World Electric Vehicle Journal

Review

Advancements and Current Developments in Integrated System Architectures of Lithium-Ion Batteries for Electric Mobility

Sandeep Rawat [1], Sushabhan Choudhury [2], Devender Kumar Saini [1,*] and Yogesh Chandra Gupta [1]

[1] Electrical Cluster, School of Engineering, UPES, Dehradun 248006, India; sandeep.rawat@ddn.upes.ac.in (S.R.); ycgupta@ddn.upes.ac.in (Y.C.G.)
[2] School of Computer Sciences, UPES, Dehradun 248007, India; schoudhury@ddn.upes.ac.in
* Correspondence: dev.iit.roorkee@gmail.com or dksaini@ddn.upes.ac.in

Abstract: Recognizing the challenges faced by power lithium-ion batteries (LIBs), the concept of integrated battery systems emerges as a promising avenue. This offers the potential for higher energy densities and assuaging concerns surrounding electric vehicle range anxiety. Moreover, mechanical design optimization, though previously overlooked, is gaining traction among researchers as a viable alternative to achieve enhanced energy and power densities. This review paper provides a comprehensive overview of recent research and progress in this domain, emphasizing the significance of battery architectures in enabling the widespread adoption of electric mobility. Beginning with an exploration of fundamental principles underlying LIB systems, the paper discusses various architectures involving different cell form factors, like pouch cells, cylindrical cells, and prismatic cells, along with their advantages and limitations. Furthermore, it reviews recent research trends, highlighting innovations aimed at enhancing battery performance, energy density, and safety through advanced battery system architecture. Through case studies and discussions on challenges and future directions, the paper underscores the critical role of advanced battery system architecture in driving the evolution of e-mobility and shaping the sustainable transportation landscape.

Keywords: lithium-ion battery; NMC cell; state of charge; remaining useful life; state of temperature; battery safety; machine learning techniques

check for updates

Citation: Rawat, S.; Choudhury, S.; Saini, D.K.; Gupta, Y.C. Advancements and Current Developments in Integrated System Architectures of Lithium-Ion Batteries for Electric Mobility. *World Electr. Veh. J.* **2024**, *15*, 394. https://doi.org/10.3390/wevj15090394

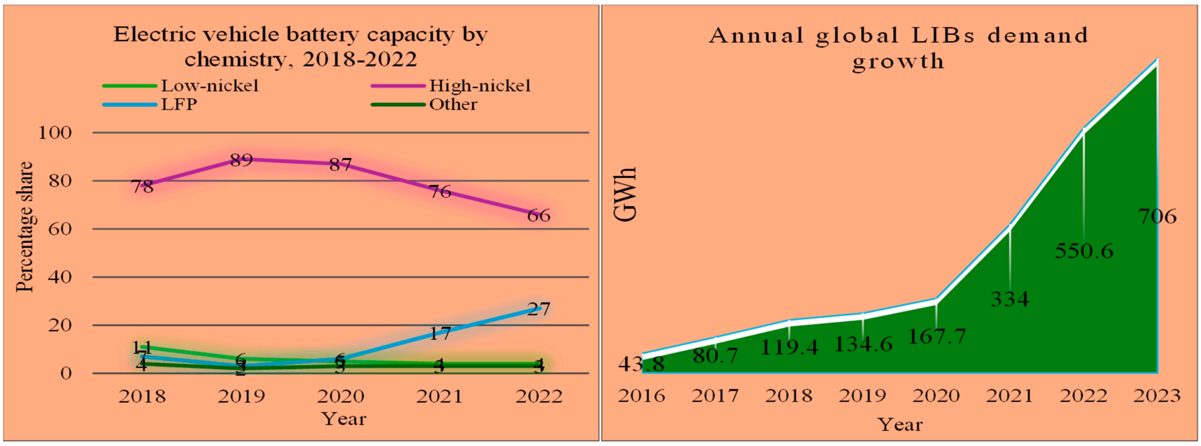
Academic Editors: Quanqing Yu, Yonggang Liu and Xiaopeng Tang

Received: 15 July 2024
Revised: 20 August 2024
Accepted: 25 August 2024
Published: 28 August 2024

1. Introduction

The CO_2 emissions measured have increased by 1.1% in 2023 across the globe, an increment of 410 million tons (Mt), and a huge record of 37.4 billion tons (Bt) as compared to the rise of 490 Mt in 2022 (1.3%) was obtained. Coal products contributed to the emission by around more than 65% in 2023. Meanwhile, the curtailing of hydropower generation due to various environmental conditions (droughts, slits) drove up the emissions by around 170 Mt. From 2019 to 2023, the overall contribution of the energy sector in emissions was recorded at around 900 Mt. However, the deployment of five clean energy technologies viz. solar PV, wind, nuclear, heat pumps, and electric cars boost up the renewable sector [1]. This increasing deployment of clean energy has contributed to a configurational reduction in emissions. Since the last few years, up to 2023, the emission scale was recorded as slightly more than 0.5% per year [2]. Additionally, the 21st century has witnessed a significant paradigm shift in the automotive industry, marked by an accelerating transition towards electric mobility [3]. This shift is propelled by a convergence of factors, including environmental concerns [4], technological advancements [5], and evolving consumer preferences [6]. As societies worldwide grapple with the challenges posed by climate change and air pollution, it is very crucial to decrease the carbon emissions from the automobile sector to the environment with strict and promising action [7]. Electric Vehicles (EVs) have emerged as a promising solution to address these challenges. Although, electrification of vehicle provides a better alternative to meet the global climate change target, but it still requires proper research and determination of references that have been most instrumental in developing in each stream of EV research [8]. This fundamental departure from fossil fuel dependency not only mitigates harmful emissions but also reduces our reliance on finite resources [2].

Consequently, the transition towards e-mobility necessitates advancements in lithium-ion battery (LIBs) system architectures to meet modern transportation demands. This growing interest in advanced rechargeable LIBs for applications across portable electronics and smart grids, apart from electric mobility, has intensified research and development on various aspects, like material development for enhanced energy-power density, safe cell technology, enhanced life and reliability, and cost, in addition to understanding the behavior of batteries under different environmental and operational conditions, battery pack making, and integration technologies [9]. To meet the energy and power densities to the level of carbonous fuels, efforts are made to boost by augmenting electrode material capacity and operational voltage output. Globally, for e-mobility applications, lithium nickel manganese cobalt oxide (NMC) maintained its lead with a 70^{+}% market share, followed by lithium iron phosphate (LFP) at nearly 27^{+}% and nickel cobalt aluminum oxide (NCA) at around 3^{+}% among all LIB cell electro-chemistries, as depicted in Figure 1a. Many combinations of oxyanions (sulfate, phosphate, silicate) and metal (Mn, Fe, Co, Ni) cations have been studied from the perspective of the cell cathode component over the past few decades, but LFP is the only one that has made it to market and is the main contender for the large-scale use for stationary energy storage because of its low cost, superior safety, and high cycle durability [10]. The formidable expansion can be attributed predominantly to the electric passenger car segment, which witnessed a meteoric 55% surge in new registrations throughout 2022 compared to its 2021 counterpart [11]. In a report unveiled by the McKinsey Battery Insights team, a tantalizing projection unfurls, as shown below in Figure 1b, which foretells the luminous trajectory of the complete LIB continuum, suggesting an annual growth rate exceeding 30 percent from the year 2022 to 2030. Moreover, it shall have a valuation of over USD 400 billion and a market of 4.7 terawatt hours [12] by 2032.



(**a**) (**b**)

Figure 1. (**a**) Global market share of different cell chemistries and (**b**) global LIB demand growth.

Despite advances in LIBs, their energy density remains insufficient, thus constraining the mileage potential of e-mobility as per Figure 1. According to current research in materials chemistry, LIBs are projected to target the total initial cell galvanic energy density of ≈350–400 Wh/kg, which falls short of meeting the energy requirements for e-mobility applications once it is converted to usable pack end-of-life values [13,14]. Several original equipment manufacturers (OEMs), including VW, Tesla, PSA, Mercedes, Renault, and BYD, aim for approximately 700–800 Wh/L and 300–350 Wh/kg at the cell level by 2025. Moreover, by 2030, they aim to achieve 800–1000 Wh/L and 350–400 Wh/kg of the total market of the EV automobile sector, so that the vision of clean energy can be targeted by the end of 2040 [14].

The automobile industry's transition to electric mobility has brought LIBs more attention; current research endeavors to improve LIBs' energy density, safety, and dependability. By 2030, the market for LIBs—especially for electric vehicles—is expected to have grown significantly, according to forecasts. To achieve the necessary energy densities for e-mobility applications, however, present LIB technology still confronts difficulties. This has led to additional research into better materials and battery topologies.

Though they are still at the research stage, recent advancements in solid-state batteries beyond lithium-ion technologies, such as lithium metal and lithium sulfur, are demonstrating promise. To increase efficiency and prolong battery life, efforts are also being undertaken to optimize internal battery architecture and battery management systems (BMSs).

Lastly, as state of charge (SOC) and battery health (SOH) are critical components for guaranteeing the dependable and safe operation of LIBs in electric cars, the significance of precise monitoring and diagnostics of these parameters is underlined. The aim of the current research is to enhance the overall performance and safety of battery systems by addressing the several failure modes and processes that may arise.

2. Literature Review

The growing trend towards e-mobility is not without its challenges. Infrastructure development, including the expansion of charging networks, remains a crucial enabler for widespread EV adoption. Moreover, concerns regarding battery production sustainability, supply chain resilience, and end-of-life recycling must be analyzed to secure the long-term viability of e-mobility [15]. Nevertheless, the momentum behind electric mobility continues to accelerate, driven by a shared vision of a cleaner, greener future [16]. As technological innovations continue to unfold and global efforts to combat climate change intensify, electric mobility is poised to play an increasingly central role in shaping the future of transportation. Multiple developments and research are carried out in the domain of integrated system architectures of LIBs for e-mobility. The current state of commercialization is limited to the cell-to-module and cell-to-pack level, and material selection and mechanical packaging are important considerations. Using empirical battery design, LIB performance hinges on a holistic understanding of electrode architecture and the optimization of manufacturing processes and provides a comparative analysis of manufacturing methods, offering valuable insights into their architectural controllability, scalability, sustainability, simplicity, and cost, thereby guiding future electrode design and development. [17]. A study conducted from 2010 to 2019 on 25 commercially available EVs looked at trends in specific energy and energy density at the cell, module, and system levels. It was revealed that while improvements were observed in battery systems overall, the specific energy showed greater enhancement compared to energy density, which suggests that there is still considerable potential for gains in packaging optimization, which could drive further advancements in battery system development [18]. Additionally, the study identified a trend towards larger and prismatic cells in terms of cell types and sizes, indicating potential shifts in battery design preferences within the industry [19].

The impossibility of designating a single battery pack capacity to a certain vehicle segment, the increasing significance of prismatic cells, and trends in cell dimensions catered to vehicle space limits are among the major conclusions drawn by many researchers [20,21]. Furthermore, Silicon-based anodes and high-capacity insertion-type cathodes represent a promising advancement in Li-based battery technologies, offering significant energy density improvements. However, their complex chemistry and inherent challenges must be addressed to fully realize their potential for electric vehicles and renewable energy applications [22]. Notwithstanding developments, those studies discover that the most recent cell technologies are being adopted by the market more slowly than anticipated, with unrealized potential in electrode design parameters [23]. To further advance knowledge in this area, future study directions can include additional battery characteristics and xEV subgroups, like plug-in hybrids [24,25]. It was unanimously agreed by researchers that every LIB for e-mobility is different in terms of size, configuration, performance aspects, operating and environmental conditions, cost, etc. At the cell level, there are huge variations in terms of the foam factor [26], capacity [27], cycle life [28], variation in cell capacity [29], voltage during the charging/discharging cycle [30], etc.

Today's pack designs are increasingly collaborative between LIBs and vehicle development, necessitating closer partnerships between OEMs and battery suppliers to achieve efficient, high-performance, and recyclable pack designs [31]. Embracing circular economy principles, designs that prioritize disassembly offer benefits to all stakeholders by shifting recycling costs along the value chain from recyclers to manufacturers and OEMs. Early compliance with these design features is crucial for streamlining the recycling process. Advancements in LIB design require concerted efforts from scientists, industry, and policymakers.

Unlike individual cells, e-mobility battery packs comprise numerous cells interconnected in series and/or parallel, rendering the remaining useful life (RUL) estimation more intricate. Accurate battery life prediction is essential for various applications, but existing methods often rely on controlled lab conditions rather than real-world data. Combining machine learning with physical models offers a promising approach to estimate battery life from noisy field data, assess second-life conditions, and project future usage. Leveraging insights from field data can enhance battery designs and reduce costs [32]. The latest machine learning-based technologies have thus found widespread application in the production and management of lithium-ion batteries [33]. A detailed study has been carried out on thermal runaway propagation in the cell-to-chassis LIBs, which revealed the complexities of the system level, and a novel method for TR propagation estimation was proposed [34], which also explained the influence of local failure of thermal insulation on propagation behavior. Few studies have been performed on the crucial role that efficient topology plays in enabling high-efficiency hierarchical cell-to-cell equalization systems for large-scale batteries. Refs. [35,36] put forth a novel strategy to boost battery equalization systems' efficiency. They also proposed an approach that employs the second-smallest eigenvalue of the topology graph as a performance metric and accounts for energy loss and balance time when evaluating topology graph balancing connectivity. A new study proposes a two-stage module-based cell-to-cell active equalization topology for series-connected LIBs using a modified buck-boost converter. Each battery module's cell-based equalizers are controlled in parallel by the topology, which also regulates the equalizing currents within the modules. This transfers a higher balancing current directly from a strong cell to the weakest cell in a module, cutting down on the length of time required for balancing [37].

For effective fabrication of the module and battery pack, multiple efforts are been carried out to investigate the impact of connected resistance on current distribution through quantitative analysis, employing mathematical models to study various configurations of parallel module setups by examining the initial cell current distribution and exploring multiple module collector positions [38], which reveal that maintaining consistent distances between cells and their module collectors within parallel modules enhances current homogeneity and discharge capacity in series-connected packs. While several serious efforts have been carried out at the cell level to understand different states, like SOC, SOH, State of Failure (SOF), State of Temperature (SOT), State of Energy (SOE), RUL, etc., similar exercises have not been carried out for LIB packs because of complexities [39–41].

One of the primary drivers of recent research in LIBs is the quest for higher energy density, which translates to longer driving ranges for EVs, addressing a major consumer concern [42]. Innovations in electrode materials, such as the use of silicon anodes and nickel-rich cathodes, have substantially increased the capacity of LIBs [43]. These materials store more lithium ions, thereby enhancing the energy density. This progress is pivotal for making EVs more practical and appealing to a broader audience, ultimately accelerating the transition from internal combustion engine vehicles to electric mobility. Another significant area of progress is in fast-charging technologies. The development of advanced electrolytes and the optimization of electrode designs have led to batteries that can be charged more quickly without degrading their lifespan. Solid-state electrolytes, for example, offer high ionic conductivity and thermal stability, enabling faster charging rates [44]. This advancement reduces the downtime for EV users, making electric mobility more convenient and comparable to the quick refueling of traditional vehicles. Fast charging is a critical factor in the broader adoption of EVs, particularly in urban environments where quick turnaround times are essential.

The longevity of LIBs is a key factor in their economic and environmental viability. Recent research has focused on enhancing the durability of batteries through advanced material engineering and better BMSs. Innovations like the development of more stable cathode materials and the improvement of the solid electrolyte interphase (SEI) layer on anodes have significantly extended the lifespan of batteries. Enhanced BMS technologies, utilizing sophisticated algorithms and real-time monitoring, ensure optimal charging and discharging cycles, further prolonging battery life [45]. These improvements reduce the need for frequent replacements, lowering the total cost of ownership of EVs and minimizing environmental impact. Safety remains a paramount concern for LIBs, especially in the context of e-mobility. Recent breakthroughs in thermal management and the development of non-flammable electrolytes have markedly improved the safety profile of these batteries [46]. These safety enhancements are crucial for consumer confidence and regulatory approval, paving the way for more widespread adoption of EVs.

The progress in LIB system architecture directly translates to significant benefits for the e-mobility sector. Higher energy densities and faster charging capabilities make EVs more practical and attractive to consumers. Improved lifespan and safety features enhance the overall reliability and sustainability of electric transportation. These advancements support the broader goals of reducing greenhouse gas emissions and dependency on fossil fuels, aligning with global efforts to combat climate change. Moreover, the continued innovation in LIB technologies is fostering the development of new business models and industries, such as battery recycling and second-life applications. These industries create economic opportunities and contribute to a circular economy, further enhancing the sustainability of e-mobility.

To align with these goals, policy interventions, such as economic incentives and extended producer responsibilities, are essential to promote responsible business practices and sustainable technological innovation, ensuring appropriate end-of-life treatment and incentivizing cost-efficient and recyclable pack designs [47]. Another important aspect of research on state estimation, co-estimation of states, thermal runaway characteristics, and mechanical failure is still in its infancy, and understanding these aspects is important for the wide adaptation of the integrated system architectures of LIBs for e-mobility.

The creation of sustainable battery production methods, recycling, and charging infrastructure development are some of the obstacles facing the transition to electric mobility. Notwithstanding these obstacles, advancements in LIB technology are propelling development. Larger, prismatic cells are becoming more common, and package optimization is required to increase energy density and specific energy, according to recent research. Developing effective and recyclable battery packs requires cooperation between battery suppliers and OEMs. In order to increase the adoption of EVs, research is also concentrated on enhancing energy density, fast-charging technologies, battery longevity, and safety features. The objectives of lowering greenhouse gas emissions and advancing environmentally friendly transportation are supported by these developments. To fully realize the promise of integrated systems, more studies on mechanical reliability, thermal management, and state estimation are necessary.

3. Optimizing E-Mobility Battery Systems: Energy Density, Degradation Mechanisms, and Fault Analysis

The objectives roughly correspond to the 2030 cell-level targets set by the European Council for Automotive R&D (EUCAR), which are 450 Wh/kg and 1000 Wh/L. Furthermore, pack-level capabilities of 750 Wh/L (75% of the cell level) and 360 Wh/kg (80% of the cell level) are specified by EUCAR [15]. The investigation of beyond lithium-ion (BLI) research programs, which commenced approximately ten years ago, has been spurred by this difficulty. Lithium air, lithium sulfur, and lithium metal were the three primary technologies that the car industry was interested in when the first BLI initiatives were made [48,49]. Lithium air has encountered issues with energy and life, which has restricted its usefulness to lab settings [50]. While sulfur chemistries have demonstrated greater potential than lithium air, their low densities have restricted their use to specialized markets, including unmanned aerial vehicles [51]. Lithium metal has advanced the fastest among emerging technologies in the last ten years, and the United Nations Advanced Battery Consortium (USABC) has released targets for automotive lithium metal cells, indicating the potential significance of this technology [13]. The viability of solid-state batteries has been restored by the recent invention of innovative liquid electrolytes compatible with lithium metal and the finding of solid lithium superionic conductors [52,53], as shown in Figure 2.

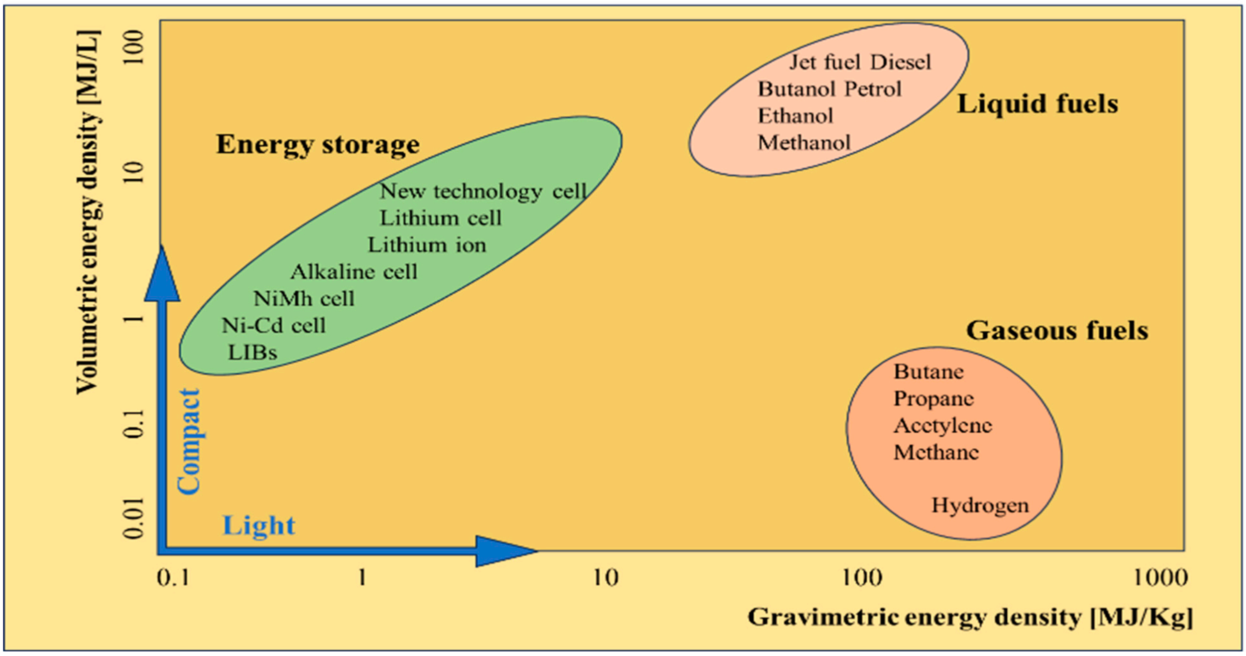


Figure 2. Comparative volumetric energy density and gravimetric energy density.

Addressing this challenge has prompted significant endeavors towards enhancing battery energy density, which has been gaining traction lately with a notable approach of the development of multifunctional batteries [54]. By imbuing batteries with the capability to bear significant mechanical loads that serve as structural components, a reduction in overall system weight can be achieved, thereby extending the potential mileage of e-mobility. This approach itself is sub-divided into several directions. Optimizing lithium-ion battery cells using sequential approximate optimization (SAO) and the progressive quadratic response surface method (PQRSM) significantly enhances specific energy density. This optimization effectively improved battery performance while managing computational complexity and model nonlinearity [55].

The indirect indices—which are various dynamic states of charge, power, energy, health, function, remaining useful life, temperature, etc.—play a crucial role in comprehending and monitoring the battery system, just as the LIB's direct measurable indices—voltage, current, internal resistance, impedance, temperature, etc.—as shown in Figure 3. SOH and SOC rank highest among them. Accurately determining SOH is essential to extending the service life and guaranteeing the secure and dependable operation of the system. SOH is a metric that compares a battery's used state to its overall condition and assesses how well it can supply a certain performance, such as capacity or impedance.

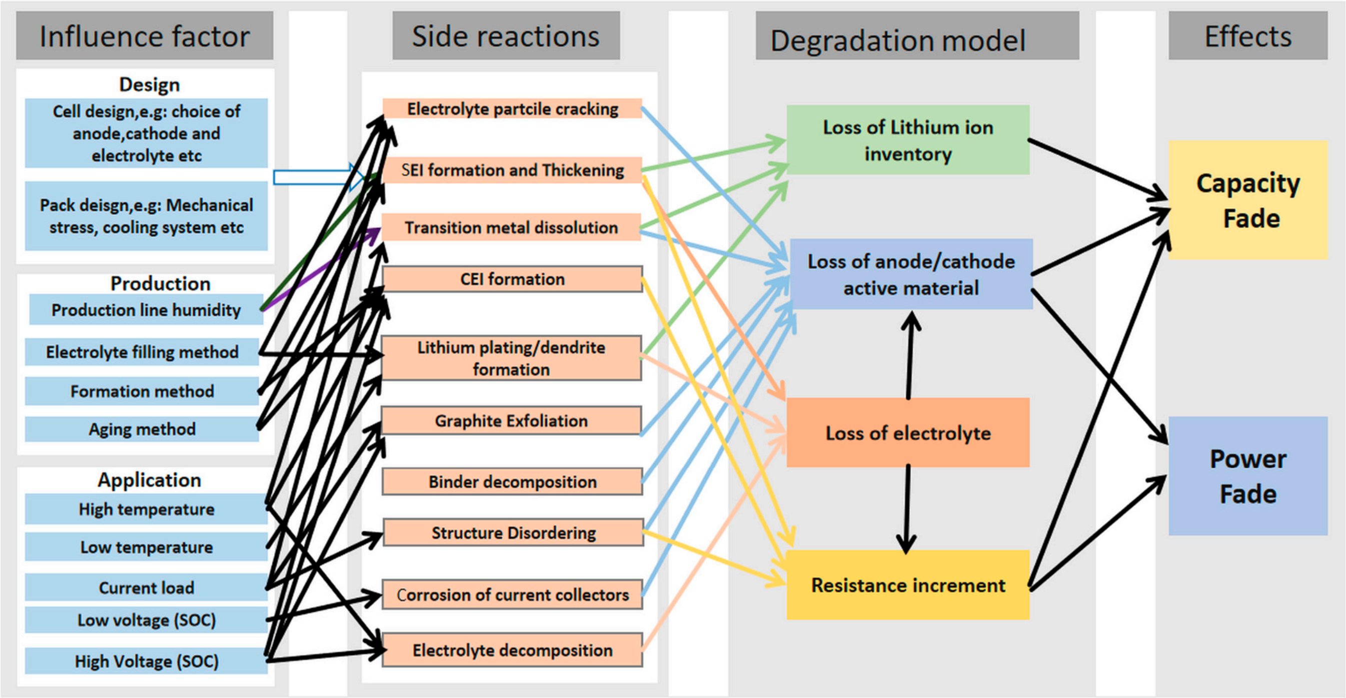


Figure 3. Cell influence factors responsible for main and side reactions. The different colors arrows show the connected side reaction box with particular color box of degradation model.

Many major and secondary responses in the cell are caused by the various influencing factors that ultimately cause capacity and power fade. These factors originate at the design level and continue until the product is used. Numerous studies have been conducted on the physics of reaction modes and effects, degradation modes, and the impacts that follow. These topics are of academic importance.

Researchers explore ways to improve the geometry and organization of the battery's internal elements, such as the cell, BMS, partitions, Battery Thermal Management System, ware and harnesses, battery box, etc. [56–60]. And, by optimizing the internal structure, they aim to enhance efficiency, and this results in more efficient and powerful battery power densities. Another way is material-oriented design. In this approach, the emphasis is on developing and utilizing advanced materials for various components of cells. Researchers work on creating new materials for the anode [61–64], cathode [65–68], and electrolyte [69,70] that offer higher energy density, better conductivity, and improved thermal stability.

The exact control of operational parameters and advances in material science will be critical to the future development of LIB technology. Comprehending the multi-stage deterioration procedure is imperative in formulating tactics to prolong the longevity of batteries, improve their efficiency, and guarantee the perpetual advancement of this important technology. SOC and cycle bandwidth, overcharging with both the high-current and high-voltage region, over-discharge and cycle frequency, temperature (high and low) during storage and operation, internal and external short circuits in the cell, overheating of the cell and battery, and accelerated degradation are the main causes of LIB health degradation. Although there is still a great deal to learn about capacity, power deterioration, and the failures that follow, there are reliable, practical models and techniques for identifying and forecasting these events. The capacity degradation of LIB-based e-mobility batteries, along with its precise estimation and dependable fault diagnosis technique, are critical guarantees of their safety, stability, and dependable operation [71,72]. Material science addresses issues related to energy and power density enhancement, safety concerns, longevity, and reliability, as well as multidisciplinary approaches to decoding cells from various angles, monitoring, estimation of various dynamic states, charge, health, and function, among other things. These approaches are used for higher deploy-ability, comprehending remaining useful life, end of life prediction, warranty prediction, and many others. [14,73,74]. For an e-mobility battery, the failures are several, and any structural design must address these potential failures, which may occur singularly or jointly, as per Figure 4.

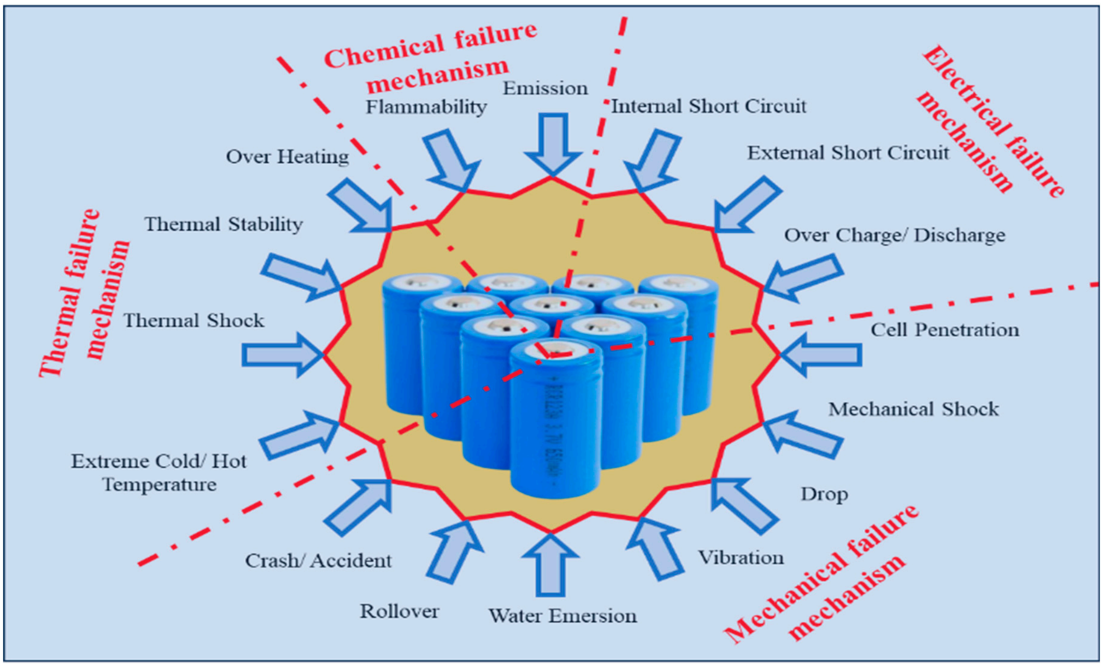


Figure 4. E-mobility battery failure mode and mechanism.

Battery system faults can be categorized into four groups: battery voltage fault, battery current fault, battery temperature fault, and SOC fault. This division highlights the interdependencies and criticalities among different aspects. The factors causing battery level or module level faults are shown in Figure 5.

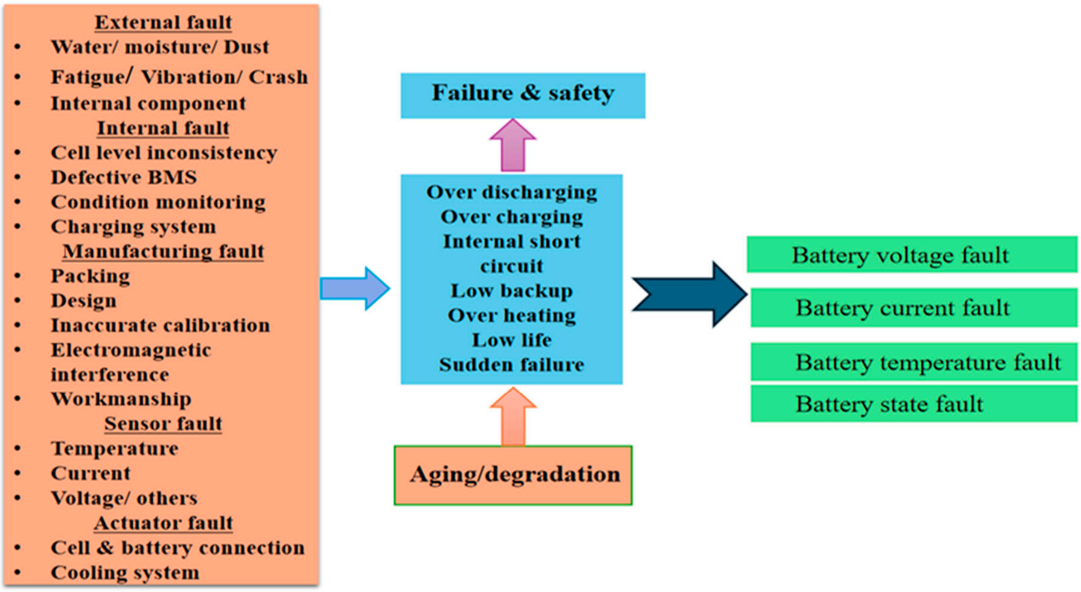


Figure 5. E-mobility battery system level faults.

4. Overview of Lithium-Ion Battery System Architectures in the Context of E-Mobility

LIB system architectures are crucial for optimizing performance, efficiency, and safety and this encompasses various components, including electrodes, electrolytes, separators, and packaging at the cell level and multiple electrical, mechanical, and electronic components at the module or battery pack level, which all work together to store and deliver electrical energy efficiently [75]. These components not only determine the energy density and power output of the battery but also influence its lifespan, charging time, and overall reliability. The complexities involved in the whole process are highly complex, and for a robust LIB system architecture, modeling at multiple stages is necessary for a suitable design, as explained in Figure 6. below.

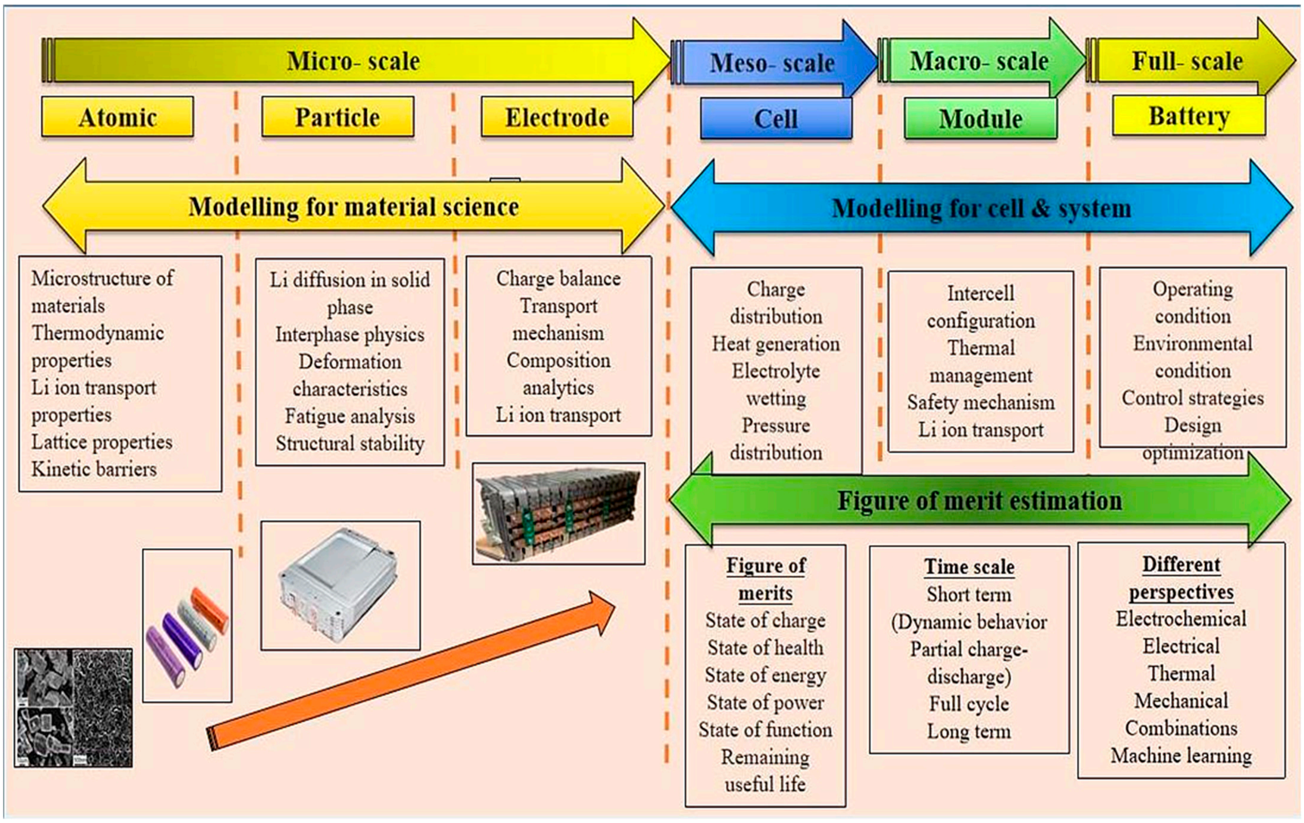


Figure 6. Flowchart of LIB system architectures from an atomic till battery with modeling necessity.

At the atomic level, the working procedure of LIBs is determined by the electrochemical properties of the materials used for the electrodes and electrolytes. Recent advancements in electrode materials for lithium-ion batteries, including elemental doping and coatings, have significantly improved Li ion diffusivity, ionic mobility, and conductivity. These enhancements have led to better performance in terms of cyclic stability, specific capacity, and charge/discharge rates, promising more efficient batteries. Such improvements are crucial for reducing dependence on fossil fuels and advancing electric transportation and high-demand applications. [76]. Molecular modeling techniques, such as density functional theory (DFT), allow scientists to predict and tailor the electronic structure, ionic conductivity, and stability of these materials. DFT simulations can help in identifying new materials with superior properties, thereby pushing the boundaries of LIB performance. At the nanostructure and particle scale, the behavior of LIBs is also heavily defined by the nanoscale frame of the electrode materials. The size, shape, and distribution of particles within the electrodes influence the kinetics of lithium-ion transport and the overall electrochemical performance. Nanostructuring can enhance the surface area, providing more active sites for lithium intercalation and deintercalation, which increases the battery's capacity and rate capability [77]. Modeling at this scale, often using molecular dynamics (MD) simulations, helps in understanding the diffusion mechanisms and mechanical stability of nanostructured materials under cycling conditions.

At the electrode and electrolyte interface level, the interface between them is critical for the battery's performance and safety. This region, where the charge transfer reactions occur, is often the site of performance-degrading phenomena, such as the evaluation of the solid electrolyte interphase (SEI) over the negative electrode. SEI layer formation can be beneficial by protecting the electrode, but its uncontrolled growth can lead to capacity loss and safety hazards. Modeling tools like phase field modeling and continuum simulations are employed to study the formation and evolution of the SEI layer, providing insights into how to control and optimize this interfacial region. At the cell scale, the arrangement of electrodes, separators, and electrolytes determines the battery's overall energy density, power density, and safety [78]. The design of the cell includes considerations of thermal management, mechanical stability, and the prevention of short circuits. Finite element analysis (FEA) and computational fluid dynamics (CFDs) are commonly used to model the thermal and mechanical behavior of battery cells. These models help with optimizing the cell design to ensure uniform temperature distribution and to mitigate the risk of thermal runaway.

As individual cells are assembled into modules and packs for practical applications, the focus shifts to thermal management, electrical balancing, and safety at a larger scale. BMS provide the imperative base to manage and balance the state of charge, temperature, and health of the battery pack [79]. Modeling at this scale involves multiphysics simulations that integrate electrical, thermal, and mechanical aspects to secure the authenticity and efficiency of the battery system. These models are essential for designing cooling systems, predicting the pack's performance under different operating conditions, and enhancing the overall lifecycle of the battery [80]. The complexity of LIB systems necessitates advanced modeling techniques across all scales to achieve optimal performance and safety. Modeling provides a virtual testing ground where different materials, designs, and operating conditions can be evaluated without the need for extensive physical prototyping. This accelerates the development process, reduces costs, and leads to better-performing and safer batteries.

An analysis of the energy density of battery packs is carried out, and it found that they typically hover around half of the volumetric energy density found at the cell level. This suggests a significant potential for enhancing overall system energy density through the efficient integration of battery cells. Disruptive system architectures, such as cell to pack (CTP) or cell to chassis (CTC), emerged as promising strategies to capitalize on this potential and, at present, are under commercialization [81]. These approaches depart from conventional system layer compositions, wherein battery active materials, electrodes, electrode stacks, cells, modules, packs/systems, (vehicle) chassis, and full battery electric vehicles are sequentially arranged. Instead, they bypass individual system levels, directly embedding cells into pack housings or vehicle chassis or even potentially replacing chassis/vehicle components in the future [56]. These collaborations yield optimum volumetric savings, concurrently augmenting energy density at the system level while ideally preserving cell-level energy density. However, achieving these advancements necessitates addressing numerous technical challenges at both product and process levels.

In the core of every battery system lies a congregation of individual cells, numbering from hundreds to thousands, arranged and interconnected in various series-parallel configurations to achieve the desired voltage-ampere hour characteristics. This architectural arrangement is further delineated either through a cell–module–battery hierarchy or a cell–battery configuration, depending on the intricacies of the system; for example, for Tesla Mode S BEV, which has a cell–module–battery hierarchy, where 7104 nos of individual 18560 cells are staked into 16 individual parallel connected modules (74P6S configuration with 444 cells) [82].

Cell level design and material level design are the two separate approaches to structural battery pack design. While the latter serves as a body structure connecting the vehicle's front and rear underbody components, this tactic enhances the mechanical qualities, facilitating the transfer of shear stress and resulting in an overall improvement in torsional rigidity. Tesla has successfully brought this to market [83]. Research has also been performed [84] on the architectural positioning that is suggested to be incorporated into the car body to provide a suitable location for the battery pack. This involves placing the battery under the vehicle's body and analyzing its utility, stability, serviceability, maintenance, etc. The process of material-level design entails integrating cells into fiber–polymer composite structures, which enable them to store electrical energy and withstand mechanical loads. This approach shows great promise for lowering the system's overall weight [85], but the mechanical properties of the resulting structures depend on several variables, including the manufacturing process, the materials used, the structural layout, and the bonding between the integrated batteries and the structure. Together with stainless steel mesh, carbon fiber reinforcement and non-carbon fiber reinforcement have been thoroughly studied as possible candidates for material-centric design.

System architectures for LIBs are essential for maximizing effectiveness, safety, and performance. At the cell and battery pack levels, these systems comprise a variety of parts, such as electrodes, electrolytes, separators, and several electrical and mechanical components. To build stable and effective LIBs, advanced modeling techniques at several scales—atomic, nanostructure, electrode/electrolyte interface, cell, and pack—are crucial.

Materials for electrodes and electrolytes are chosen at the atomic level to maximize capacity, voltage, and stability; DFT is one method that helps with this process. Through the optimization of particle behavior within electrodes, nano-structuring improves performance; molecular dynamics simulations shed light on stability and diffusion. Battery performance depends on the interface between electrodes and electrolytes, and phenomena such as the SEI layer are studied and optimized using modeling tools.

The focus switches to thermal control, electrical balancing, and safety as cells are put together into modules and packs, with BMS playing a critical role. Though these designs present considerable technical problems, novel architectures, like CTP and CTC, strive to improve energy density by integrating cells directly into the vehicle structure. All things considered, gains in LIB system efficiency, safety, and energy density are being driven by cutting-edge modeling and creative design.

5. Present Status

The principal objective of a structural battery is to facilitate weight reduction and augment the available volume within vehicles in contrast to vehicles equipped with distinct structure and battery components, thereby enhancing vehicular performance. The present status of any commercially available LIBs is weak, as it is made of components having very low tensile and compressive strength, which are housed in hermetically sealed metallic covers, mostly made of either nickel-coated steel or high-pressure die casting aluminum or ABS plastic for protection.

The electrode within the cell is composed of carbon components, polymeric binding agents, and active substance particles coated on the surface of metal foil. Granular particles with a porosity of approximately 30% compose the active material layer of an electrode, which has far lower compressive characteristics than traditional structural materials. Furthermore, the weak adhesion between the active material particles and the trace levels of binders impairs the tensile characteristics. Although the porous polymer film separator shows good electrolyte permeability, it is not strong enough to support a load. Furthermore, there is no connection between the electrode and separator layers, which results in inadequate load transmission between the parts and a decline in the mechanical characteristics of batteries, including flexural stiffness.

As a result, there is a growing demand for new battery pack designs aimed at enhancing mechanical strength, with multiple categories of strengthening methods being proposed. Multiple strategies were employed for achieving the desired results as described in Figure 7 below.

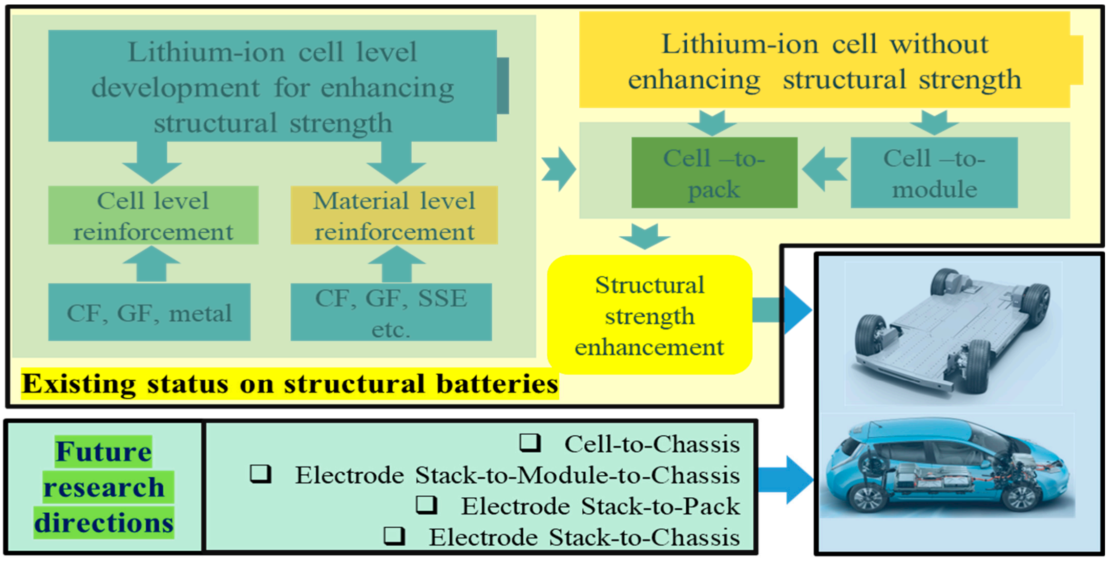


Figure 7. Existing and future directions in the development of cell-to-vehicle strategies.

The current trend in battery systems is to have safety, durability, and better thermal management. To achieve this, lithium-ion cell-level development for enhancing structural strength is more commonly employed. Enhancing structural strength mainly covered cell-level reinforcement and material-level reinforcement. Cell-level reinforcement deals with strengthening the battery cells individually to increase the structural integrity of each cell. Moreover, in order to improve structural integrity, the material-level reinforcement method focusses on strengthening the materials employed in the cells, such as carbon fiber (CF), glass fiber (GF), or solid-state electrolytes (SSEs). However, achieving higher energy densities without enhanced structural strength techniques is also in trend. In this case, the lithium-ion batteries are merged into larger modules or packs rather than being reinforced separately. This technique deals with the cell-to-module and cell-pack strategy to incorporate the cells into packs and modules to strengthen the battery system's overall structural integrity. This technique is simple and easy, as it requires fewer materials and less processing time but may require more frequent replacement or maintenance. A safety risk is that deformation over time may impair thermal management, making the cell more susceptible to overheating, especially during high-power use or fast charging.

Present production processes concentrate on incorporating lithium-ion batteries into EVs without appreciably strengthening their structural integrity. This method usually entails cell-to-module (CTM) and CTP arrangements, in which separate cells are put together to form modules or packs, which are subsequently included in the vehicle. Because standard designs and materials are well established in manufacturing processes, they may be produced more easily and at a lower cost using this method. With the best overall performance in terms of weight reduction and structural efficiency, the electrode stack-to-chassis technique seems to be the most sophisticated and comprehensive approach, as it attempts to integrate the structural elements directly with the vehicle's chassis.

Since the electrode stack-to-chassis method integrates battery systems into automobiles in a more intricate and creative way, it is probably still in the research and development stage. Before it becomes economically practical, there may a need to be considerable improvements the fields of materials science, automotive engineering, and battery design. A large number of these cutting-edge materials and designs are currently in the investigation stage. Before they are used in large manufacturing, they must undergo comprehensive testing to guarantee their performance, safety, and dependability.

6. Interdisciplinarity Challenges in LIB Design for E-Mobility

The design of LIBs for e-mobility presents significant interdisciplinarity challenges, requiring the integration of diverse scientific and engineering fields to overcome technological hurdles. Developing advanced electrode materials and stable electrolytes demands deep expertise in materials science and chemistry [86]. Researchers must understand the electrochemical properties and interactions at the atomic level to enhance energy density, charging speed, and lifespan. This involves complex synthesis processes and precise characterization techniques. The architecture and design of cells and packs necessitate robust electrical and mechanical engineering solutions. Engineers must optimize the layout to maximize energy efficiency, ensure thermal management, and prevent mechanical failures [87,88]. This requires sophisticated modeling and simulation tools to predict performance under various conditions. Ensuring the thermal stability and safety of LIBs involves challenges in thermal management and safety engineering. Advanced cooling systems and fail-safe mechanisms must be developed to prevent overheating and thermal runaway, necessitating a thorough understanding of heat transfer and material stability [89,90].

BMS is critical for monitoring and controlling the battery's health and performance [91–93]. This demands knowledge in systems engineering, software development, and data analytics to create algorithms that ensure optimal charging, discharging, and longevity. The sustainability and economic viability of LIBs also pose challenges that span environmental science and economics. Developing recycling processes and assessing the lifecycle impacts of battery materials require a holistic approach, integrating environmental impact assessments and cost–benefit analyses [94,95]. Addressing these interdisciplinarity challenges is essential for advancing LIB technology to meet the demands of e-mobility, ensuring efficient, safe, and sustainable energy solutions.

There exist myriad interdisciplinary hurdles entwined with the design of LIBs for e-mobility, as graphically depicted below. These design intricacies exert extreme influence on the ultimate performance of the batteries and, thus, e-vehicles [96,97]. Moreover, each battery pack's design, configuration, choice of cell types, and alignment with vehicular specifications are inherently distinctive, thereby exacerbating the complexity of the challenges. These multifaceted challenges arise from various underlying factors, intensifying manifold when scrutinized across short-term and long-term validation processes, as explained in Figure 8.

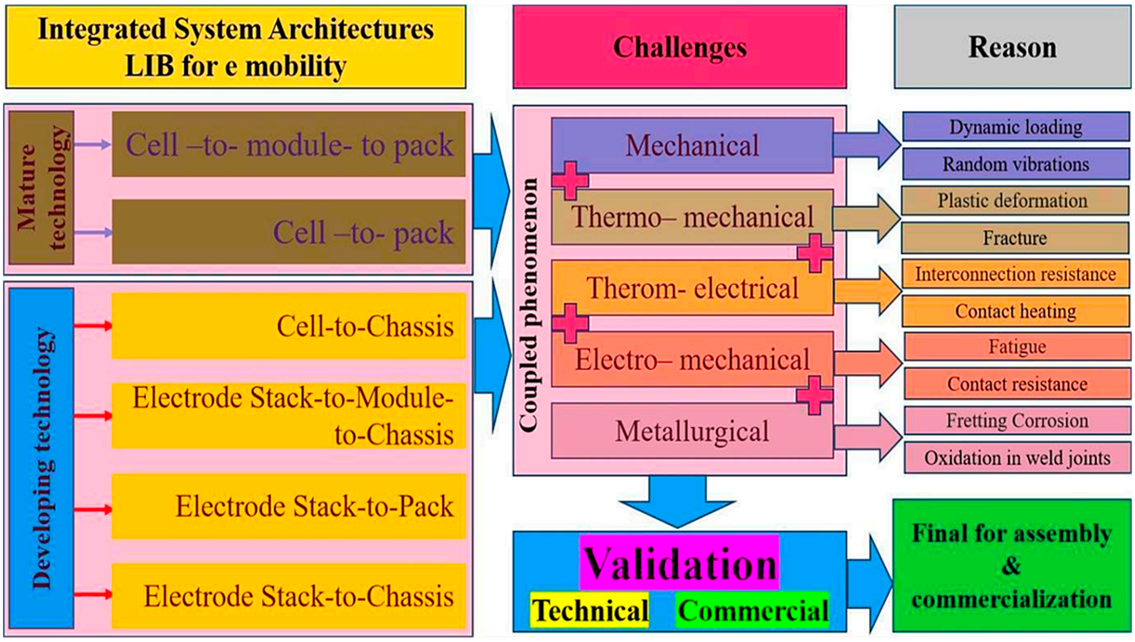


Figure 8. Integrated battery system architecture and challenges and their reasons.

The optimum and best-suited design of lithium-ion batteries for e-mobility is an interdisciplinary challenge. The integration of materials science, chemistry, electrical and mechanical engineering, thermal management, safety engineering, systems engineering, software development, and environmental science are required to achieve the desired goal in battery manufacturing. Advanced materials and stable electrolytes must be developed, cell and pack designs must be optimized, thermal stability must be guaranteed, and efficient BMSs for monitoring and control must be created by researchers. Additionally, lifespan analyses and recycling procedures need to take sustainability and economic viability into account. The distinct design specifications of every battery pack and the requirement for extensive validation procedures to guarantee optimal performance in electric vehicles exacerbate these difficulties.

7. Novel Designs, Materials, and Manufacturing Techniques

There are numerous studies that concentrate on particular battery system components, individual cells, or specific cell parameters [98–102]. However, there are not many thorough analyses; for example, some studies examine active material selection, thermal properties, internal structures, fast charging capability, aging, or cost in great detail, each using a different methodology. While battery cell properties are frequently analyzed at the individual cell level, pack-level property discussions usually center around particular models. These studies frequently use simulated or well-established cells, and their published results may not accurately reflect the performance of the cells in real life [103]. While commercial dismantling of the newest pack and cell models is on the rise, access to such information is frequently restricted [104].

A literature review has shown that while diversified work has been carried out in limited aspects, the significance of integrated system architectures of LIBs for e-mobility is well established. There are several applications that demand high energy and high power density; therefore, possibilities to design a novel system architecture are infinite. It has been theoretically proved that the current best-performing system achieves a specific energy along with the best efficiencies for cell-to-module and module-to-system conversions, and potential improvements could yield a system with a significant 22% enhancement [69]. Whichever cell format is chosen—cylindrical, pouch, or prismatic hard case—has a significant impact on a number of system parameters, including pack design, cell cooling, pack safety, cell-to-module or cell-to-pack integration, and mechanical stability. As a result, studies looking at energy density and specific energy have shown that cell formats are important in determining pack-level performance [105].

The performance of any energy storage is defined in several ways.

The below equation can be used to express the coulombic efficiency (CE) at the nth cycle, which is defined as the discharge capacity divided by the charge capacity.

$$\mathrm{CE_n} = \mathrm{Capacity_{Disc(n)}}/\mathrm{Capacity_{Charge(n)}} \tag{1}$$

The number of completed cycles ($\mathrm{Capacity_{Disc(n)}}$) before the battery capacity drops to a predetermined value from its beginning ($\mathrm{Capacity_{Disc(1)}}$) is known as capacity retention (CR) at the nth cycle.

$$\mathrm{CR_n} = \mathrm{Capacity_{Disc(n)}}/\mathrm{Capacity_{Disc(1)}} \tag{2}$$

The following formulas are used to calculate the volumetric energy density (VED) and the gravimetric energy density (GED):

$$\mathrm{VED} = (\mathrm{Capacity} \times \mathrm{Voltage})/\mathrm{Active\ volume\ (Wh/L)} \tag{3}$$

$$\mathrm{GED} = (\mathrm{Capacity} \times \mathrm{Voltage})/\mathrm{Active\ mass\ (Wh/Kg)} \tag{4}$$

The following formulas are used to calculate the minimum unit volumetric energy density (MUVED) and the minimum unit gravimetric energy density (MUGED):

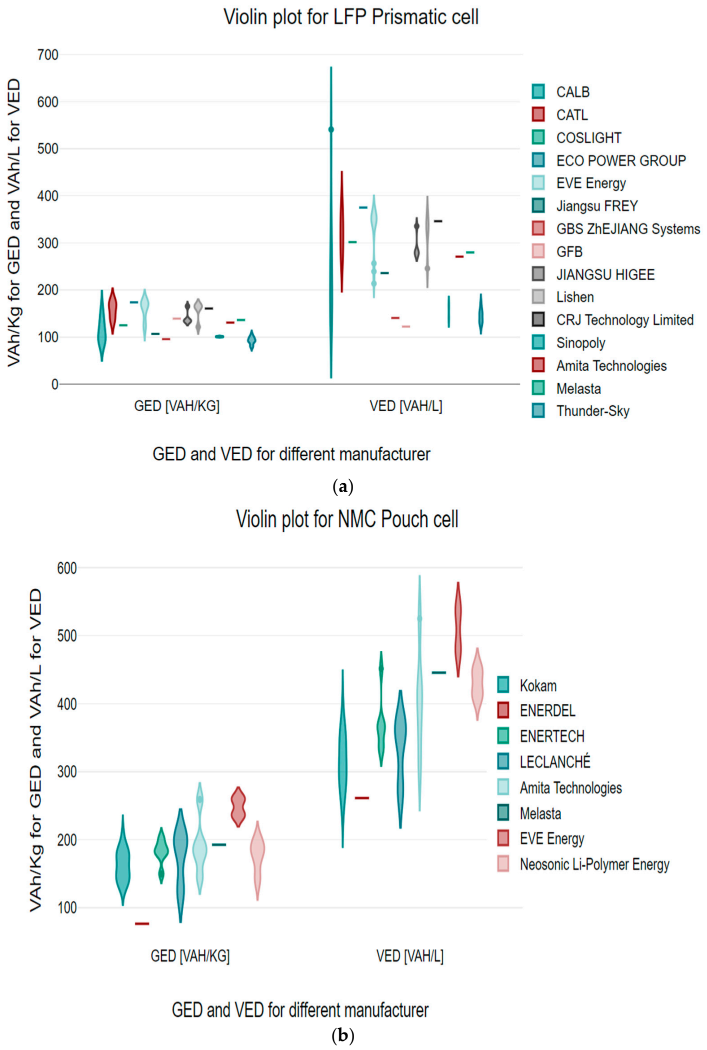
$$\text{MUVED} = (\text{Capacity}_{\text{Mus}} \times \text{Voltage})/\text{Mass}_{\text{Mus}}\ (\text{Wh/L}) \quad (5)$$

$$\text{MUGED} = (\text{Capacity}_{\text{Mus}} \times \text{Voltage})/\text{Volume}_{\text{Mus}}\ (\text{Wh/kg}) \quad (6)$$

where "$\text{Capacity}_{\text{MUs}}$" is the reversible capacity in minimum units (MUs) determined by initially considering the cathode and anode material's CE and N/P ratio. The term "Voltage" refers to the nominal voltage at discharge. The total mass and volume of the MUs are shown by "Mass_{MUs}" and "$\text{Volume}_{\text{MUs}}$".

Coulombic efficiency (CE), capacity retention (CR), volumetric energy density (VED), and gravimetric energy density (GED) are examples of performance measures for energy storage systems. Plots showing the performance differences between different manufacturers and chemistries include the box and whisker plot for cylindrical cells and the violin plot for LFP prismatic and NMC pouch cells.

A violin plot for the GED and VED for several LFP prismatic cells from different manufacturers is given below in Figure 9a, whereas Figure 9b represents the NMC pouch cell from a different manufacturer [24].



(**a**)

(**b**)

Figure 9. Violin plot for the GED and VED from different manufacturers: (**a**) LFP prismatic cell; (**b**) NMC pouch cell.

Similarly, a box and whisker plot and analysis of the GED and VED for cylindrical cells among different manufacturers for different electrochemistries are performed and are placed in Figure 10 below.

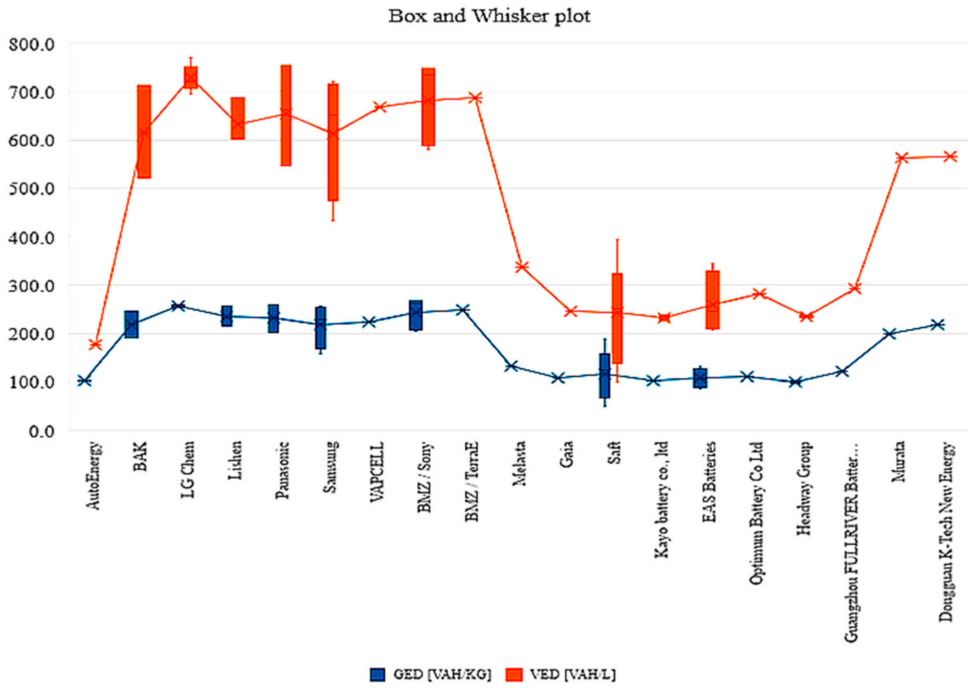


Figure 10. Box and whisker plot of the GED and VED from different manufacturers of cylindrical cells for different electrochemistries.

The LIB cells for e-mobility, which traditionally use the NMC or NCA of different foam factors, are always smaller in comparison to other electrochemistries and are compared among a database [106] of 171 commercially available models of the NMC and NCA. Among them, only 62 models had a capacity range of 40 Ah–100 Ah, with very few exceptions, as given below in Figure 11.

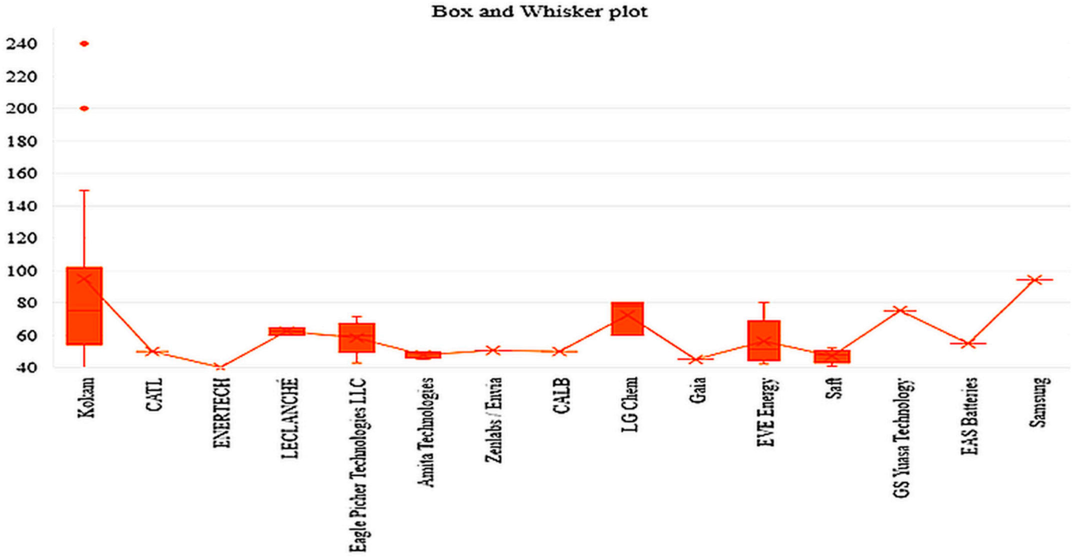


Figure 11. Box and whisker plot for capacity comparison.

At the same time, the trend for a bigger capacity within the same format is catching up significantly. For cylindrical and pouch cells, average capacities doubled from 2010 to

2021 to around 70 Ah (pouch) and 4.5 Ah (cylindrical). Similarly, deployment for more 21700 formats rather than 18650 foam factors in e-mobility batteries or even bigger formats, like 4680 by Tesla, are catching up, which have significant energy densities. Research into structural batteries has surged, with decoupled structural batteries demonstrating superior performance compared to their coupled counterparts [107], with the coupling mechanism having a greater impact on specific energy than the underlying chemistry and holding promise for enhancing the range and autonomy of e-mobility.

Studies on LIB systems for e-mobility frequently concentrate on particular parts or cell characteristics, which results in a disjointed knowledge of the total performance of the system. Although active material choices, thermal characteristics, and fast charging capabilities have all been studied in studies, thorough evaluations that incorporate all of these factors are uncommon. Most research uses established or simulated cells, which might not accurately represent performance in the real world. There is also restricted access to commercial dismantle data.

This section emphasizes how crucial integrated system architectures are for lithium-ion batteries (LIBs) in e-mobility, particularly for high-power and high-energy applications. It is theoretically possible for the best-performing systems in use to now improve their specific energy by 22%. Pack design, cooling, safety, and integration are all greatly impacted by the cell format selection—cylindrical, pouch, or prismatic—which, in turn, affects pack-level performance.

8. Challenges and Future Directions

LIBs are essentially electro–chemo–thermo–mechanical devices, which constitute a significant area of study when integrating into the vehicle, where the interplay between stress/strain and electrochemical processes within components is particularly pertinent, notably in investigations into decay and failure mechanisms and ultimately addressing the thermal runaway phenomenon. Thus, comprehending such coupling becomes paramount in addressing potential challenges inherent in either form of the structural integration of cells, which must have the capability to absorb these significant loads during vehicular operation. A typical cylindrical cell (NMC, 18650 and 21700) has the following specification [108], which is compared with the cylindrical cell (NMC, 4680) [109,110], as per Table 1.

Table 1. Comparison of different cylindrical cell foam factors.

Description	18650	21700	4680 [110]
Electrode thicknesses (double side coated) (anode)	~126 µm	~126 µm	~121 µm
Electrode thicknesses (double side coated) (cathode)	125 µm	125 µm	~85 µm
Current collector foil thicknesses (anode)	10 µm (Cu)	10 µm (Cu)	8 µm (Cu)
Current collector foil thicknesses (cathode)	20 µm (Al)	20 µm (Al)	10 µm (Al)
Areal capacity (cathode)	5.00 mAh/cm^2	5.00 mAh/cm^2	4.9 mAh/cm^2
Areal capacity (anode)	4.12 mAh/cm^2	4.12 mAh/cm^2	5.5 mAh/cm^2
N/P ratio (cathode)	1.21	1.21	~1.08
Separator thickness	16 µm		9 µm
Cell capacity	1.625 ± 0.007 Ah	2.457 ± 0.040 Ah	26.136 ± 0.040 Ah
Weight	40.99 ± 0.03 g	59.71 ± 0.10 g	355 g
Internal resistance (50% SOC and 25 °C)	25.0 ± 0.2 mΩ	13.2 ± 0.1 mΩ	5.77 ± 0.1 mΩ
Electrolyte	~12 wt.-%		
Separator	~15 wt.-%		
Housing	20 wt.-%	18 wt.-%	23 wt.-%
Weight of the electrodes	53 wt.-%	55 wt.-%	55 wt.-%
Number of windings	21	26	

Table 1. *Cont.*

Description	18650	21700	4680 [110]
Electrolyte	5 mL	7 mL	60 mL
Cell case	Nickel-plated steel or stainless		
Cell case thickness	~0.22 to 0.28 mm		~0.30 mm
Energy density (Wh/L)	~575	~629	670–700
Spec. energy (Wh/kg)	280–310	280–310	272–300

For integrated system architectures of LIBs for e-mobility, various prerequisites must initially be met, encompassing mechanical and electrochemical performance, safety, and financial considerations. Subsequently, this section will offer a brief examination of these requirements, addressing both present obstacles and prospective avenues for its advancement.

Anodes made of silicon, which are utilized more and more to boost energy density, enlarge considerably when charging and discharging. Over time, this expansion causes mechanical stress inside the battery, which results in cracking, delamination, and capacity loss. The ability of sophisticated structural battery designs to absorb mechanical loads from vehicle operation—such as bumps, twists, and crashes—while maintaining the integrity of the battery is a requirement. Making sure the battery maintains the vehicle's structural integrity without compromising on performance or safety is the difficult part. To safeguard the internal components against external stressors like drops, collisions, or compression, LIB cell housings and module enclosures must have a strong mechanical construction. A major mechanical difficulty in battery design is creating lightweight, robust housing, particularly for high-energy-density batteries used in mobile and automotive applications. Additionally, it is quite difficult to achieve fast charging without compromising cycle life or security. Issues may arise from the fast charging of lithium-ion batteries, like lithium plating and high heat generation. For long-term battery performance, the electrode–electrolyte contact must remain stable. An increase in impedance, parasitic responses, and overall capacity decline might result from any instability at this interface.

The quick development of renewable energy storage and EVs has increased demand for vital raw minerals, including nickel, cobalt, and lithium. The cost of producing LIBs has increased due to price surges brought on by this imbalance. Establishing and expanding battery production facilities, especially gigafactories, necessitates a substantial initial investment. Before being profitable, these plants must be outfitted with specialized technology to manufacture high-quality batteries, which may take many years.

The evolution of e-mobility has provided a better alternative to coal-based fuels in the automation industry; however, there are still some challenges to achieving the optimum use of LIBs in the industry. As mentioned above, mechanical, electrochemical, safety and financial challenges are still there in the current scenario, which are barriers to the better adaptability of LIBs. However, some future research scopes are also available on the above-discussed challenges. The development of a silicon-based anode with improved mechanical resilience is essential. The nano-structuring technique and composite material can be introduced to mitigate contraction and expansion during the cycling of the battery, as it can better handle stress while minimizing cracking and delamination. Apart from that, better electrode technology can be helpful in fast charging without any lithium plating and heat generation, and 3D porous and highly conductive coatings are the alternatives.

Investing in the development of low-cost recycling techniques that allow end-of-life batteries to reproduce precious materials like nickel, cobalt, and lithium is need of the hour. A circular economy model could help stabilize material costs and ease supply limitations by reducing reliance on mining.

9. Conclusions

Although the development of EVs depends heavily on LIBs, integrating LIBs into vehicle architectures presents difficult obstacles. This study provides a thorough overview of recent advancements in structural power composites. Recent developments in the integration methods for commercially available lithium-ion batteries inside composite structures and the production of multifunctional materials for power applications have spurred several studies in this area. Significant advancements in structural battery elements have been shown in recent field testing. Notable contributions include the electrochemical characterization of carbon fibers as structural anodes, the development of epoxy systems to produce stiff, ion-conductive structural solid electrolytes, and the application of doping techniques to construct cathodes based on carbon fiber. Nonetheless, differences between full- and half-cell batteries' mechanical and storage performance are clearly visible and have been reported in the literature, highlighting how complicated this topic is. The creation of strong analytical and numerical frameworks is essential to handle issues including safety concerns, capacity degradation, restricted specific energy and energy density, and manufacturing limits. Furthermore, the application of novel ferroelectric–electrolyte non-flammable composites show potential for ameliorating some of these problems, indicating future strides towards the development of structural batteries.

Author Contributions: Conceptualization, S.R. and D.K.S.; methodology, S.R., D.K.S. and S.C.; validation, S.R., D.K.S. and S.C.; investigation, S.R., D.K.S. and Y.C.G.; Writing-original draft, S.R.; Writing-review and editing, D.K.S., S.C. and Y.C.G.; Supervision, D.K.S. and S.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No new data was created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. I.—International Energy Agency, CO_2 Emissions in 2023. 2023. Available online: https://www.iea.org (accessed on 23 April 2024).
2. IPCC. *Global Warming of 1.5 °C*; Cambridge University Press (CUP): Cambridge, UK, 2022. [CrossRef]
3. Global Energy Trends. Enerdata. Available online: https://www.enerdata.net/publications/reports-presentations/world-energy-trends.html (accessed on 8 June 2024).
4. Jackson, R.B.; Friedlingstein, P.; Le Quéré, C.; Abernethy, S.; Andrew, R.M.; Canadell, J.G.; Ciais, P.; Davis, S.J.; Deng, Z.; Liu, Z.; et al. Global fossil carbon emissions rebound near pre-COVID-19 levels. *Environ. Res. Lett.* **2022**, *17*, 031001. [CrossRef]
5. Hossain, M.S.; Kumar, L.; Assad, M.E.H.; Alayi, R. Advancements and Future Prospects of Electric Vehicle Technologies: A Comprehensive Review. *Complexity* **2022**, *2022*, 3304796. [CrossRef]
6. Das, K.; Kumar, R. Assessment of Electric Two-Wheeler Ecosystem Using Novel Pareto Optimality and TOPSIS Methods for an Ideal Design Solution. *World Electr. Veh. J.* **2023**, *14*, 215. [CrossRef]
7. Bouter, A.; Guichet, X. The greenhouse gas emissions of automotive lithium-ion batteries: A statistical review of life cycle assessment studies. *J. Clean. Prod.* **2022**, *344*, 130994. [CrossRef]
8. Haghani, M.; Sprei, F.; Kazemzadeh, K.; Shahhoseini, Z.; Aghaei, J. Trends in electric vehicles research. *Transp. Res. D Transp. Environ.* **2023**, *123*, 103881. [CrossRef]
9. Das, K.; Kumar, R.; Krishna, A. Supervised Learning and Data Intensive Methods for the Prediction of Capacity Fade of Lithium-ion Batteries under Diverse Operating and Environmental Conditions. *Water Energy Int.* **2023**, *66*, 53–59. Available online: https://www.indianjournals.com/ijor.aspx?target=ijor:wei&volume=66r&issue=1&article=008 (accessed on 29 August 2023).
10. United states council for automotive research(USCAR). Development of Lithium Electrode-Based Cell and Manufacturing for Automotive Traction Applications. Available online: https://uscar.org/wpfd_file/development-of-lithium-electrode-based-cell-and-manufacturing-for-automotive-traction-applications/ (accessed on 10 August 2024).
11. International Energy Agency. Global EV Outlook 2023: Catching up with Climate Ambitions. 2023. Available online: https://www.iea.org (accessed on 12 May 2024).
12. Fleischmann, J.; Hanicke, M.; Horetsky, E.; Ibrahim, D.; Jautelat, S.; Linder, M.; Schaufuss, P.; Torscht, L.; van de Rijt, A. *Battery 2030: Resilient, Sustainable, and Circular*; McKinsey & Company: Chicago, IL, USA, 2023.
13. Masias, A.; Marcicki, J.; Paxton, W.A. Opportunities and Challenges of Lithium Ion Batteries in Automotive Applications. *ACS Energy Lett.* **2021**, *6*, 621–630. [CrossRef]
14. Li, M.; Lu, J.; Chen, Z.; Amine, K. 30 Years of Lithium-Ion Batteries. *Adv. Mater.* **2018**, *30*, 1800561. [CrossRef]
15. Link, S.; Neef, C.; Wicke, T. Trends in Automotive Battery Cell Design: A Statistical Analysis of Empirical Data. *Batteries* **2023**, *9*, 261. [CrossRef]

16. Brighente, A.; Conti, M.; Donadel, D.; Poovendran, R.; Turrin, F.; Zhou, J. Electric Vehicles Security and Privacy: Challenges, Solutions, and Future Needs. *arXiv* **2023**, arXiv:2301.04587. Available online: http://arxiv.org/abs/2301.04587 (accessed on 7 April 2024).
17. Zhu, P.; Slater, P.R.; Kendrick, E. Insights into architecture, design and manufacture of electrodes for lithium-ion batteries. *Mater. Des.* **2022**, *223*, 111208. [CrossRef]
18. Löbberding, H.; Wessel, S.; Offermanns, C.; Kehrer, M.; Rother, J.; Heimes, H.; Kampker, A. From Cell to Battery System in BEVs: Analysis of System Packing Efficiency and Cell Types. *World Electr. Veh. J.* **2020**, *11*, 77. [CrossRef]
19. Yang, B.; Wang, J.; Cao, P.; Zhu, T.; Shu, H.; Chen, J.; Zhang, J.; Zhu, J. Classification, summarization and perspectives on state-of-charge estimation of lithium-ion batteries used in electric vehicles: A critical comprehensive survey. *J. Energy Storage* **2021**, *39*, 102572. [CrossRef]
20. Che, Y.; Deng, Z.; Tang, X.; Lin, X.; Nie, X.; Hu, X. Lifetime and Aging Degradation Prognostics for Lithium-ion Battery Packs Based on a Cell to Pack Method. *Chin. J. Mech. Eng.* **2022**, *35*, 4. [CrossRef]
21. Pampel, F.; Pischinger, S.; Teuber, M. A systematic comparison of the packing density of battery cell-to-pack concepts at different degrees of implementation. *Results Eng.* **2022**, *13*, 100310. [CrossRef]
22. Eshetu, G.G.; Zhang, H.; Judez, X.; Adenusi, H.; Armand, M.; Passerini, S.; Figgemeier, E. Production of high-energy Li-ion batteries comprising silicon-containing anodes and insertion-type cathodes. *Nat. Commun.* **2021**, *12*, 5459. [CrossRef]
23. Feng, F.; Hu, X.; Hu, L.; Hu, F.; Li, Y.; Zhang, L. Propagation mechanisms and diagnosis of parameter inconsistency within Li-Ion battery packs. *Renew. Sustain. Energy Rev.* **2019**, *112*, 102–113. [CrossRef]
24. Wang, J.; Deng, Z.; Peng, K.; Deng, X.; Xu, L.; Guan, G.; Abudula, A. Early Prognostics of Lithium-Ion Battery Pack Health. *Sustainability* **2022**, *14*, 2313. [CrossRef]
25. Xue, Q.; Li, G.; Zhang, Y.; Shen, S.; Chen, Z.; Liu, Y. Fault diagnosis and abnormality detection of lithium-ion battery packs based on statistical distribution. *J. Power Sources* **2021**, *482*, 228964. [CrossRef]
26. Zhang, Y.; Jiang, M.; Zhou, Y.; Zhao, S.; Yuan, Y. Towards High-Safety Lithium-Ion Battery Diagnosis Methods. *Batteries* **2023**, *9*, 63. [CrossRef]
27. Gan, N.; Sun, Z.; Zhang, Z.; Xu, S.; Liu, P.; Qin, Z. Data-Driven Fault Diagnosis of Lithium-Ion Battery Overdischarge in Electric Vehicles. *IEEE Trans. Power Electron.* **2022**, *37*, 4575–4588. [CrossRef]
28. Yao, L.; Xu, S.; Xiao, Y.; Hou, J.; Gong, X.; Fu, Z.; Tang, A. Fault Identification of Lithium-Ion Battery Pack for Electric Vehicle Based on GA Optimized ELM Neural Network. *IEEE Access* **2022**, *10*, 15007–15022. [CrossRef]
29. Tran, M.-K.; Panchal, S.; Khang, T.D.; Panchal, K.; Fraser, R.; Fowler, M. Concept Review of a Cloud-Based Smart Battery Management System for Lithium-Ion Batteries: Feasibility, Logistics, and Functionality. *Batteries* **2022**, *8*, 19. [CrossRef] [PubMed]
30. Messier, P.; LeBel, F.-A.; Rouleau, J.; Trovao, J.P.F. Multi-Cell Emulation for Battery Management System Validation. In Proceedings of the 2018 IEEE Vehicle Power and Propulsion Conference (VPPC), Chicago, IL, USA, 27–30 August 2018; pp. 1–6.
31. Johannisson, A.; Jayasuriya, J.; Smajila, L. *Outlook of EV Battery Pack Design Trends, Assessment of Trend Impact from a Recycling Perspective*; KTH Royal Institute of Technology Depart. of Technology SE-10044: Stockholm, Sweden, 2023.
32. Sulzer, V.; Mohtat, P.; Aitio, A.; Lee, S.; Yeh, Y.T.; Steinbacher, F.; Khan, M.U.; Lee, J.W.; Siegel, J.B.; Stefanopoulou, A.G.; et al. The challenge and opportunity of battery lifetime prediction from field data. *Joule* **2021**, *5*, 1934–1955. [CrossRef]
33. Chang, C.; Wu, Y.; Jiang, J.; Jiang, Y.; Tian, A.; Li, T.; Gao, Y. Prognostics of the state of health for lithium-ion battery packs in energy storage applications. *Energy* **2022**, *239*, 122189. [CrossRef]
34. Wang, G.; Gao, W.; He, X.; Peng, R.; Zhang, Y.; Dai, X.; Ping, P.; Kong, D. Numerical investigation on thermal runaway propagation and prevention in cell-to-chassis lithium-ion battery system. *Appl. Therm. Eng.* **2024**, *236*, 121528. [CrossRef]
35. Zhong, H.; Lei, F.; Liu, J.; Ding, F.; Zhu, W.; Chi, X. Optimal design for efficiency enhanced hierarchical cell-to-cell equalization systems based on centralized model predictive control. *Sustain. Energy Technol. Assess.* **2023**, *60*, 103470. [CrossRef]
36. Kim, K.; Choi, J.-I. Effect of cell-to-cell variation and module configuration on the performance of lithium-ion battery systems. *Appl. Energy* **2023**, *352*, 121888. [CrossRef]
37. Manjunath, K.; Kalpana, R.; Singh, B.; Kiran, R. A Two-Stage Module Based Cell-to-Cell Active Balancing Circuit for Series Connected Lithium-Ion Battery Packs. *IEEE Trans. Energy Convers.* **2023**, *38*, 2282–2297. [CrossRef]
38. Yu, Z.; Sun, Z.; Chang, L.; Ma, C.; Li, C.; Li, H.; Luan, C.; Al-Saidi, M.Y.M. Impact of Multiple Module Collectors on the Cell Current Distribution within the Battery Pack. *Batteries* **2023**, *9*, 501. [CrossRef]
39. Gao, Y.; Liu, K.; Zhu, C.; Zhang, X.; Zhang, D. Co-Estimation of State-of-Charge and State-of- Health for Lithium-Ion Batteries Using an Enhanced Electrochemical Model. *IEEE Trans. Ind. Electron.* **2022**, *69*, 2684–2696. [CrossRef]
40. Hu, C.; Ma, L.; Guo, S.; Guo, G.; Han, Z. Deep learning enabled state-of-charge estimation of LiFePO4 batteries: A systematic validation on state-of-the-art charging protocols. *Energy* **2022**, *246*, 123404. [CrossRef]
41. Cadini, F.; Sbarufatti, C.; Cancelliere, F.; Giglio, M. State-of-life prognosis and diagnosis of lithium-ion batteries by data-driven particle filters. *Appl. Energy* **2019**, *235*, 661–672. [CrossRef]
42. Yang, Z.; Wang, J.; Cui, C.; Jin, Y.; Zhang, G.; Zhou, H.; Qian, W. High power density & energy density Li-ion battery with aluminum foam enhanced electrode: Fabrication and simulation. *J. Power Sources* **2022**, *524*, 230977. [CrossRef]
43. Jia, T.; Zhong, G.; Lv, Y.; Li, N.; Liu, Y.; Yu, X.; Zou, J.; Chen, Z.; Peng, L.; Kang, F.; et al. Prelithiation strategies for silicon-based anode in high energy density lithium-ion battery. *Green Energy Environ.* **2023**, *8*, 1325–1340. [CrossRef]

44. Kirkaldy, N.; Samieian, M.A.; Offer, G.J.; Marinescu, M.; Patel, Y. Lithium-Ion Battery Degradation: Measuring Rapid Loss of Active Silicon in Silicon–Graphite Composite Electrodes. *ACS Appl. Energy Mater.* **2022**, *5*, 13367–13376. [CrossRef]
45. Meng, Q.; An, Z.; Yu, X.; Wang, N.; Bai, D.; Liu, S. The Influence of Temperature on the Secondary Use of Lithium Iron Phosphate Power Battery. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *791*, 012129. [CrossRef]
46. Fan, Y.; Bao, Y.; Ling, C.; Chu, Y.; Tan, X.; Yang, S. Experimental study on the thermal management performance of air cooling for high energy density cylindrical lithium-ion batteries. *Appl. Therm. Eng.* **2019**, *155*, 96–109. [CrossRef]
47. Rizk, R.; Louahlia, H.; Gualous, H.; Schaetzel, P. Passive Cooling of High Capacity Lithium-Ion Batteries. In Proceedings of the 2018 IEEE International Telecommunications Energy Conference (INTELEC), Turino, Italy, 7–11 October 2019; pp. 1–4.
48. Xiong, R.; Pan, Y.; Shen, W.; Li, H.; Sun, F. Lithium-ion battery aging mechanisms and diagnosis method for automotive applications: Recent advances and perspectives. *Renew. Sustain. Energy Rev.* **2020**, *131*, 110048. [CrossRef]
49. Alipour, M.; Ziebert, C.; Conte, F.V.; Kizilel, R. A review on temperature-dependent electrochemical properties, aging, and performance of lithium-ion cells. *Batteries* **2020**, *6*, 35. [CrossRef]
50. Chen, W.; Liang, J.; Yang, Z.; Li, G. A Review of Lithium-Ion Battery for Electric Vehicle Applications and Beyond. *Energy Procedia* **2019**, *158*, 4363–4368. [CrossRef]
51. Swornowski, P.J. Destruction mechanism of the internal structure in Lithium-ion batteries used in aviation industry. *Energy* **2017**, *122*, 779–786. [CrossRef]
52. Wu, C.; Lou, J.; Zhang, J.; Chen, Z.; Kakar, A.; Emley, B.; Ai, Q.; Guo, H.; Liang, Y.; Lou, J.; et al. Current status and future directions of all-solid-state batteries with lithium metal anodes, sulfide electrolytes, and layered transition metal oxide cathodes. *Nano Energy* **2021**, *87*, 106081. [CrossRef]
53. Dall-Orsoletta, A.; Ferreira, P.; Dranka, G.G. Low-carbon technologies and just energy transition: Prospects for electric vehicles. *Energy Convers. Manag. X* **2022**, *16*, 100271. [CrossRef]
54. Jeevanantham, B.; Shobana, M.K. Enhanced cathode materials for advanced lithium-ion batteries using nickel-rich and lithium/manganese-rich LiNi MnCoO_2. *J. Energy Storage* **2022**, *54*, 105353. [CrossRef]
55. Kim, J.S.; Lee, D.C.; Lee, J.J.; Kim, C.W. Optimization for maximum specific energy density of a lithium-ion battery using progressive quadratic response surface method and design of experiments. *Sci. Rep.* **2020**, *1*, 15586. [CrossRef]
56. Huang, C.-S.; Cheng, Z.; Chow, M.-Y. A Robust and Efficient State-of-Charge Estimation Methodology for Serial-Connected Battery Packs: Most Significant Cell Methodology. *IEEE Access* **2021**, *9*, 74360–74369. [CrossRef]
57. Saw, L.H.; Poon, H.M.; Thiam, H.S.; Cai, Z.; Chong, W.T.; Pambudi, N.A.; King, Y.J. Novel thermal management system using mist cooling for lithium-ion battery packs. *Appl. Energy* **2018**, *223*, 146–158. [CrossRef]
58. Saqli, K.; Bouchareb, H.; M'Sirdi, N.K.; Oudghiri, M. Battery Pack Thermal Modeling, Simulation and electric model Identification. In Proceedings of the 2021 9th International Renewable and Sustainable Energy Conference (IRSEC), Tetouan, Morocco, 23–27 November 2021.
59. Zhang, C.; Cheng, G.; Ju, Q.; Zhang, W.; Jiang, J.; Zhang, L. Study on Battery Pack Consistency Evolutions during Electric Vehicle Operation with Statistical Method. *Energy Procedia* **2017**, *105*, 3551–3556. [CrossRef]
60. Hu, L.; Ye, Y.; Bo, Y.; Huang, J.; Tian, Q.; Yi, X.; Li, Q. Performance evaluation strategy for battery pack of electric vehicles: Online estimation and offline evaluation. *Energy Rep.* **2022**, *8*, 774–784. [CrossRef]
61. Balagopal, B.; Huang, C.S.; Chow, M.-Y. Sensitivity Analysis of Lithium Ion Battery Parameters to Degradation of Anode Lithium Ion Concentration. In Proceedings of the IECON 2019—45th Annual Conference of the IEEE Industrial Electronics Society, Lisbon, Portugal, 14–17 October 2019; pp. 4543–4548.
62. Burow, D.; Sergeeva, K.; Calles, S.; Schorb, K.; Börger, A.; Roth, C.; Heitjans, P. Inhomogeneous degradation of graphite anodes in automotive lithium ion batteries under low-temperature pulse cycling conditions. *J. Power Sources* **2016**, *307*, 806–814. [CrossRef]
63. Zhang, G.; Wei, X.; Han, G.; Dai, H.; Zhu, J.; Wang, X.; Tang, X.; Ye, J. Lithium plating on the anode for lithium-ion batteries during long-term low temperature cycling. *J. Power Sources* **2021**, *484*, 229312. [CrossRef]
64. Pavlovskii, A.A.; Pushnitsa, K.; Kosenko, A.; Novikov, P.; Popovich, A.A. Organic anode material for Lithium-ion batteries: Recent Progress and Challenges. *Materials* **2023**, *16*, 177. [CrossRef] [PubMed]
65. Wang, L.; Qiu, J.; Wang, X.; Chen, L.; Cao, G.; Wang, J.; Zhang, H.; He, X. Insights for understanding multiscale degradation of LiFePO4 cathodes. *eScience* **2022**, *2*, 125–137. [CrossRef]
66. Gao, J.-Y.; Yang, Y.-F.; Zhang, X.-K.; Li, S.-L.; Hu, P.; Wang, J.-S. A review on recent progress of thermionic cathode. *Tungsten* **2020**, *2*, 289–300. [CrossRef]
67. Zhang, C.; Wang, Y.; Gao, Y.; Wang, F.; Mu, B.; Zhang, W. Accelerated fading recognition for lithium-ion batteries with Nickel-Cobalt-Manganese cathode using quantile regression method. *Appl. Energy* **2019**, *256*, 113841. [CrossRef]
68. Wu, X.; Ruan, D.; Tan, S.; Feng, M.; Li, B.; Hu, G. Effect of stirring environment humidity on electrochemical performance of nickel-rich cathode materials as lithium ion batteries. *Ionics* **2020**, *26*, 5427–5434. [CrossRef]
69. Dixon, B.; Mason, A.; Sahraei, E. Effects of electrolyte, loading rate and location of indentation on mechanical integrity of li-ion pouch cells. *J. Power Sources* **2018**, *396*, 412–420. [CrossRef]
70. Gauthier, R.; Luscombe, A.; Bond, T.; Bauer, M.; Johnson, M.; Harlow, J.; Louli, A.; Dahn, J.R. How do Depth of Discharge, C-rate and Calendar Age Affect Capacity Retention, Impedance Growth, the Electrodes, and the Electrolyte in Li-Ion Cells? *J. Electrochem. Soc.* **2022**, *169*, 020518. [CrossRef]
71. Li, W.; Zhang, H.; van Vlijmen, B.; Dechent, P.; Sauer, D.U. Forecasting battery capacity and power degradation with multi-task learning. *Energy Storage Mater.* **2022**, *53*, 453–466. [CrossRef]

72. Johnen, M.; Pitzen, S.; Kamps, U.; Kateri, M.; Dechent, P.; Sauer, D.U. Modeling long-term capacity degradation of lithium-ion batteries. *J. Energy Storage* **2021**, *34*, 102011. [CrossRef]
73. Baskin, I.; Ein-Eli, Y. Electrochemoinformatics as an Emerging Scientific Field for Designing Materials and Electrochemical Energy Storage and Conversion Devices—An Application in Battery Science and Technology. *Adv. Energy Mater.* **2022**, *12*, 2202380. [CrossRef]
74. Shen, X.; Zhang, X.-Q.; Ding, F.; Huang, J.-Q.; Xu, R.; Chen, X.; Yan, C.; Su, F.-Y.; Chen, C.-M.; Liu, X.; et al. Advanced Electrode Materials in Lithium Batteries: Retrospect and Prospect. *Energy Mater. Adv.* **2021**, *2021*, 1205324. [CrossRef]
75. Thackeray, M.M.; Wolverton, C.; Isaacs, E.D. Electrical energy storage for transportation—Approaching the limits of, and going beyond, lithium-ion batteries. *Energy Environ. Sci.* **2012**, *5*, 7854–7863. [CrossRef]
76. Mishra, A.; Mehta, A.; Basu, S.; Malode, S.J.; Shetti, N.P.; Shukla, S.S.; Nadagouda, M.N.; Aminabhavi, T.M. Electrode materials for lithium-ion batteries. *Mater. Sci. Energy Technol.* **2018**, *1*, 182–187. [CrossRef]
77. Zhang, Y.; Tang, Q.; Zhang, Y.; Wang, J.; Stimming, U.; Lee, A.A. Identifying degradation patterns of lithium ion batteries from impedance spectroscopy using machine learning. *Nat. Commun.* **2020**, *11*, 1706. [CrossRef]
78. Hosen, S.; Jaguemont, J.; Van Mierlo, J.; Berecibar, M. Battery lifetime prediction and performance assessment of different modeling approaches. *iScience* **2021**, *24*, 102060. [CrossRef]
79. Zhang, Y.; Peng, Z.; Guan, Y.; Wu, L. Prognostics of battery cycle life in the early-cycle stage based on hybrid model. *Energy* **2021**, *221*, 119901. [CrossRef]
80. Zeng, M.; Zhang, P.; Yang, Y.; Xie, C.; Shi, Y. SOC and SOH joint estimation of the power batteries based on fuzzy unscented Kalman filtering algorithm. *Energies* **2019**, *12*, 3122. [CrossRef]
81. Gabbar, H.A.; Othman, A.M.; Abdussami, M.R. Review of Battery Management Systems (BMS) Development and Industrial Standards. *Technologies* **2021**, *9*, 28. [CrossRef]
82. Sharma, A.; Zanotti, P.; Musunur, L.P. Enabling the Electric Future of Mobility: Robotic Automation for Electric Vehicle Battery Assembly. *IEEE Access* **2019**, *7*, 170961–170991. [CrossRef]
83. Jin, T.; Singer, G.; Liang, K.; Yang, Y. Structural batteries: Advances, challenges and perspectives. *Mater. Today* **2023**, *62*, 151–167. [CrossRef]
84. Belingardi, G.; Scattina, A. Battery Pack and Underbody: Integration in the Structure Design for Battery Electric Vehicles—Challenges and Solutions. *Vehicles* **2023**, *5*, 498–514. [CrossRef]
85. Galos, J.; Pattarakunnan, K.; Best, A.S.; Kyratzis, I.L.; Wang, C.; Mouritz, A.P. Energy Storage Structural Composites with Integrated Lithium-Ion Batteries: A Review. *Adv. Mater. Technol.* **2021**, *6*, 2001059. [CrossRef]
86. Li, Y.; Yang, J.; Liu, W.L.; Liao, C.L. Multi-Level Model Reduction and Data-Driven Identification of the Lithium-Ion Battery. *Energies* **2020**, *13*, 3791. [CrossRef]
87. Park, S.; Kato, D.; Gima, Z.; Klein, R.; Moura, S. Optimal Experimental Design for Parameterization of an Electrochemical Lithium-Ion Battery Model. *J. Electrochem. Soc.* **2018**, *165*, A1309–A1323. [CrossRef]
88. Sadeghi, E.; Zand, M.H.; Hamzeh, M.; Saif, M.; Alavi, S.M.M. Controllable Electrochemical Impedance Spectroscopy: From Circuit Design to Control and Data Analysis. *IEEE Trans. Power Electron.* **2020**, *35*, 9933–9942. [CrossRef]
89. Jiaqiang, E.; Yue, M.; Chen, J.; Zhu, H.; Deng, Y.; Zhu, Y.; Zhang, F.; Wen, M.; Zhang, B.; Kang, S. Effects of the different air cooling strategies on cooling performance of a lithium-ion battery module with baffle. *Appl. Therm. Eng.* **2018**, *144*, 231–241. [CrossRef]
90. Lu, M.; Zhang, X.; Ji, J.; Xu, X.; Zhang, Y. Research progress on power battery cooling technology for electric vehicles. *J. Energy Storage* **2019**, *27*, 101155. [CrossRef]
91. Lipu, M.S.H.; Al Mamun, A.; Ansari, S.; Miah, S.; Hasan, K.; Meraj, S.T.; Abdolrasol, M.G.M.; Rahman, T.; Maruf, H.; Sarker, M.R.; et al. Battery Management, Key Technologies, Methods, Issues, and Future Trends of Electric Vehicles: A Pathway toward Achieving Sustainable Development Goals. *Batteries* **2022**, *8*, 119. [CrossRef]
92. Cosley, M.R.; Garcia, M.P. Battery thermal management system. In Proceedings of the INTELEC, International Telecommunications Energy Conference (Proceedings), Chicago, IL, USA, 19–23 September 2004; pp. 38–45.
93. Han, W.; Wik, T.; Kersten, A.; Dong, G.; Zou, C. Next-Generation Battery Management Systems: Dynamic Reconfiguration. *IEEE Ind. Electron. Mag.* **2020**, *14*, 20–31. [CrossRef]
94. Gaines, L. The future of automotive lithium-ion battery recycling: Charting a sustainable course. *Sustain. Mater. Technol.* **2014**, *1–2*, 2–7. [CrossRef]
95. Akhmetov, N.; Manakhov, A.; Al-Qasim, A.S. Li-Ion Battery Cathode Recycling: An Emerging Response to Growing Metal Demand and Accumulating Battery Waste. *Electronics* **2023**, *12*, 1152. [CrossRef]
96. Hassan, M.U.; Saha, S.; Haque, E.; Islam, S.; Mahmud, A.; Mendis, N. A comprehensive review of battery state of charge estimation techniques. *Sustain. Energy Technol. Assess.* **2022**, *54*, 102801. [CrossRef]
97. Wei, Z.; Hu, J.; Li, Y.; He, H.; Li, W.; Sauer, D.U. Hierarchical soft measurement of load current and state of charge for future smart lithium-ion batteries. *Appl. Energy* **2022**, *307*, 118246. [CrossRef]
98. Kumar, R.; Pachauri, R.K.; Badoni, P.; Bharadwaj, D.; Mittal, U.; Bisht, A. Investigation on parallel hybrid electric bicycle along with issuer management system for mountainous region. *J. Clean. Prod.* **2022**, *362*, 132430. [CrossRef]
99. Cheng, J.; Shuai, S.; Tang, Z.; Changfa, T. Thermal performance of a lithium-ion battery thermal management system with vapor chamber and minichannel cold plate. *Appl. Therm. Eng.* **2023**, *222*, 119694. [CrossRef]
100. Alzwayi, A.; Paul, M.C. Heat transfer enhancement of a lithium-ion battery cell using vertical and spiral cooling fins. *Therm. Sci. Eng. Prog.* **2024**, *47*, 102304. [CrossRef]

101. Yu, H.; Mu, X.; Zhu, Y.; Liao, C.; Han, L.; Wang, J.; Cai, W.; Kan, Y.; Song, L.; Hu, Y. Sandwich structured ultra-strong-heat-shielding aerogel/copper composite insulation board for safe lithium-ion batteries modules. *J. Energy Chem.* **2023**, *76*, 438–447. [CrossRef]
102. Wang, S.; Wu, F.; Takyi-Aninakwa, P.; Fernandez, C.; Stroe, D.-I.; Huang, Q. Improved singular filtering-Gaussian process regression-long short-term memory model for whole-life-cycle remaining capacity estimation of lithium-ion batteries adaptive to fast aging and multi-current variations. *Energy* **2023**, *284*, 128677. [CrossRef]
103. Pejman, R.; Gorman, J.; Najafi, A.R. Multi-physics design of a new battery packaging for electric vehicles utilizing multifunctional composites. *Compos. Part B Eng.* **2022**, *237*, 109810. [CrossRef]
104. Sui, X.; He, S.; Meng, J.; Stroe, D.-I.; Huang, X.; Teodorescu, R. Optimization of the discharge cut-off voltage in LiFePO4 battery packs. In Proceedings of the 2019 21st European Conference on Power Electronics and Applications (EPE '19 ECCE Europe), Genova, Italy, 3–5 September 2019.
105. Das, K.; Kumar, R.; Krishna, A. Analyzing electric vehicle battery health performance using supervised machine learning. *Renew. Sustain. Energy Rev.* **2024**, *189*, 113967. [CrossRef]
106. Steffen, L.; Catherine, J.A. Open-Source Database for Lithium-Ion Batteries Released. Available online: https://www.isi.fraunhofer.de (accessed on 21 May 2024).
107. Silva, G.; Dutra, T.A.; Nunes-Pereira, J.; Silva, A.; Silva, G.; Dutra, T.A.; Nunes-Pereira, J.; Silva, A. Coupled and decoupled structural batteries: A comparative analysis. *J. Power Sources* **2024**, *604*, 234392. [CrossRef]
108. Waldmann, T.; Scurtu, R.-G.; Richter, K.; Wohlfahrt-Mehrens, M. 18650 vs. 21700 Li-ion cells—A direct comparison of electrochemical, thermal, and geometrical properties. *J. Power Sources* **2020**, *472*, 228614. [CrossRef]
109. Chen, Y.; Ye, C.; Zhang, N.; Liu, J.; Li, H.; Davey, K.; Qiao, S.Z. Prospects for practical anode-free sodium batteries. *Mater. Today* **2024**, *73*, 260–274. [CrossRef]
110. Ank, M.; Sommer, A.; Gamra, K.A.; Schöberl, J.; Leeb, M.; Schachtl, J.; Streidel, N.; Stock, S.; Schreiber, M.; Bilfinger, P.; et al. Lithium-Ion Cells in Automotive Applications: Tesla 4680 Cylindrical Cell Teardown and Characterization. *J. Electrochem. Soc.* **2023**, *170*, 120536. [CrossRef]