a comprehensive overview of the pyrometallurgical techniques currently used for recycling used LIBs. They concentrated on laboratory- and large-scale industrial-scale thermal pretreatment techniques for recovering active cathode material. Further, legislation, challenges and future outlook for recycling LIBs are discussed. Sommerville et al. (2021) studied several commercial recyclers and evaluated their recycling and reclamation methods. They proposed a qualitative assessment matrix to compare various materials' strategic importance and value. They found that most recyclers use mechanical treatment, pyrometallurgical or hydrometallurgical recycling of metals and component materials; thus, highlighting the technological gap.

The primary principal approaches for recycling used LIBs include mechanical treatment, pyro-metallurgy, hydrometallurgy and bio-treatment, according to the literature that is currently accessible. As a process that can be used to recover valuable metals from used LIBs, hydrometallurgy leads to other recycling methods. Organic acids (environmentally friendly leaching agents) are critical in extracting lithium, nickel, cobalt and manganese from used LIBs. Despite being weaker than inorganic acids, organic acids have been studied more extensively for the leaching of wasted LIBs, assisting in the avoidance of oxidising agents, reducing the complexity of maintaining the pregnant fluid, and the reduction of energy loss. GHG emissions for extracting 90% CO using organic acids are estimated to be around 500 g/$CO_2$ eq per kilogram Co, compared to nearly 4000 g/$CO_2$ eq per kg Co for an inorganic acid leaching procedure. To achieve a win-win situation in terms of economics and environmental benefits, efforts should be made to separate the leached metals from these organic acid media.

## *3.1 Sustainability impact*

Various researchers studied the impact of LIBs on the sustainability aspect. Notter et al. (2010) compiled a detailed life-cycle inventory of LIBs and a rough life-cycle analysis of EVs. They demonstrated that the operating phase of both ICE- and EV-powered cars is the major contributor to mobility-related environmental issues. They came to the conclusion that the availability of copper and aluminium to make cathode and anode is a crucial factor in the environmental issues brought on by the battery. Zackrisson et al. (2010) explored the utilisation of life cycle assessment to optimise the design of LIBs for hybrid EVs. They found that water is a better solvent than other chemicals in the slurry of the cathode and anode of LIBs. Future research should examine the environmental impacts of producing binders and lithium salts, making and assembling cells, examining the connection between vehicle weight and energy usage, examining battery efficiency and examining the recycling of LIBs. Wanger (2011) found that the demand for lithium resources would overshoot the availability by 2025. In addition, lithium extraction causes water pollution, thus causing human health issues. They concluded that effective lithium recycling strategies should be implemented urgently. Williard et al. (2011) proposed a methodology for dismantling batteries considering parameters depending upon the nature and purpose of post-dismantling analysis. They further reviewed the safety hazards of dismantling.

Dunn et al. (2012) analysed the environmental burdens of the production of material, assembly, and recycling of LIBs. They computed energy consumed and emissions while recovering lithium, aluminium and copper in hydrometallurgical and physical recycling. Pistoia (2013) reviewed the origin of manufacturing costs of LIBs and pathways to lower them. They presented a model that enables the evaluation of manufacturing cost and provided details on significant contributions to total battery cost. They also presented a review of regulatory and market trends; required for the electrification of the automotive market. Oliveira et al. (2015) focused on the environmental impact of two lithium batteries used in EVs and issues associated with resource availability. Three distinct product life stages – production, use, and end-of-life – are reviewed in an analysis using life cycle assessment methodologies. They came to the conclusion that the efficiency of batteries and the energy mixtures related to their use directly affect their overall performance. Boyden et al. (2016) investigated different recycling processes for portable LIBs like hydrometallurgy, pyrometallurgy and combination processes using surveys of many companies. They also carried out a life cycle assessment of these processes to understand their environmental impact. They found that electricity generation, incineration of plastics and landfilling are major contributors.

Peters et al. (2017) provided a review of life cycle analysis studies focused on the battery production process. They identified key assumptions, located the origins of the inventory data, and summarised the original research. They observed that the impact of toxicity is also as crucial as GHG emissions and energy demand. They concluded that future research directions are maximising cycle life and increasing charge-discharge efficiency. Vandepaer et al. (2017) compared the environmental performance of Li-metal batteries with LIBs using a life cycle assessment methodology. They examined models with storage capacity for centralised and distributed grids. They found that the environmental impact of the battery manufacturing stage is the highest. LIBs are more hazardous to the environment than LIBs in terms of global warming and ozone depletion; however, LIBs cause aquatic eutrophication due to mining. Also, centralised battery systems should be favoured over distributed systems. Hao et al. (2017) Estimated Greenhouse Gas (GHG) emissions from the fabrication of LIBs in China. They observed a 30% increase in GHG emissions using EVs than conventional vehicles due to the cathode and wrought aluminium production.

Mauger and Julien (2017) compared and analysed the performance of batteries with different chemistries with more emphasis on safety factors. They also pointed out problems involving anode, cathode, electrolyte, lithium salt and separator recycling. Further, they discussed the position of LIBs in the sustainability context. Huang et al. (2018) provided a review of developments in the recycling processes of spent LIBs, including the development of recycling processes and products obtained from recycling. Further, they highlighted the remaining challenges and future scope in this domain. Üçtuğ and Azapagic (2018) studied the life cycle environmental impacts of Turkey's domestic-scale hybrid solar photovoltaic battery system. The system could meet nearly 13% of households' annual electricity requirements and demonstrated clear environmental benefits. Further, they suggested that incentives for battery storage should be provided. Gaines (2018) compared several processes for recycling on the basis of technical and economical areas with individual advantages and limitations. They concluded that separation technologies are the most promising domains for the development of improved recycling methods.

Ciez and Whitacre (2019) assessed the greenhouse gas emissions, the energy used, and the cost related to the production and recycling of LIBs using life-cycle analysis and process-based cost models. They compared hydrometallurgical and pyrometallurgical processes for recovering ceramic powder cathodes for reuse in subsequent batteries. They suggested that they incentivise battery collection through efficient recycling processes. Dai et al. (2019) analysed total energy use, emissions of greenhouse gases and consumption of water-related to the industrial production of batteries. They also performed a life cycle analysis on greenhouse gases, regulated emissions and energy utilisation in the transportation model. They found that cathode material, aluminium and energy use are significant factors for environmental impacts. They estimated that direct physical recycling of precious metals reduces energy consumption during material production by 48%. Meshram et al. (2020) attempted to review the literature about methods used in discharging, classification and separation of parts, after which metal recovery will be made. They also reviewed various acids used for recycling methods and highlighted the use of green techniques. They concluded that efforts are needed in separating leached metals from lixiviants ensuring economic and environmental benefit.

Mossali et al. (2020) analysed present alternatives to recycle LIBs, i.e., pyro- and hydro-metallurgical processes. They also highlighted their benefits and limitations regarding energy consumption, recovery efficiency and safety issues. Yang et al. (2020) used a life cycle assessment to compare the environmental impact of LIBs and lead-acid batteries in energy storage stations. They found that manufacturing and reusing contribute more to the environmental impact of LIBs, and recycling can reduce the impacts. Further, they concluded that the cycle life of LIBs and using a cleaner energy mix reduces environmental impacts. Yang et al. (2021) examined technologies related to battery recycling from an economic perspective and life cycle inventory. They also outlined challenges faced in battery recycling, the role of battery design and circular economy in the sustainable development of the battery industry.

LIBs are increasingly widely used in high-tech goods, electric and hybrid vehicles and other applications because of their high-energy density for weight, minimal memory effect and numerous supported charging/discharging cycles. Because of this, LIB usage and production will increase over the next years, gaining global attention for their End-of-Life management. Recycling is currently the only option for the market's social, economic and environmental sustainability, able to reduce the toxicity of End-of-Life products, generate revenue and lead to independence from foreign resources or essential materials. Unfortunately, waste LIB treatments are still in development and far from optimising recycling processes and technologies.

### *3.2 Product life cycle analysis*

Many researchers studied the product life cycle analysis of LIBs. Dewulf et al. (2010) conducted a thorough investigation of lithium mixed metal oxide battery recycling; they found that cobalt and nickel are recovered and combined again into battery manufacture as opposed to regular production activities. They also performed resource-saving analyses. Sullivan and Gaines (2010) conducted a literature review and evaluation of life cycle inventory studies of various types of batteries. They came to the conclusion that lead-acid batteries emit the fewest pollutants, carbon dioxide and energy during manufacture. Ramadesigan et al. (2011) predicted capacity fade accurately and efficiently for the subsequent cycles with the help of discrete methods. Using a mathematical reformulation of the porous electrode model, they also calculated effective parameters and uncertainties. Gaines et al. (2011) focused on battery manufacture and constituent-material production while examining the LIBs' life-cycle costs. They studied the impact of battery-material recycling on battery manufacturing. They estimated that energy utilisation and GHG emissions related to battery manufacturing constitute only some percentage of hybrid vehicle's life cycle energy use.

Li et al. (2014) reported the life cycle assessment of a high-capacity Li-ion battery pack with the help of Silicon Nanowires (SiNW) fabricated using metal-assisted chemical etching. They also reported nano waste and nanoparticle emissions from SiNW synthesis. They found that 50% most impacts originated from battery operations, and the anode of SiNW material constitutes 15% of global warming potential. Ellingsen et al. (2014) provided a transparent inventory for Li-ion Nickel-Cobalt-Manganese (NMC) traction batteries depending on primary data. They discovered that the manufacturing chains utilised by cell manufacturers, the positive electrode paste and the negative current collector had an influence on battery production. From sensitivity analysis, they found that battery cells with electricity should be produced from a cleaner energy mix to minimise emissions. Deng et al. (2017) presented a life cycle analysis using the ReCiPe method on advanced LIBs with molybdenum disulfide ($MoS_2$) and NMC oxide cathode. They found that NMC-$MoS_2$ has a high environmental impact that NMC-Graphite batteries. They checked the robustness and reliability of LCA results by performing sensitivity analysis. Liang et al. (2017) proposed an optimised design of secondary LIBs using carbon footprints and life cycle assessment. They showed that the carbon dioxide equivalence of the assembly method is highest for nickel metal hydride batteries.

Lu et al. (2017) studied flows, stocks and loss of lithium using substance flow analysis. They found that production and use of the batteries in the studied duration increased. They discovered that society's lithium reserves cannot serve as a reliable second source of lithium production. Romare and Dahllöf (2017) presented a report on life cycle energy consumption and GHG emissions from LIBs used in light-duty vehicles. They highlighted the percentage contribution of the production stage, including mining, refining and assembly on emissions. Ahmadi et al. (2017) performed a life cycle analysis on LIBs used in EVs and then reused in energy storage systems. Pellow et al. (2020) carried out literature review surveys for present studies on grid-scale stationary Li-ion battery energy storage systems and highlighted research gaps about environmental impacts. Asef et al. (2021) discussed recent trends in the development of batteries in EVs and performed a literature review of recent literature. They provided a framework for selecting batteries depending on their extraordinary performance performed for traction applications and subjected to sustainability issues. In addition, they carried out aging assessment for various types of batteries. Finally, they predicted future trends in Li-ion battery market.

Bouillass et al. (2021) described an all-inclusive S-LCA framework. The innovation of the work includes a novel framework of two approaches risk analysis for identification of impact and participatory method of prioritisation. They proposed a novel set of mobility-pertaining subcategories. Koh et al. (2021) performed LCA and techno-economic analysis and observed that the developed hybrid energy storage system configuration minimises environmental and economic influences. They highlighted the environmental and economic benefits of utilising lithium-titanate battery technology in a novel hybrid energy storage system. Machedon-Pisu and Borza (2021) proposed a methodology depending on balancing rapports between supply and demand. The findings of this study are compared to the outputs of various models and frameworks that try to examine the long-term viability of transportation systems.

The role of battery chemistry and storage capacity in predicting the market adoption of different powertrains. Glöser-Chahoud et al. (2021) argued that higher levels of circularity are required for industrial disassembly systems. In the best-case scenario, these systems are fully automated and employ life-cycle data, such as production and use-phase data, for decision support, allowing for an optimal module or even cell use. They comprehensively investigated multiple utilisation pathways and compared state-of-the-art treatment with an advanced disassembly system to highlight the advantages of an industrial disassembling system in battery treatment. Rather than circular business models, Wrålsen et al. (2021) researched focuses on technological and economic concerns based on recycling and the second use of batteries. This research aims to look into the circular business models, drivers, roadblocks and stakeholders that are needed to enable value recapturing. They used the Delphi panel approach to connect with battery specialists from diverse fields. They concluded that national and international legislation and policies are the most important drivers, and financial feasibility is the most crucial hurdle. Governments and vehicle manufacturers are the most important players. Spreafico's (2021) researched aims to determine which upgrades of automotive components can have the most impact on the environment, reducing the field to only those currently on the market. Even if their study does not overlook minor shape optimisation, controls and production processes, the approach of material replacement is more examined along with mass reduction. Another goal of their study is to differentiate the environmental benefits based on the car's size and power source, such as gasoline, hybrid and electric.

Filho et al. (2021) presented a thorough assessment of the literature and a detailed analysis of the current state of electromobility in Europe, evaluating social, economic and environmental concerns in the circular Economy Context (CE). They also evaluated current issues and provided solutions for enhancing electro-environmental mobility's performance and urban quality-of-life. Furthermore, they argued that a narrow technology-only agenda in electromobility would be less successful without the imperative of the CE, which includes not only materials and resources but also energy, to unlock the medium-term co-benefits of decarbonisation in both the transportation and building and energy sectors. Based on continuous approximations, the study carried out by Barraza and Estrada (2021) defined a methodology for designing an efficient transit network operated by battery-electric buses in cities with grid-shaped road networks. An analytical model determined the best network layout for lowering agency costs, monetising emissions and reducing transit customers' journey time. The analytical model enabled the bus's cost, emissions and performance to be compared to various fuel powertrains.

Kotak et al. (2021) pointed out that there are a variety of commercially available recycling processes and those under development for recovering the most significant amount of materials and quantity possible. The concept of battery reuse (second life) seems promising since batteries from electric vehicles can be used for various applications after their initial life, such as storing renewable energy to keep the national grid running. On the other hand, the cost and LCA demonstrated that battery reuse applications involve a variety of considerations. Mechlia et al. (2021) developed a model that takes into account how frequently non-polluting cars are utilised as well as the Preventive Maintenance (PM) schedule that ought to be followed for each of the N different kinds of vehicles. Researchers want to know how many automobiles of each type should be used, how long they should be used for, how often they should be used and how often each type of car should receive preventative maintenance. A mathematical model is built to specify and optimise the expected total cost, which includes expenses related to procurement, operation, maintenance and environmental impact, in addition to determining the resale value. Zeng et al. (2021) compared gasoline Internal Combustion Engine Vehicles (ICEVs), Battery Electric Vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) driven by the present average Chinese electricity mix offering 23 percent and 17 percent reductions in Global Warming Potential (GWP), respectively. However, it comes at the cost of significant increases in mineral resource scarcity and ecological and human toxicity.

Manzolli et al. (2022) reviewed literature related to electric bus research. They used science mapping methods and content analysis to support critical thinking for important research types, methods and gaps in this domain. They concluded that research would be focused on sustainability, management of energy strategies and fleet operation shortly. Arshad et al. (2022) provided a study of Life-Cycle Assessment (LCA) to determine and resolve the impact on the environment focused on the LIB manufacturing process. They adopted a scientific framework of LCA to recognise the advantages and disadvantages of this analysis technique. They also extrapolated this study to next-generation batteries. Soares and Wang (2022) critically reviewed the technological development of Electric Vehicles (EV) charging on electrified roadways (eRoads) and offered a novel understanding of electrified roadways infrastructure. They provided unique aspects about components of charging modules, arrangements of charging lanes, methods of construction and maintenance requirements. Lastly, they identified research gaps as lacking systematic design and building eRoads for efficient functioning.

Jiang et al. (2022) conducted an LCA study of two LIBs and reusing materials in China. They observed that recycling causes environmental benefits; however, the net benefits of direct recycling are higher. Performed sensitivity analysis showed that these recycling benefits depend upon recovering efficiency and concluded that all-inclusive management strategies are needed. The study contributed by providing a life cycle inventory for hydro-metallurgical recycling LIBs. Liu et al. (2022) applied a framework of tele-coupling. They brought together a survey with Q-method to evaluate how EV consumers notice the life-cycle development of EVs, with the influence of extraction of minerals and schemes of the government. They found a lack of awareness of influence among consumers studied. They also highlighted necessity for tele-coupling view in governance of minerals and suggested a shift in supply of EVs to incorporate wider development of sustainable goals.

Wangsa et al. (2022) carried out a comprehensive literature review of 1596 papers. They utilised a strategic diagram to reveal emerging research themes in the last five years and proposed the scope of future research. They found that technologies for the energy of combustion, energy for renewable, and electric vehicles have been developing sustainability. Alramadhan et al. (2022) developed a mathematical model of sustainability. Parameters obtained from environmental, economic and societal fields were weighted and normalised. They evaluated the LCA of EVs and internal combustion engines. They also developed optimisation models with a mixed-integer program and then performed sensitivity analysis. Zhang et al. (2022) compared traditional diesel internal combustion engines and EVs in terms of the total cost of ownership and life-cycle emissions for electrification of heavy-duty trucks. They also performed scenario and sensitivity analysis to explore the life-cycle effects of electrification options in China during years 2020–2040. They concluded that plug-in hybrid vehicles performed better because of reduced capacity of battery and present grid status in China.

Onat (2022) developed an integrated sustainability framework of assessment. This combines hybrid multi-regional input-output-based LCA and multi-criteria decision-making methods. They developed a scalable framework that will be useful for developing better national policies for sustainable transportation. Siragusa et al. (2022) compared EVs and internal combustion engine vehicles for their environmental impact on Business-to-Customers (B2C) and e-commerce. They used LCA to evaluate the influence on responses related to the environment. They also performed economic analysis based on total cost of ownership, which depends on two types of vehicles in their period of ownership. Furthermore, they observed that EVs are best options in all assumed scenarios.

### *3.3 Thermal abuse strategies*

The thermal runaway of lithium-ion batteries is a critical phenomenon characterised by a series of chain exothermic reactions occurring within the battery. These reactions trigger a rapid increase in the internal temperature of the battery, leading to the destabilisation and degradation of its internal structures. Ultimately, this process culminates in the failure of the battery (Shahid Shahid and Agelin-Chaab, 2022). Thermal runaway typically initiates due to factors such as overcharging, external heat exposure, manufacturing defects or physical damage to the battery. The reactions involved in thermal runaway are highly exothermic, meaning they release a significant amount of heat energy. As the reactions progress, a self-sustaining loop is established, whereby the heat generated by the reactions further accelerates the reaction rate, leading to a dangerous and uncontrollable rise in temperature (Feng et al., 2020; Kim et al., 2019). To mitigate the risk of thermal runaway, battery manufacturers incorporate various safety features and strategies. These include thermal management systems, such as cooling mechanisms and thermal barriers, that help regulate and dissipate heat. Additionally, advanced battery management systems are need to design to monitor battery temperature and prevent the occurrence of conditions that could trigger thermal runaway.

### *3.4 Comparison of the LIBs with presently available battery techniques*

This subsection discussed papers comparing the LIBs with presently available battery techniques. Omar et al. (2010) assessed the capability of LIBs for use in EVs. They assessed a number of battery characteristics, including thermal stability, internal resistance, efficiency and charging and discharging. They found that Li-nickel-cobalt-manganese batteries offered the best performance and Li-nickel-manganese-cobalt batteries are the most expensive. Oswal et al. (2010) compared the performance of two LIBs, namely Li-ion phosphate and Li-ion cobalt batteries. Chen et al. (2012) reviewed four types of LIBs based on capabilities and suitability as energy storage in EVs. Stan et al. (2014) highlighted the uses of the various Li-ion battery chemistries that are now on the market and provided an overview of them. They suggested that the battery chemistry should be selected as per application. Anuphappharadorn et al. (2014) presented an economic analysis of a Photovoltaic (PV) stand-alone system consisting of a module, inverter and two types of batteries. They found that lead-acid batteries are suitable in PV stand-alone systems.

Four Li-ion battery technologies' outcomes of ageing were compared by Eddahech et al. (2015). They discovered that compared to other batteries, cathodes with manganese are more sensitive to temperature rise and state of charge. From impedance spectroscopy, they observed a significant increase in the resistance of Li-nickel-manganese-cobalt and Li-manganese-oxide cells. Farmann et al. (2015) provide a summary of the current approaches for predicting LIBs' on-board capacity. They examined several estimating techniques for states of charge, health and function. Wang et al. (2016) investigated techniques for thermal control and the creation of battery thermal models. They reviewed heat production techniques, reactions to low temperatures and the thermal impacts of LIBs.

Peters and Weil (2016) assessed different types of LIBs and Na-ion batteries under resource depletion. They found high importance in indirect resource depletion caused by the co-extraction of metals from the mixed ores. Also, the metal required for the battery management system is depleting sharply. Blomgren (2016) observed that LIBs would continue to improve cost, energy, power capacity and safety in years to come. Jaguemont et al. (2016) reviewed the effect of cold temperature on the capacity fade of LIBs, and focused on its aging mechanism. The detailed thermal strategies outlined an ideal method for cold-temperature activities. Keshan et al. (2016) compared the efficiencies, charging properties, life cycle, and costs of LIBs and lead-acid batteries for stationary energy storage. They concluded that LIBs are better than lead-acid batteries in terms of cost when the life cycle is considered. Manthiram (2017) presented an outlook on LIBs by providing current status, opportunities and challenges. They also formulated practically viable near-term strategies.

Zou et al. (2018) provided an overview of fractional-order techniques for managing LIBs, lead- acid batteries, and supercapacitors. They further presented modelling principles of the energy systems by identifying dispersed dynamic responses and electrochemical impedance spectroscopy. Zubi et al. (2018) reviewed papers related to LIBs related to sustainability and emissions. Farmann and Sauer (2018) conducted a comparative study of several impedance-based equivalent circuit models to predict state-of-available-power. They also investigated LIBs at various states of aging for different materials. Hannan et al. (2018) provided a comprehensive study on state-of-art of LIBs. They observed favourable characteristics of these batteries for EV applications as low price, light-weightiness and high-power density.

Benveniste et al. (2018) reviewed articles related to Li-Sulphur battery usage in EVs related to technical, modelling, economic and environmental aspects. They found advantages of these batteries in terms of economic and environmental aspects, but they also found their limitations as issues with durability, self-discharge and modelling. Kim et al. (2019) discussed important aspects of current and future battery technologies based on the working electrode. They also provided information about a stand-alone energy device that combines energy harvesting technologies and LIBs. Abraham (2020) studied reports available related to sodium-ion (Na-ion) batteries and compared them with LIBs.

They concluded that Na-ion batteries having hard-carbon anodes and cobalt-free cathodes would be helpful for short-range EVs and large-scale energy storage systems.

## 4 Literature review recommendations

Next-generation rechargeable Li-ion batteries should be targeted at high performance, safety, low cost and environmentally friendly. Some of the most significant research gaps have been highlighted in this section, and recommendations for further research have been made. Based on a critical literature review, the scope for future research is recognised as follows:

- A standardised procedure is required to recover various kinds of used LIB components.
- The recovery process in green chemistry calls for adhering to the 3R (reduce, reuse and recycle), 3E (energy, economy and environment) and 4H (high technology, environmental returns, security, economic return) principles. Research in this direction needs further investigation.
- Identification and sorting of spent Li-ion batteries should be reduced to enhance cycle efficiency.
- The impact of operating factors and kinetics has to be more carefully considered in future efforts to dispose of old Li-ion batteries.
- There is a need for standardisation of material, design of the battery and simple assembly as it will lead to energy conservation.
- Ore-related problems will be lessened by a system of manufacture, production, assembly and recovery of spent LIBs that is standardised around the world. This will further reduce the energy consumption of the recycling process. Further research in this direction is needed.
- Continuous research and development are required in pyro-metallurgical recycling to cope with the increasing number of spent Li-ion batteries.
- For the battery business to function effectively over the long term, it is crucial to locate a cost-effective, adaptable recycling plant that will recover a wide range of essential components.
- A resource-efficient recycling system with little chemical and off-gas output has to be developed.
- Each cathode material will be treated along a particular path, determining its cost, energy consumption and environmental impact. It is impossible to recycle all LIBs using the same technique, which causes issues in downstream processing and necessitates particular types and property separation.
- Material interrelation at the molecular level, interface and interphase changes, and aging should be deeply understood to investigate the fundamental process.

- In the case of aluminium batteries, the reaction mechanism and difficulties arising from the trivalent reaction medium in electrolytes, electrodes and electrolyte-electrode interface should be carefully studied.
- The selection of media for leaching and optimising conditions for leaching requires research.
- A complicated structure of leaching solution comprising lithium, cobalt, iron, aluminium, manganese, copper and nickel requires the development of participating and extraction medium.

It is clear from looking at current battery recycling methods that they need to be upgraded in various ways and that the status quo needs to be questioned. To make LIB recycling cost-effective and ecologically benign, several elements of current technology must be rethought and improved. Regulatory regulations and government incentives will surely spur innovation and make sure that all parties in the LIB value chain are participating in the quest to create new technologies.

## 5 Conclusions

Research articles published from the year 2010 to 2022 in LIBs have been reviewed in the present paper. Lithium-ion batteries have emerged as the preferred energy source for powering electric vehicles, primarily due to their exceptional energy and power densities The literature review is classified into six sections: types of batteries, battery technologies, opportunities, challenges, mechanical recycling techniques and proper recycling techniques, sustainability impact, product life cycle analysis and comparison of the lithium-ion batteries with presently available battery techniques. Research papers have been reviewed critically. Owing to their longer lifespan and higher energy and power density, LIBs are promising technology for energy storage. It is observed that research work is required in the domains of recovery of spent LIB components, media and optimised condition for leaching, the universal process for recovery of components of spent LIB, disposing of LIBs and recycling systems. Recycling of batteries is the only option available for the sustainability of this technology. Thus, the cumulative effect of the above-stated research would be developing advanced LIB technology for EVs and energy storage systems. Moreover, stringent safety testing standards and regulations have been established to evaluate the performance and safety of lithium-ion batteries, particularly in high-demand applications such as electric vehicles. These measures aim to ensure that lithium-ion batteries meet the necessary safety requirements and provide reliable and secure energy storage solutions for a wide range of applications, including electric vehicles.

By analysing the literature, this paper identifies research gaps and areas that warrant further investigation. It also explores the potential for future research in the field. This comprehensive review serves as a valuable resource for researchers, engineers and stakeholders interested in understanding the current state of LIBs and their implications. By addressing these research gaps, scientists can contribute to the development of more efficient and sustainable battery technologies, ensuring the continued growth and success of electric vehicles and energy storage systems.

## References

Abraham, K. (2020) 'How comparable are sodium-ion batteries to lithium-ion counterparts?', *ACS Energy Letters*, Vol. 5, pp.3544–3547.

Ahmad, F., Alam, M.S., Alsaidan, I.S. and Shariff, S.M. (2020) 'Battery swapping station for electric vehicles: opportunities and challenges', *IET Smart Grid*, Vol. 3, pp.280–286.

Ahmadi, L., Yip, A., Fowler, M., Young, S.B. and Fraser, R.A. (2014) 'Environmental feasibility of reuse of electric vehicle batteries', *Sustainable Energy Technologies and Assessments*, Vol. 6, pp.64–74.

Ahmadi, L., Young, S.B., Fowler, M., Fraser, R.A. and Achachlouei, M.A. (2017) 'A cascaded life cycle: reuse of electric vehicle lithium-ion battery packs in energy storage systems', *The International Journal of Life Cycle Assessment*, Vol. 22, pp.111–124.

Alramadhan, D., Alabduljaleel, S., Almulla, D. and Aleisa, E. (2022) 'Multicriteria optimization for electric vehicles in an arid oil state based on a triple bottom line approach', *The International Journal of Life Cycle Assessment*, pp.1–19.

Anuphappharadorn, S., Sukchai, S., Sirisamphanwong, C. and Ketjoy, N. (2014) 'Comparison the economic analysis of the battery between lithium-ion and lead-acid in PV stand-alone application', *Energy Procedia*, Vol. 56, pp.352–358.

Arshad, F., Li, L., Amin, K., Fan, E., Manurkar, N., Ahmad, A., Yang, J., Wu, F. and Chen, R. (2020) 'A comprehensive review of the advancement in recycling the anode and electrolyte from spent lithium-ion batteries', *ACS Sustainable Chemistry and Engineering*, Vol. 8, pp.13527–13554.

Arshad, F., Lin, J., Manurkar, N., Fan, E., Ahmad, A., Wu, F., Chen, R. and Li, L. (2022) 'Life cycle assessment of lithium-ion batteries: a critical review', *Resources, Conservation and Recycling*, Vol. 180, 106164.

Asef, P., Milan, M., Lapthorn, A. and Padmanaban, S. (2021) 'Future trends and aging analysis of battery energy storage systems for electric vehicles', *Sustainability*, Vol. 13, 13779.

Barraza, O. and Estrada, M. (2021) 'Battery electric bus network: efficient design and cost comparison of different powertrains', *Sustainability*, Vol. 13, 4745.

Benveniste, G., Rallo, H., Casals, L.C., Merino, A. and Amante, B. (2018) 'Comparison of the state of lithium-sulphur and lithium-ion batteries applied to electromobility', *Journal of Environmental Management*, Vol. 226, pp.1–12.

Blomgren, G.E. (2016) 'The development and future of lithium-ion batteries', *Journal of The Electrochemical Society*, Vol. 164, A5019.

Bollini, R. (2022) *Lithium-Ion Cell Supply Chain Ev Reporter Issue 24.*

Bouillass, G., Blanc, I. and Perez-Lopez, P. (2021) 'Step-by-step social life cycle assessment framework: a participatory approach for the identification and prioritization of impact subcategories applied to mobility scenarios', *The International Journal of Life Cycle Assessment*, Vol. 26, pp.2408–2435.

Boyden, A., Soo, V.K. and Doolan, M. (2016) 'The environmental impacts of recycling portable lithium-ion batteries', *Procedia Cirp*, Vol. 48, pp.188–193.

Ceder, G. (2010) 'Opportunities and challenges for first-principles materials design and applications to Li battery materials', *MRS Bulletin*, Vol. 35, pp.693–701.

Chen, F., Taylor, N. and Kringos, N. (2015) 'Electrification of roads: opportunities and challenges', *Applied Energy*, Vol. 150, pp.109–119.

Chen, S., Dai, F. and Cai, M. (2020) 'Opportunities and challenges of high-energy lithium metal batteries for electric vehicle applications', *ACS Energy Letters*, Vol. 5, pp.3140–3151.

Chen, X., Shen, W., Vo, T.T., Cao, Z. and Kapoor, A. (2012) 'An overview of lithium-ion batteries for electric vehicles', *Proceedings of the 10th International Power and Energy Conference (IPEC)*, IEEE, pp.230–235.

Chen, Y., Kang, Y., Zhao, Y., Wang, L., Liu, J., Li, Y., Liang, Z., He, X., Li, X., Tavajohi, N. and Li, B. (2021) 'A review of lithium-ion battery safety concerns: the issues, strategies, and testing standards', *Journal of Energy Chemistry*, Vol. 59, pp.83–99. Doi: 10.1016/j.jechem.2020.10.017.

Ciez, R.E. and Whitacre, J. (2019) 'Examining different recycling processes for lithium-ion batteries', *Nature Sustainability*, Vol. 2, pp.148–156.

Costa, C.M., Barbosa, J.C., Gonçalves, R., Castro, H., Del Campo, F. and Lanceros-Méndez, S. (2021) 'Recycling and environmental issues of lithium-ion batteries: advances, challenges and opportunities', *Energy Storage Materials*, Vol. 37, pp.433–465.

Dai, Q., Kelly, J.C., Gaines, L. and Wang, M. (2019) 'Life cycle analysis of lithium-ion batteries for automotive applications', *Batteries*, Vol. 5, 48.

Dehghani-Sanij, A., Tharumalingam, E., Dusseault, M. and Fraser, R. (2019) 'Study of energy storage systems and environmental challenges of batteries', *Renewable and Sustainable Energy Reviews*, Vol. 104, pp.192–208.

Deng, Y., Li, J., Li, T., Zhang, J., Yang, F. and Yuan, C. (2017) 'Life cycle assessment of high-capacity molybdenum disulfide lithium-ion battery for electric vehicles', *Energy*, Vol. 123, pp.77–88.

Dewulf, J., Van Der Vorst, G., Denturck, K., Van Langenhove, H., Ghyoot, W., Tytgat, J. and Vandeputte, K. (2010) 'Recycling rechargeable lithium-ion batteries: critical analysis of natural resource savings', *Resources, Conservation and Recycling*, Vol. 54, pp.229–234.

Diouf, B. and Pode, R. (2015) 'Potential of lithium-ion batteries in renewable energy', *Renewable Energy*, Vol. 76, pp.375–380.

Dunn, J. B., Gaines, L., Sullivan, J. and Wang, M.Q. (2012) 'Impact of recycling on cradle-to-gate energy consumption and greenhouse gas emissions of automotive lithium-ion batteries', *Environmental Science and Technology*, Vol. 46, pp.12704–12710.

Eddahech, A., Briat, O. and Vinassa, J-M. (2015) 'Performance comparison of four lithium–ion battery technologies under calendar aging', *Energy*, Vol. 84, pp.542–550.

Ellingsen, L.A.W., Majeau-Bettez, G., Singh, B., Srivastava, A.K., Valøen, L.O. and Strømman, A.H. (2014) 'Life cycle assessment of a lithium-ion battery vehicle pack', *Journal of Industrial Ecology*, Vol. 18, pp.113–124.

Elmahallawy, M., Elfouly, T., Alouani, A. and Massoud, A.M. (2022) 'A comprehensive review of lithium-ion batteries modeling, and state of health and remaining useful lifetime prediction', *Survey*, Vol. 10, pp.119040–119070. Available online at: https://ieeexplore.ieee.org/document/9944663

Etacheri, V., Marom, R., Elazari, R., Salitra, G. and Aurbach, D. (2011) 'Challenges in the development of advanced Li-ion batteries: a review', *Energy and Environmental Science*, Vol. 4, pp.3243–3262.

Fan, E., Li, L., Wang, Z., Lin, J., Huang, Y., Yao, Y., Chen, R. and Wu, F. (2020) 'Sustainable recycling technology for Li-ion batteries and beyond: challenges and future prospects', *Chemical Reviews*, Vol. 120, pp.7020–7063.

Farmann, A. and Sauer, D.U. (2018) 'Comparative study of reduced order equivalent circuit models for on-board state-of-available-power prediction of lithium-ion batteries in electric vehicles', *Applied Energy*, Vol. 225, pp.1102–1122.

Farmann, A., Waag, W., Marongiu, A. and Sauer, D.U. (2015) 'Critical review of on-board capacity estimation techniques for lithium-ion batteries in electric and hybrid electric vehicles', *Journal of Power Sources*, Vol. 281, pp.114–130.

Feng, X., Ren, D., He, X. and Ouyang, M. (2020) 'Mitigating thermal runaway of lithium-ion batteries (perspective)', *Joule*, Vol. 4, No. 4, pp.743–770. Doi: 10.1016/j.joule.2020.02.010.

Filho, W.L., Abubakar, I.R., Kotter, R., Grindsted, T.S., Balogun, A-L., Salvia, A.L., Aina, Y.A. and Wolf, F. (2021) 'Framing electric mobility for urban sustainability in a circular economy context: an overview of the literature', *Sustainability*, Vol. 13. Doi: 10.3390/su13147786.

Gaines, L. (2018) 'Lithium-ion battery recycling processes: research towards a sustainable course', *Sustainable Materials and Technologies*, Vol. 17, e00068.

Gaines, L., Sullivan, J., Burnham, A. and Belharouak, I. (2011) 'Life-cycle analysis for lithium-ion battery production and recycling', *Transportation Research Board 90th Annual Meeting*, Washington, DC, pp.23–27.

Gaines, L.L. and Dunn, J.B. (2014) *Lithium-ion Battery Environmental Impacts*, Lithium-Ion Batteries, Elsevier.

Geng, D., Ding, N., Hor, T.A., Chien, S.W., Liu, Z., Wuu, D., Sun, X. and Zong, Y. (2016) 'From lithium-oxygen to lithium-air batteries: challenges and opportunities', *Advanced Energy Materials*, Vol. 6.

Glöser-Chahoud, S., Huster, S., Rosenberg, S., Baazouzi, S., Kiemel, S., Singh, S., Schneider, C., Weeber, M., Miehe, R. and Schultmann, F. (2021) 'Industrial disassembling as a key enabler of circular economy solutions for obsolete electric vehicle battery systems', *Resources, Conservation and Recycling*, Vol. 174, 105735.

Goikolea, E., Palomares, V., Wang, S., De Larramendi, I.R., Guo, X., Wang, G. and Rojo, T. (2020) 'Na-ion batteries – approaching old and new challenges', *Advanced Energy Materials*, Vol. 10.

Gurung, A. and Qiao, Q. (2018) 'Solar charging batteries: advances, challenges, and opportunities', *Joule*, Vol. 2, pp.1217–1230.

Hanisch, C., Loellhoeffel, T., Diekmann, J., Markley, K.J., Haselrieder, W. and Kwade, A. (2015) 'Recycling of lithium-ion batteries: a novel method to separate coating and foil of electrodes', *Journal of Cleaner Production*, Vol. 108, pp.301–311.

Hannan, M.A., Hoque, M.M., Hussain, A., Yusof, Y. and Ker, P.J. (2018) 'State-of-the-art and energy management system of lithium-ion batteries in electric vehicle applications: issues and recommendations', *IEEE Access*, Vol. 6, pp.19362–19378.

Hao, H., Mu, Z., Jiang, S., Liu, Z. and Zhao, F. (2017) 'GHG Emissions from the production of lithium-ion batteries for electric vehicles in China. Sustainability, Vol. 9, pp.504.

Harting, K., Kunz, U. and Turek, T. (2012) 'Zinc-air batteries: prospects and challenges for future improvement', *Zeitschrift für Physikalische Chemie*, Vol. 226, pp.151–166.

He, Y. and Xu, Z. (2014) 'The status and development of treatment techniques of typical waste electrical and electronic equipment in China: a review', *Waste Management and Research*, Vol. 32, pp.254–269.

Hu, X., Zou, C., Zhang, C. and Li, Y. (2017) 'Technological developments in batteries: a survey of principal roles, types, and management needs', *IEEE Power and Energy Magazine*, Vol. 15, pp.20–31.

Huang, B., Pan, Z., Su, X. and An, L. (2018) 'Recycling of lithium-ion batteries: recent advances and perspectives', *Journal of Power Sources*, Vol. 399, pp.274–286.

Jaguemont, J., Boulon, L. and Dubé, Y. (2016) 'A comprehensive review of lithium-ion batteries used in hybrid and electric vehicles at cold temperatures', *Applied Energy*, Vol. 164, pp.99–114.

Jiang, S., Hua, H., Zhang, L., Liu, X., Wu, H. and Yuan, Z. (2022) 'Environmental impacts of hydrometallurgical recycling and reusing for manufacturing of lithium-ion traction batteries in China', *Science of The Total Environment*, Vol. 811, 152224.

Keshan, H., Thornburg, J. and Ustun, T.S. (2016) 'Comparison of lead-acid and lithium-ion batteries for stationary storage in off-grid energy systems', *Proceedings of the 4th IET Clean Energy and Technology Conference*', IET, Kuala Lumpur, Malaysia.

Kim, T., Song, W., Son, D-Y., Ono, L.K. and Qi, Y. (2019) 'Lithium-ion batteries: outlook on present, future, and hybridized technologies', *Journal of Materials Chemistry A*, Vol. 7, pp.2942–2964.

Kim, T., Song, W., Son, D-Y., Ono, L.K. and Qi, Y. (2019) 'Lithium–ion batteries: outlook on present, future, and hybridized technologies', *Journal of Materials Chemistry A*, Vol. 7, pp.2942–2964. Doi: 10.1039/x0xx00000x.

Koh, S., Smith, L., Miah, J., Astudillo, D., Eufrasio, R., Gladwin, D., Brown, S. and Stone, D. (2021) 'Higher 2nd life lithium titanate battery content in hybrid energy storage systems lowers environmental-economic impact and balances eco-efficiency', *Renewable and Sustainable Energy Reviews*, Vol. 152. Doi: 10.1016/j.rser.2021.111704.

Kotak, Y., Marchante Fernández, C., Canals Casals, L., Kotak, B.S., Koch, D., Geisbauer, C., Trilla, L., Gómez-Núñez, A. and Schweiger, H-G. (2021) 'End of electric vehicle batteries: reuse vs. recycle', *Energies*, Vol. 14. Doi: 10.3390/en14082217.

Kuang, Y., Chen, C., Kirsch, D. and Hu, L. (2019) 'Thick electrode batteries: principles, opportunities, and challenges', *Advanced Energy Materials*, Vol. 9. Doi: Doi: 10.1002/aenm.201901457.

Kushnir, D. (2015) *Lithium-ion Battery Recycling Technology 2015*, Current State and Future Prospects; ESA Report, p.18.

Li, B., Gao, X., Li, J. and Yuan, C. (2014) 'Life cycle environmental impact of high-capacity lithium-ion battery with silicon nanowires anode for electric vehicles', *Environmental Science and Technology*, Vol. 48, pp.3047–3055.

Li, J., He, X. and Zeng, X. (2017) 'Designing and examining e-waste recycling process: methodology and case studies', *Environmental Technology*, Vol. 38, pp.652–660.

Liang, Y., Su, J., Xi, B., Yu, Y., Ji, D., Sun, Y., Cui, C. and Zhu, J. (2017) 'Life cycle assessment of lithium-ion batteries for greenhouse gas emissions', *Resources, Conservation and Recycling*, Vol. 117, pp.285–293.

Liu, W., Agusdinata, D.B., Eakin, H. and Romero, H. (2022) 'Sustainable minerals extraction for electric vehicles: a pilot study of consumers' perceptions of impacts', *Resources Policy*, Vol. 75, 102523.

Lu, B., Liu, J. and Yang, J. (2017) 'Substance flow analysis of lithium for sustainable management in mainland China: 2007–2014', *Resources, Conservation and Recycling*, Vol. 119, pp.109–116.

Machedon-Pisu, M. and Borza, P.N. (2021) 'A methodological approach to assess the impact of energy and raw materials constraints on the sustainable deployment of light-duty vehicles by 2050', *Sustainability*, Vol. 13. Doi: 10.3390/su132111826.

Makuza, B., Tian, Q., Guo, X., Chattopadhyay, K. and Yu, D. (2021) 'Pyrometallurgical options for recycling spent lithium-ion batteries: a comprehensive review', *Journal of Power Sources*, Vol. 491. Doi: 10.1016/j.jpowsour.2021.229622.

Manthiram, A. (2017) 'An outlook on lithium-ion battery technology', *ACS Central Science*, Vol. 3, pp.1063–1069.

Manzolli, J.A., Trovão, J.P. and Antunes, C.H. (2022) 'A review of electric bus vehicles research topics – methods and trends', *Renewable and Sustainable Energy Reviews*, Vol. 159. Doi: 10.1016/j.rser.2022.112211.

Masias, A., MarcickI, J. and Paxton, W.A. (2021) 'Opportunities and challenges of lithium-ion batteries in automotive applications', *ACS Energy Letters*, Vol. 6, pp.621–630.

Mauger, A. and Julien, C. (2017) 'Critical review on lithium-ion batteries: are they safe? Sustainable', *Ionics*, Vol. 23, pp.1933–1947.

Mechlia, M.B., Schutz, J., Dellagi, S. and Chelbi, A. (2021) 'Quasi-optimal sizing of a vehicle fleet considering environmental impact, maintenance, and eventual containment measures', *Sustainability*, Vol. 13, pp.1–17.

Meshram, P., Mishra, A. and Sahu, R. (2020) 'Environmental impact of spent lithium-ion batteries and green recycling perspectives by organic acids – a review', *Chemosphere*, Vol. 242. Doi: 10.1016/j.chemosphere.2019.125291.

Mossali, E., Picone, N., Gentilini, L., Rodrìguez, O., Pérez, J.M. and Colledani, M. (2020) 'Lithium-ion batteries towards circular economy: a literature review of opportunities and issues of recycling treatments', *Journal of Environmental Managemen*t, Vol. 264. Doi: 10.1016/j.jenvman.2020.110500.

Nair, J.R., Imholt, L., Brunklaus, G. and Winter, M. (2019) 'Lithium metal polymer electrolyte batteries: opportunities and challenges', *The Electrochemical Society Interface*, Vol. 28. Doi: 10.1149/2.F05192if.

Notter, D.A., Gauch, M., Widmer, R., Wager, P., Stamp, A., Zah, R. and Althaus, H-J. (2010) *Contribution of Li-ion Batteries to the Environmental Impact of Electric Vehicles*, ACS Publications.

Oliveira, L., Messagie, M., Rangaraju, S., Sanfelix, J., Rivas, M.H. and Van Mierlo, J. (2015) 'Key issues of lithium-ion batteries – from resource depletion to environmental performance indicators', *Journal of Cleaner Production*, Vol. 108, pp.354–362.

Omar, N., Verbrugge, B., Mulder, G., Van Den Bossche, P., Van Mierlo, J., Daowd, M., Dhaens, M. and Pauwels, S. (2010) 'Evaluation of performance characteristics of various lithium-ion batteries for use in BEV application', *IEEE Vehicle Power and Propulsion Conference*, IEEE, pp.1–6.

Onat, N.C. (2022) 'How to compare sustainability impacts of alternative fuel vehicles?', *Transportation Research Part D: Transport and Environment*, Vol. 102. Doi: 10.1016/j.trd.2021.103129.

Oswal, M., Paul, J. and Zhao, R. (2010) 'A comparative study of lithium-ion batteries', *University of Southern California*, pp.2419–2430.

Pellow, M.A., Ambrose, H., Mulvaney, D., Betita, R. and Shaw, S. (2020) 'Research gaps in environmental life cycle assessments of lithium-ion batteries for grid-scale stationary energy storage systems: End-of-life options and other issues', *Sustainable Materials and Technologies*, Vol. 23, e00120.

Perner, A. and Vetter, J. (2015) 'Lithium-ion batteries for hybrid electric vehicles and battery electric vehicles', *Advances in Battery Technologies for Electric Vehicles*, Elsevier.

Peters, J.F. and Weil, M. (2016) 'A critical assessment of the resource depletion potential of current and future lithium-ion batteries', *Resources*, Vol. 5. Doi: 10.3390/resources5040046.

Peters, J.F., Baumann, M., Zimmermann, B., Braun, J. and Weil, M. (2017) 'The environmental impact of Li-Ion batteries and the role of key parameters – a review', *Renewable and Sustainable Energy Reviews*, Vol. 67, pp.491–506.

Pistoia, G. (2013) *Lithium-Ion Batteries: Advances and Applications*, 1st ed., Elsevier.

Ramadesigan, V., Chen, K., Burns, N.A., Boovaragavan, V., Braatz, R.D. and Subramanian, V. R. (2011) 'Parameter estimation and capacity fade analysis of lithium-ion batteries using reformulated models', *Journal of the Electrochemical* Society, Vol. 158, pp.11–19.

Romare, M. and Dahllöf, L. (2017) 'The life cycle energy consumption and greenhouse gas emissions from lithium-ion batteries', *IVL Svenska Miljoinstitutet*, pp.1–58.

Shahid, S. and Agelin-Chaab, M. (2022) 'A review of thermal runaway prevention and mitigation strategies for lithium-ion batteries', *Energy Conversion and Management*, Vol. 16. Doi: 10.1016/j.ecmx.2022.100310.

Siragusa, C., Tumino, A., Mangiaracina, R., Perego, A. (2022) 'Electric vehicles performing last-mile delivery in B2C e-commerce: an economic and environmental assessment', *International Journal of Sustainable Transportation*, Vol. 16, pp.22–33.

Soares, L. and Wang, H. (2022) 'A study on renewed perspectives of electrified road for wireless power transfer of electric vehicles', *Renewable and Sustainable Energy Reviews*, Vol. 158. Doi: 10.1016/j.rser.2022.112110.

Sommerville, R., Zhu, P., Rajaeifar, M.A., Heidrich, O., Goodship, V. and Kendrick, E. (2021) 'A qualitative assessment of lithium-ion battery recycling processes', *Resources, Conservation and Recycling*, Vol. 165. Doi: 10.1016/j.resconrec.2020.105219.

Sonoc, A. and Jeswiet, J. (2014) 'A review of lithium supply and demand and a preliminary investigation of a room temperature method to recycle lithium-ion batteries to recover lithium and other materials', *Procedia CIRP*, Vol. 15, pp.289–293.

Sonoc, A., Jeswiet, J. and Soo, V.K. (2015) 'Opportunities to improve recycling of automotive lithium-ion batteries', *Procedia CIRP*, Vol. 29, pp.752–757.

Spreafico, C. (2021) 'Can modified components make cars greener: a life cycle assessment', *Journal of Cleaner Production*, Vol. 307. Doi: 10.1016/j.jclepro.2021.127190.

Stan, A-I., Świerczyński, M., Stroe, D-I., Teodorescu, R. Andreasen, S.J. (2014) 'Lithium-ion battery chemistries from renewable energy storage to automotive and back-up power applications – an overview', *Proceedings of the International Conference on Optimization of Electrical and Electronic Equipment (OPTIM)*, IEEE, pp.713–720.

Sullivan, J. and Gaines, L. (2010) 'A review of battery life-cycle analysis: state of knowledge and critical needs', *Energy Systems Division*, pp.1–45.

Tarascon, J-M. and Armand, M. (2011) 'Issues and challenges facing rechargeable lithium batteries', *Material for Sustainable Energy*, pp.171–179.

Tian, Y., Zeng, G., Rutt, A., Shi, T., Kim, H., Wang, J., Koettgen, J., Sun, Y., Ouyang, B., Chen, T., Lun, Z., Rong, Z., Persson, K. and Ceder, G. (2021) 'Promises and challenges of next-generation 'beyond li-ion' batteries for electric vehicles and grid decarbonization', *Chemistry Review*, Vol. 121, No. 3, pp.1623–1669.

Üçtuğ, F.G. and Azapagic, A. (2018) 'Environmental impacts of small-scale hybrid energy systems: Coupling solar photovoltaics and lithium-ion batteries', *Science of the Total Environment*, Vol. 643, pp.1579–1589.

Vandepaer, L., Cloutier, J. and Amor, B. (2017) 'Environmental impacts of lithium metal polymer and lithium-ion stationary batteries', *Renewable and Sustainable Energy Reviews*, Vol. 78, pp.46–60.

Wang, N. and Yang, Q. (2021) 'Optimised design of LCC-S compensation topologies for wireless power transfer with dynamic load for electric vehicles', *International Journal of Vehicle Information and Communication Systems*, Vol. 6, No. 2, pp.107–120. Doi: 10.1504/IJVICS.2021.115252.

Wang, Q., Jiang, B., Li, B. and Yan, Y. (2016) 'A critical review of thermal management models and solutions of lithium-ion batteries for the development of pure electric vehicles', *Renewable and Sustainable Energy Reviews*, Vol. 64, pp.106–128.

Wanger, T.C. (2011) 'The Lithium future resources, recycling, and the environment', *Conservation Letters*, Vol. 4, pp.202–206.

Wangsa, I. D., Vanany, I. and Siswanto, N. (2022) 'Issues in sustainable supply chain's futuristic technologies: a bibliometric and research trend analysis', *Environmental Science and Pollution Research*, pp.1–28.

Werner, D., Peuker, U.A. and Mütze, T. (2020) 'Recycling chain for spent lithium-ion batteries', *Metals*, Vol. 10, pp.316.

Williard, N., Sood, B., Osterman, M. and Pecht, M. (2011) 'Disassembly methodology for conducting failure analysis on lithium–ion batteries', *Journal of Materials Science: Materials in Electronics*, Vol. 22, pp.1616–1630.

Wrålsen, B., Prieto-Sandoval, V., Mejia-Villa, A., O'born, R., Hellström, M. and Faessler, B. (2021) 'Circular business models for lithium-ion batteries-stakeholders, barriers, and drivers', *Journal of Cleaner Production*, Vol. 317. Doi: 10.1016/j.jclepro.2021.128393.

Wu, X., Leonard, D.P. and Ji, X. (2017) 'Emerging non-aqueous potassium-ion batteries: challenges and opportunities', *Chemistry of Materials*, Vol. 29, pp.5031–5042.

Xie, J. and Lu, Y-C. (2020) 'A retrospective on lithium-ion batteries', *Nature Communications*. Vol, 11. Doi: 10.1038/s41467-020-16259-9.

Xu, P., Dai, Q., Gao, H., Liu, H., Zhang, M., Li, M., Chen, Y., An, K., Meng, Y.S. and Liu, P. (2020) 'Efficient direct recycling of lithium-ion battery cathodes by targeted healing', *Joule*, Vol. 4, pp.2609–2626.

Yang, H., Li, H., Li, J., Sun, Z., He, K., Cheng, H. M. and Li, F. (2019) 'The rechargeable aluminum battery: opportunities and challenges', *Angewandte Chemie International Edition*, Vol. 58, pp.11978–11996.

Yang, J., Gu, F. and Guo, J. (2020) 'Environmental feasibility of secondary use of electric vehicle lithium-ion batteries in communication base stations', *Resources, Conservation and Recycling*, Vol. 156. Doi: 10.1016/j.resconrec.2020.104713.

Yang, Y., Okonkwo, E. G., Huang, G., Xu, S., Sun, W. and He, Y. (2021) 'On the sustainability of lithium-ion battery industry – a review and perspective', *Energy Storage Materials*, Vol. 36, pp.186–212.

Zackrisson, M., Avellán, l. and Orlenius, J. (2010) 'Life cycle assessment of lithium-ion batteries for plug-in hybrid electric vehicles – critical issues', *Journal of Cleaner Production*, Vol. 18, pp.1519–1529.

Zeng, D., Dong, Y., Cao, H., Li, Y., Wang, J., Li, Z. and Hauschild, M. Z. (2021) 'Are the electric vehicles more sustainable than the conventional ones influences of the assumptions and modeling approaches in the case of typical cars in China', *Resources, Conservation and Recycling*, Vol. 167. Doi: 10.1016/j.resconrec.2020.105210.

Zeng, X., Li, J. and Liu, L. (2015) 'Solving spent lithium-ion battery problems in China: opportunities and challenges', *Renewable and Sustainable Energy Reviews*, Vol. 52, pp.1759–1767.

Zhang, L. and Xu, Z. (2016) 'A review of current progress of recycling technologies for metals from waste electrical and electronic equipment', *Journal of Cleaner Production*, Vol. 127, pp.19–36.

Zhang, X., Lin, Z., Crawford, C. and Li, S. (2022) 'Techno-economic comparison of electrification for heavy-duty trucks in China by *2040*', *Transportation Research Part D: Transport and Environment*, Vol. 102, pp.1–39.

Zhao, G. (2017) *Reuse and Recycling of Lithium-Ion Power Batteries*, John Wiley and Sons.

Zhao, S., He, W. and Li, G. (2019) 'Recycling technology and principle of spent lithium-ion battery', *Recycling of Spent Lithium-Ion Batteries*, pp.1–26.

Zhu, S., He, W., Li, G., Zhou, X., Huang, J. and Zhang, X. (2011) 'Recovering copper from spent lithium-ion battery by a mechanical separation process', *International Conference on Materials for Renewable Energy and Environment*, IEEE, pp.1008–1012.

Zou, C., Zhang, L., Hu, X., Wang, Z., Wik, T. and Pecht, M. (2018) 'A review of fractional-order techniques applied to lithium-ion batteries, lead-acid batteries, and supercapacitors', *Journal of Power Sources*, Vol. 390, pp.286–296.

Zubi, G., Dufo-López, R., Carvalho, M. and Pasaoglu, G. (2018) 'The lithium-ion battery: state of the art and future perspectives', *Renewable and Sustainable Energy Reviews*, Vol. 89, pp.292–308.