INTERNATIONAL JOURNAL OF AUTOMOTIVE SCIENCE AND TECHNOLOGY

2024, VOL. 8, NO:3, 332-340 www.ijastech.org e-ISSN: 2587-0963

Evaluation of Lithium-ion Batteries in Electric Vehicles

Erdi Tosun[1*], Sinan Keiyinci[1], Ali Cem Yakaryılmaz[1], Şafak Yıldızhan[1] and Mustafa Özcanlı[1]

[1] *Automotive Engineering Department, Faculty of Engineering, Çukurova University, Adana, 01250, Turkiye*

Review Article

Abstract

Growing awareness of climate change concerns and the environmental impacts of fossil fuel vehicles has heightened interest in electric vehicles (EVs). Therefore, EVs represent a significant component of sustainable transportation solutions. Additionally, with advancements in battery technology, EVs now have longer ranges and are offered at more competitive prices. With their notable features such as high energy density, lightness, low maintenance requirement, and long life, lithium-ion batteries (LiBs) appear to be the most suitable battery option for EVs. Nevertheless, current LiB technology faces battery costs, energy storage capacity, charging times, and safety issues. In this context, it is clear that future research and development will focus on improving the efficiency of LiB technology and making these batteries more sustainable, reliable, and economical. This study aims to provide an evaluation of the LiBs used in the automotive sector by examining the historical development, basics of operational principles, various geometric types, cost evaluation, and their advantages and disadvantages. By covering these aspects, the study seeks to offer a comprehensive assessment of the LiBs employed in the automotive industry, spanning from their historical evolution to their present-day utilization. The study also intends to serve as a reference source for researchers planning to conduct studies on LiBs in EVs by providing fundamental concepts and evaluations related to these batteries.

Keywords: Automotive industry; Electric vehicle; Energy source; Lithium-ion battery

History
Received 29.03.2024
Revised 18.05.2024
Accepted 16.08.2024

Contact
* Corresponding author
Erdi Tosun
etosun@cu.edu.tr
Address: Automotive Engineering Department, Faculty of Engineering, Çukurova University, Adana, Turkiye
Tel:+905068394496

To cite this paper: Tosun, E., Keiyinci, S., Yakaryılmaz, A.C., Yıldızhan, Ş., Özcanlı, M., Evaluation of Lithium-ion Batteries in Electric Vehicles. International Journal of Automotive Science and Technology. 2024; 8(3): 332-340. http://dx.doi.org/10.29228/ijastech..1460955

1. Introduction

Conventional internal combustion engine (ICE) vehicles have demonstrated lower energy efficiency and increased greenhouse gas (GHG) emissions. The electrification of vehicles presents potential remedy for these challenges, concurrently mitigating reliance on fossil fuels. Therefore, there is a remarkable global shift from ICE vehicles to electric vehicles (EVs) to avoid the problems mentioned above [1-6].

EVs were quite popular, especially in the early 1900s, and the ratio of electrically powered vehicles was 25% of all. In the following years, interest in these vehicles declined due to high costs and low-capacity batteries, giving way to conventional fuel-powered ICEs over the next 10 decades. However, both efforts to reduce transportation-related carbon emissions released by ICE-operated vehicles and advances in battery technologies have reignited interest in EVs. [7].

Modern EV components are conceptually illustrated in Figure 1. The modern EV consists of three major subsystems: electric propulsion, energy source, and auxiliary. Based on the inputs from the accelerator and brake pedals, the vehicle controller generates appropriate control signals to the electronic power converter. The converter regulates the power flow between the electric motor and the energy source. The reverse power flow results from the EV's regenerative braking system, allowing the recovered energy to be returned to the energy source. Most EV batteries are readily capable of accepting regenerated energy. The energy management unit collaborates with the vehicle controller to regulate regenerative braking and energy recovery. Additionally, it interfaces with the energy refueling unit to manage refueling operations and monitor the usability of the energy source. The auxiliary power supply delivers the required power at various voltage levels for all EV auxiliary systems, particularly the climate control and power steering units [8].

The most significant breakthrough in battery technology development since the millennium has occurred in the field of LiBs. Thanks to their lower costs and extended operation ranges, lithium-ion batteries (LiBs) became the preferred technology in the 21st century for EVs.

One of the most important components of EVs is the batteries, which store energy in chemical form and provide it in electrical form to move the vehicle. Recently, LiBs, distinguished by their high energy density and efficiency allowing for lighter and smaller designs, have become indispensable elements of EVs. Besides that, longer life cycles, lower maintenance cost and low self-discharge, increased cell voltage, and no memory effect are other considerable advantages of LiBs. All these opportunities for LiBs make them the most attractive candidate for EV applications [9,10].

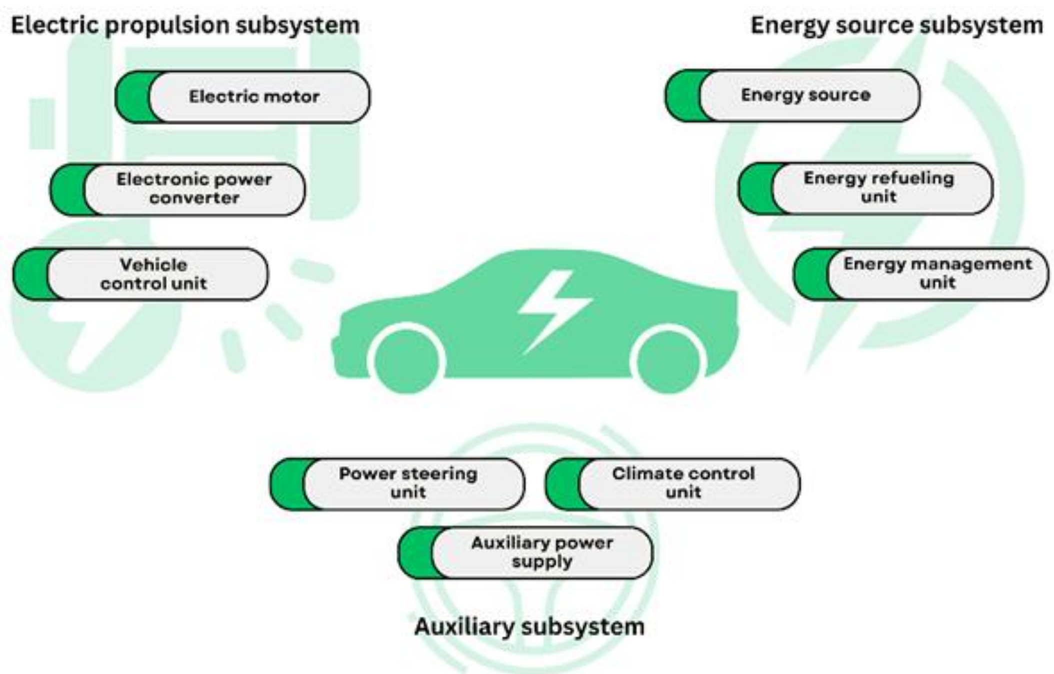

Fig. 1. Conceptual diagram of a general EV configuration

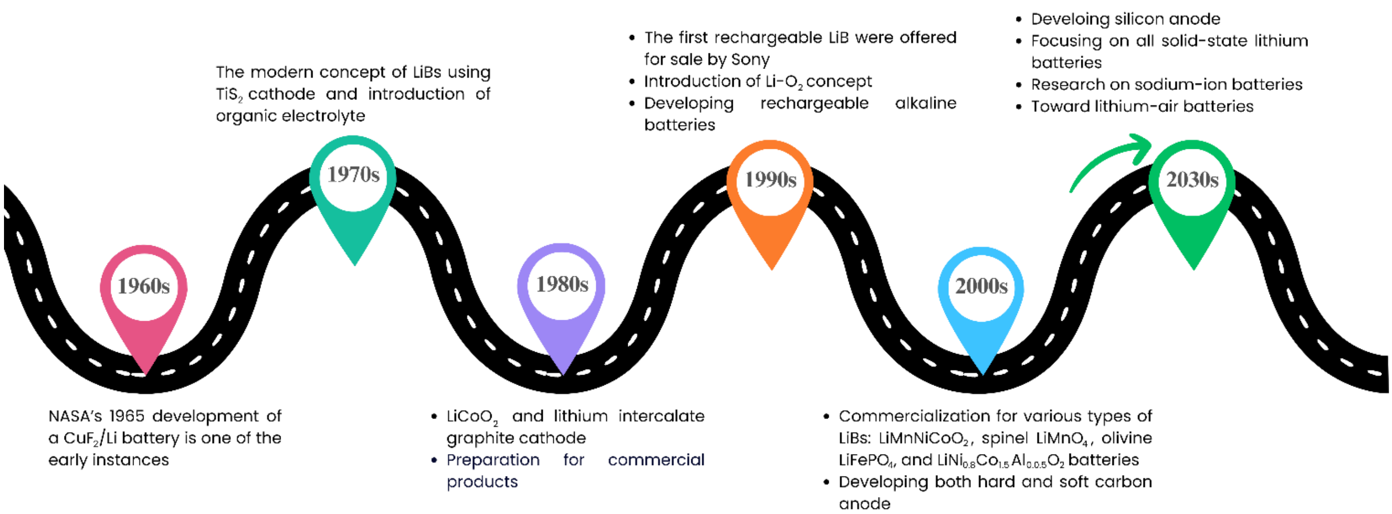

Fig. 2. Milestones of LiBs (reproduced from ref. [12])

In recent years, LiBs have garnered significant attention as a cornerstone technology for powering EVs with their superior working characteristics driving transformative changes in the automotive sector. Conducting a holistic assessment, this study aims to evaluate LiBs within EVs, spanning historical progression, operational principles, widely used geometries, cost factors, advantages, drawbacks, and automotive sector integration.

2. Historical Development and Milestones

The interest in higher-capacity and more compact rechargeable batteries has increased with the widespread use of devices such as computers, mobile phones, and video cameras. However, traditional rechargeable batteries like lead-acid and nickel-cadmium batteries, along with the nickel-metal hydride batteries then in development, presented constraints regarding size and weight reduction. Consequently, there was a demand for a new, compact, and lightweight rechargeable battery to be effectively utilized [11]. All these expectations led to the birth of LiBs. As a result of intensive studies on LiB technology, it has become highly advanced and continues to progress. Figure 2 illustrates the significant milestones in the history of LiB technology.

Three giant steps taken by John Bannister Goodenough, Michael Stanley Whittingham, and Akira Yoshino to contribute to the development of LiBs were awarded the Nobel Prize in Chemistry in 2019. The huge efforts of these three scientists guided the creation of rechargeable, lightweight, high-power LiBs.

The foundation of the LiB emerged during the 1970s oil crisis as Michael Stanley Whittingham developed methods to generate energy without relying on fossil fuels. He worked to find an innovative cathode material (titanium disulphide) that contains spaces at a molecular level to host lithium ions. On the other hand, metallic lithium was used as an anode material. Unfortunately, the reactiveness of metallic lithium led to create an explosive structure in the battery. The schematic of Whittingham's battery is given in Figure 3 [13].

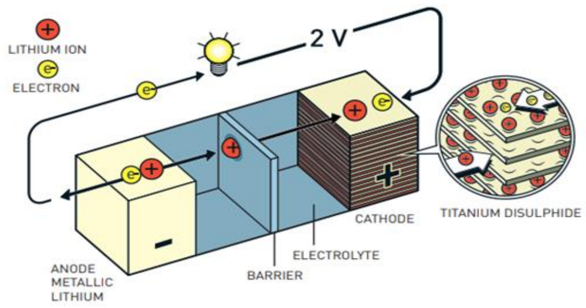

Fig. 3. Whittingham's battery [38]

John Bannister Goodenough used metal oxide instead of metal sulfate as the cathode material to obtain higher potential. In 1980, he observed higher potential with cobalt oxide utilization as cathode material and it opened the way for powerful batteries. In Figure 4, Goodenough's battery is illustrated [13].

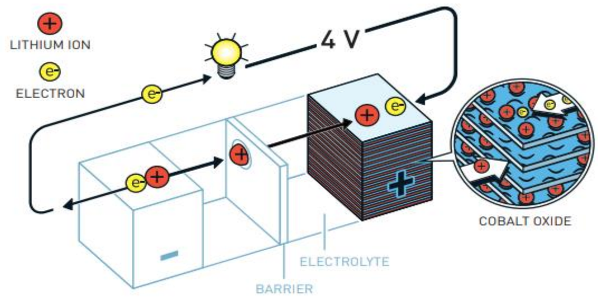

Fig. 4. Goodenough's battery [39]

In 1985, the first commercial LiB was introduced by Akira Yoshino. Yoshino's battery differs from Goodenough's by anode material. A carbon material petroleum coke was selected instead of metallic lithium as an anode material. This material can intercalate lithium ions such as cobalt oxide in the cathode. The schematic of Yoshino's battery is supplied in Figure 5. [13]

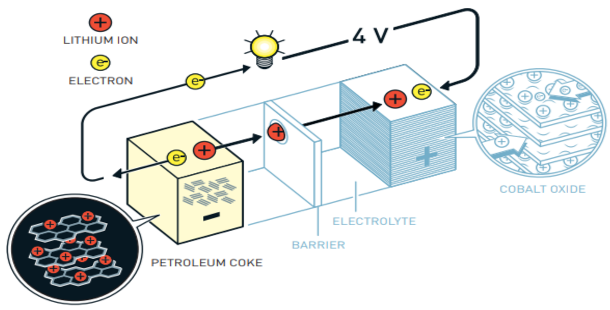

Fig. 5. Yoshino's battery [39]

3. Geometry

The common geometries widely used in LiBs are cylindrical, pouch, and prismatic types, as shown in Figure 6. Cylindrical and prismatic cells are housed within a rigid enclosure typically composed of aluminum or stainless steel, whereas pouch cells are enveloped within multilayered aluminum composite foils. Cylindrical types include electrodes wound together with separators, creating a structure resembling a jelly roll. On the other hand, configurations of either stacked or flat jelly rolls for electrodes are utilized by prismatic cells. Electrodes of pouch cells are solely characterized by stacked arrangement [14]. Figure 7 schematically illustrates the different design considerations in the manufacturing of cells. Prismatic winding is the prevalent technique employed by Asian battery manufacturers, whereas the single-sheet stacking process is the favored method among European manufacturers [15].

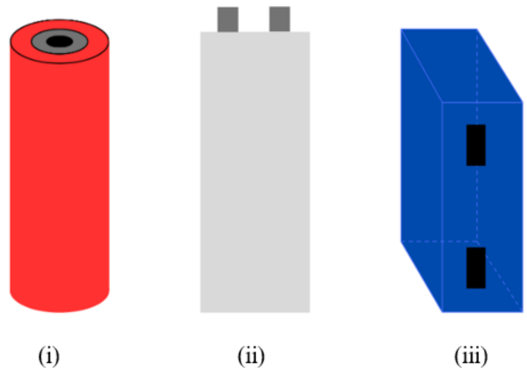

Fig. 6. LiB geometries in various applications; i) cylindrical ii) pouch iii) prismatic

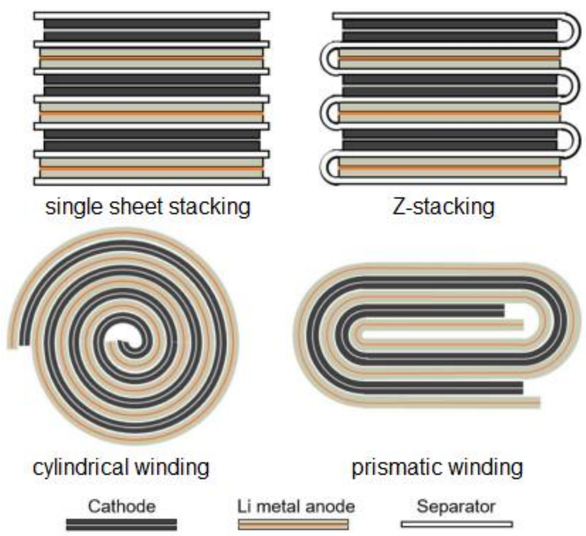

Fig. 7. Various design considerations in battery geometries [15]

4. Anode/Cathode Chemistry and Operation Principle of LiBs

The anode, cathode, electrolyte, and separator are the four main components of a typical LiB. The charge-discharge processes of LiBs are provided by the movements of lithium ions (Li^+)between the anode and cathode. Li^+ions are intercalated at the anode and cathode sides at the charged and discharged positions. During discharge, intercalated Li^+ions move from the anode to the cathode, while the opposite occurs during charging. In Figure 8, a graphical representation of discharge and charge periods were supplied in detail. The travel routes of

Li^+ions which are represented by red circles and the direction of electron movement can be seen from the subjected Figure 8 during charge and discharge. The separator serves to both prevent internal short-circuits and facilitate the flow of Li^+ions by physically separating the electrodes. The carriage of Li^+ions occur in an electrolyte medium composed of lithium-based salts such as lithium hexafluorophosphate $(LiPF_6)$ and lithium perchlorate $(LiClO_4)$ [16,17].

Following Eq. (1) and Eq. (2) reveal the electrochemical reactions that occurred at the anode and cathode sides, respectively [17]:

$$C_6 + yLi^+ + \ ye^- \underset{\leftarrow discharge}{\overset{\rightarrow charge}{}} Li_yC_6 \qquad 0 \le y \le 1 \qquad (1)$$

$$LiMeO_2 \underset{\leftarrow discharge}{\overset{\rightarrow charge}{}} Li_{1-x}MeO_2 + xLi^+ + xe^- \quad 0 \le y \le 0.5 \qquad (2)$$

In the above equations, Me and C_6 refer to a transition metal (such as Cobalt (Co)) and graphite, correspondingly.

Carbon (graphite) and lithium alloyed metals such as $Li_4Ti_5O_{12}$ (spinel lithium titanate) and Li_2TiO_3 (lithium titanate) currently come into prominence as the two predominant choices for anode materials in widespread usage [18]. Besides anode materials, Table 1 summarizes the different cathode materials utilized in commercial LiBs. As seen from the table, LiBs are mainly characterized by their cathode materials which serve various advantages and limitations.

5. Cost

Cost evaluation for LiBs typically involves assessing the cost per kilowatt-hour (kWh) of energy storage capacity. This metric provides a standardized measure to compare the cost-effectiveness of different battery technologies and sizes. Factors influencing the cost per kWh include the upfront investment in battery cells, modules, and management systems, as well as installation and maintenance expenses. In 1991, Sony has been announced the first rechargeable LiBs. In the following years, uninterrupted development in the LiB sector is ongoing to decrease the cost of the batteries in the first place. Since their initial introduction in 1991, when considering their energy capacities, it has been observed that LiBs cost has decreased by 97% [19]. However, in the last few years, the cost of LiBs has decreased more slowly than expected. This is partly because of the COVID-19 pandemic and the tension between Russia and Ukraine. In fact, for the first time, costs went up almost 8% from 2021 to 2022 [20]. Figure 9 illustrates the cost changes of LiBs over the past decade. After experiencing remarkable cost escalations in 2022, there is now a downward trend in battery costs in 2023. According to an analysis conducted by research provider Bloomberg New Energy Finance (BNEF), the cost of LiB packs in 2023 has decreased by 14% (compared to the previous year) to reach a historic low of $139/kWh. In the forthcoming years, advancements in technological innovation and enhancements in manufacturing processes are expected to propel continued reductions in battery pack prices. Forecasts predict a decline to $113/kWh by 2025 and further to $80/kWh by 2030 [21].

6. Advantages and Drawbacks

LiBs have gained widespread recognition as the predominant energy storage solution for EVs, primarily due to their exceptional advantages such as high energy density, lightweight and compact, fast charging [22-24]. The standout feature of high energy density empowers LiBs to provide a substantial amount of energy storage per unit weight, consequently affording EVs extended driving ranges and heightened overall performance (Figure 10). This advantage contributes to making EVs more practical and appealing to consumers, driving the widespread adoption of EVs as a cleaner and more sustainable mode of transportation.

The ability of LiBs to support fast-charging capabilities, while easing concerns regarding the range of EVs, provides users with a more positive experience. Furthermore, research and development efforts focusing on improving the charging infrastructure and battery technology continue to enhance the performance and feasibility of fast-charging LiBs, further solidifying their position as a cornerstone of modern EV technology.

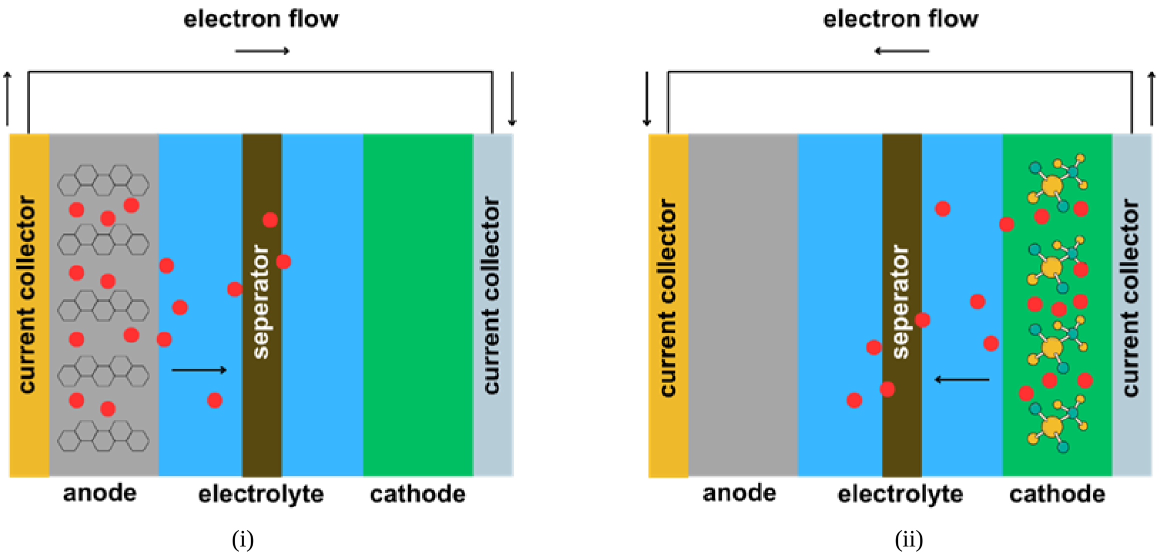

Fig. 8. (i) discharge (ii) charge periods

Table 1. Different commercial types of LiBs about their chemistries [12]

Type	LCO	LMO	LPO	NCA	NMC	LTO
Cathode	$LiCoO_2$	$LiMn_2O_4$	$LiFePO_4$	$LiNiCoAlO_2$	$LiNiMnCoO_2$	$LiMn_2O_4$ or $LiNiMnCoO_2$
Anode	Graphite	Graphite	Graphite	Graphite	Graphite	Li_2TiO_3
Commercial time	1991	1996	1996	1999	2008	2008
Nominal Voltage (V)	3.6	3.7	3.2	3.6	3.6 and 3.7	2.4
Working voltage range (V)	3 - 4.2	3 - 4.2	2.5 - 3.65	3 - 4.2	3 - 4.2	1.8 - 2.85
Energy density (Wh/kg)	150 - 200	100 - 150	90 - 120	200 – 260	150 - 220	50 - 80
Charge (C-rate)	0.7 - 1C	0.7 - 1C	1C	~0.7C	0.7 - 1C	1C
Charge limitations	>1C shortens battery life	max. 3C	-	-	-	max. 5C
Discharge (C-rate)	1C	1C	1C	1C	1C	1C
Discharge limitations	>1C shortens battery life	max. 10C (for special versions)	-	-	-	max. 10C
Cycle life (cycles)	500 - 1000	300 - 700	~2000	500	1000 - 2000	3000-7000
Thermal runaway (ºC)	150	250	270	150	210	100
Applications	Consumer electronics (cell phones, laptops, tablets, etc.)	Power tools, medical devices, some kind of electric vehicles	Power tools	Automotive industry	Power tools, medical devices, and electric vehicles	Automotive industry, electric power train

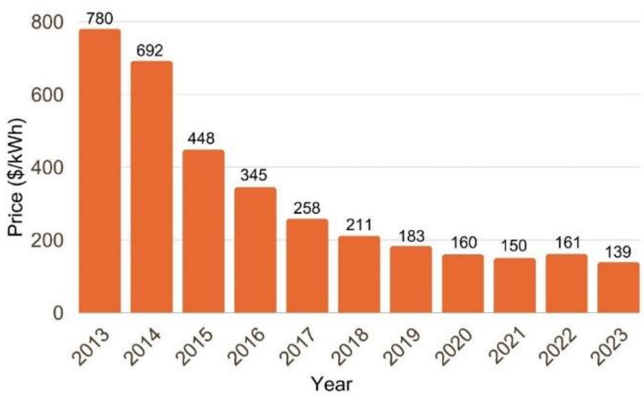

Fig. 9. Cost change of LiBs over the last decade [21]

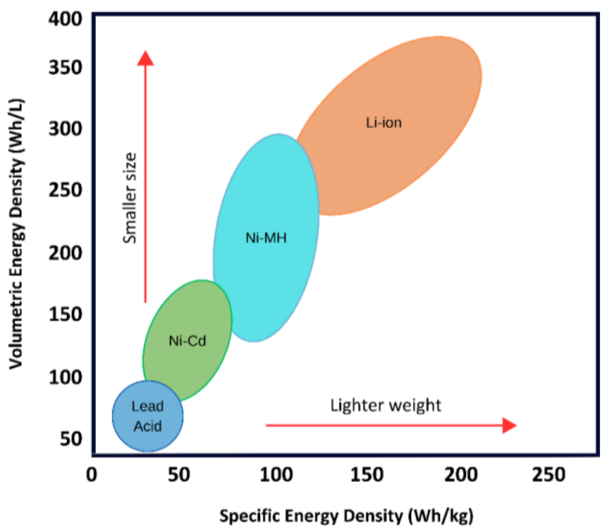

Fig. 10. Energy density comparison of different battery types [25]

However, alongside these advantages, LiBs come with a set of drawbacks. One prominent drawback is the high manufacturing cost of LiBs, which constitutes a substantial portion of the overall cost of EVs. Addressing this cost factor is imperative for achieving broader market penetration and making EVs more accessible to a wider range of consumers. Recently, the capital cost of a LiB for EV usage is still around $139/kWh [26], thus, although it varies depending on the vehicle class, the battery cost still accounts for almost half of the EV sales price. Aside from the initial cost of LiBs in EVs, cycle life is one of the most important concerns [27]. The limited lifespan of LiBs, influenced by factors such as charge-discharge cycles and operating conditions, particularly temperature, poses a concern for long-term durability. Temperature plays a crucial role in LiBs as high temperatures accelerate chemical reactions within the battery, leading to reduced cycle life [28,29]. Moreover, thermal runaway may occur as a result of high-temperature reactions, and this may lead to dangers such as battery explosion and fire risk. Conversely, low temperatures can also negatively impact the battery's performance and longevity by slowing down chemical reactions and decreasing the battery's efficiency. Therefore, maintaining an optimal operating temperature range is crucial for maximizing the cycle life of LiBs. Generally, temperatures between 15°C to 35°C are considered ideal for LiB performance and longevity [30]. Exposing the battery to temperatures outside of this range, especially high temperatures, can lead to faster degradation and shorter cycle life.

In addition to temperature, cell chemistry, and design play crucial roles; batteries featuring durable materials and well-engineered electrodes generally exhibit extended cycle life [31]. The state of charge and idle time also matter, with prolonged full charges or extended periods of inactivity potentially causing permanent damage. Furthermore, frequency of use and depth of discharge influence cycle life, with heavier usage accelerating aging. Taken together, these factors collectively determine a battery's cycle life, emphasizing the importance of optimizing conditions for maximum performance and longevity.

The disadvantages mentioned so far were related to the application of LiBs. Besides these, there are two major concerns regarding LiBs: issues related to their production and the management of waste after their use. The production process of LiBs involves extracting and processing finite natural resources such as lithium, cobalt, and nickel. This raises significant environmental and ethical concerns since these resources are typically obtained through mining and extraction activities, which can lead to habitat destruction, water pollution, and carbon emissions. However, the disposal of end-of-life LiBs poses environmental challenges due to the potential for toxic substances to be released into the environment. Improper disposal methods, such as landfilling or incineration, can release hazardous chemicals into soil and water, posing risks to human health and ecosystems [32]. Additionally, LiBs contain valuable materials that can be recycled; however, existing recycling infrastructure is often inadequate, resulting in low recycling rates and increased waste generation.

Despite these difficulties, ongoing research and development in battery technology aims to find solutions to these problems. The goal is to create more efficient, cost-effective, and environmentally sustainable LiBs for EVs.

7. Utilization in the Automotive Sector

Rangarajan et al. [33] published a study claiming that, global EV sales exceeded expectations and continue to grow. It was projected for Europe, an additional 200 GWh of capacity for EVs and LiBs in 2020, which was expected to increase to 600 GWh in 2021. The rapid growth of the EV market caused high competition among manufacturers like Tesla, Volkswagen, GM, SK Innovation, and LG Chem. As a result, it has become critical to understand the problematic issues of LiBs, along with their evolving design and implementation trends. In 2017, the world produced around 103 GWh or 11,400 metric tons of LiBs. This demand is projected to grow faster in the coming years. Projections indicate that by 2030, the annual demand for LiBs will reach approximately 1300 GWh (145,000 metric tons). The growing demand for LiBs is mostly caused by the increasing number of EVs, the life span of the batteries, and the availability of recycling options [34]. Currently, 60% of the world's capacity for converting lithium products into battery-grade equivalents is under China's control. [35]. The country's investments in large battery factories have fueled this growth to meet the high demand for energy storage and EVs. As a result of China's massive production, battery prices have fallen, making batteries more accessible to end users. Also, EVs are becoming more popular, as can be seen from the increasing sales. Between 2011 and 2021, sales of hybrid electric vehicles (HEVs) in the United States nearly tripled, from about 268,749 to nearly 798,992. Sales of plug-in hybrid electric vehicles (PHEVs) rose significantly from around 7,671 to about 173,457, while plug-in electric vehicle (PEV) sales surged from 10,092 to nearly 459,426. Globally, PHEV sales grew from about 9,330 to over 1.9 million, and PEV sales increased from around 43,680 to more than 4.8 million during the same period [36].

The use of LiBs in the automotive sector has a very significant impact on the industry, and the trend towards EVs and sustainable transportation practices is increasing daily. Thanks to ongoing advances in battery technology and contributions from influential individuals, the future of LiBs in the automotive industry looks promising with the potential to revolutionize the way vehicles are powered and driven. However, it is crucial to address the challenges and concerns associated with LiBs to ensure their long-term sustainability and applicability in the automotive industry. By prioritizing innovation, collaboration, and sustainability, the path can be paved for a greener and more efficient transport future supported by LiBs.

8. Recent Advancements in LiBs

As shown in Figure 11 below, developments in LiB technologies demonstrate that researchers have recently been focusing on certain areas.

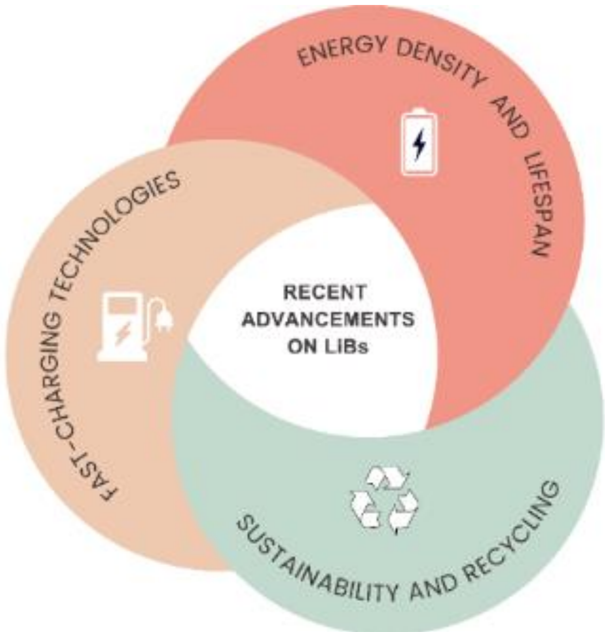

Fig. 11. Recent advancements in LiBs

In LiBs, the anode, cathode, and electrolyte materials have a significant impact on the energy density, performance, and life of the battery. The performance of the battery is directly related to these materials, and the anode and cathode materials must have high capacity to achieve high energy density levels. The chemical stability and durability of the anode and cathode materials affect the life of the battery. The fact that the materials are chemically stable and do not deteriorate when repeatedly charged and discharged ensures long-term use of the battery. European Council for Automotive R&D (EUCAR) and United States Advanced Battery Consortium (USABC) revealed energy goals for anode and cathode materials with targets for the automotive industry as seen from Figure 12 below. A review of cathode material performance indicates that no practical candidate materials currently exist that can meet or exceed future automotive material targets. The absence of viable future cathode materials for improving LiB energy presents a major challenge to the ongoing development of the field. On the other hand, although carbon anodes have historically dominated the LiB market and cannot meet future energy targets, lithium and silicon anodes, depending on their usage, are capable of meeting these targets [37].

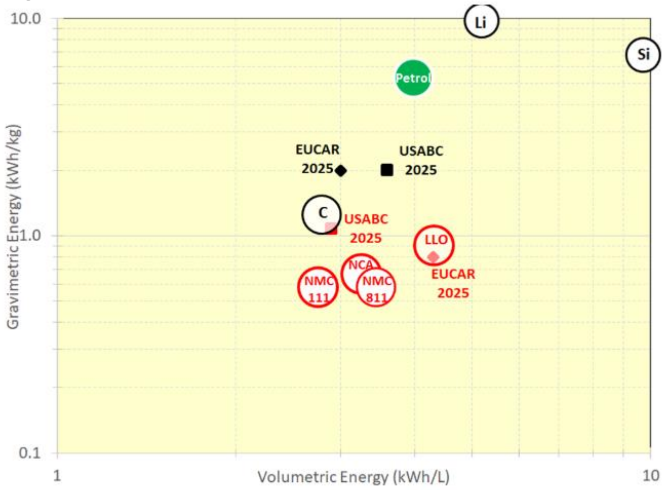

Fig. 12. The anode (black circles) and cathode (red circles) materials and targets set by EUCAR and USABC [37]

On the other hand, sustainability and recycling are becoming increasingly important. The limited availability of rare elements used in LiB production and concerns about waste management are prompting the industry to focus on recycling technologies and material reuse. Another remarkable research area for LiBs where current studies are concentrated is fast-charging technologies since one of the greatest expectations of EV customers is a reduction in charging times. Researchers are studying various anode, cathode, and electrolyte materials that will enable lithium ions inside the battery to be transported and stored more quickly and efficiently for the fast-charging opportunity.

To sum up, recent advancements in LiBs for the automotive sector include increasing energy density, reducing charging times, lowering costs, enhancing safety, and improving recycling. Silicon anodes increase energy capacity, and reducing cobalt use cuts costs and environmental impact. Fast-charging technologies and advanced battery management systems improve efficiency and lifespan. Improved recycling processes and second-life applications ensure sustainable use of materials. These innovations make EVs more competitive with traditional ICE vehicles in range, performance, and cost.

9. Conclusions

As a result, in this study, LiBs have been briefly evaluated in EV applications, focusing on their historical development, operating principles, cost issues, benefits, limitations, and integration in the automotive industry.

While the study shows that LiBs are emerging as the preferred energy storage solution for EVs, offering advantages such as high energy density, lightweight design and fast charging capabilities, it underlines that high production costs, limited lifespan and environmental impacts are still significant areas of concern.

Since their invention, LiBs have experienced a remarkable reduction in costs due to ongoing advancements in battery technology and manufacturing processes. This cost reduction has significantly impacted the automotive sector, driving the growing demand for LiBs as EV sales continue to rise globally. Going forward, future research and development efforts should also focus on improving the efficiency, sustainability, and affordability of LiB technology. This requires advances in battery chemistry, manufacturing processes, recycling infrastructure, and regulatory frameworks. By overcoming these challenges, LiBs can further revolutionize the automotive industry, facilitate the widespread adoption of EVs, and contribute to a cleaner and more sustainable transportation ecosystem.

Acknowledgments

This research was supported by Çukurova University Scientific Research Project Unit with FBA-2022-15234 project code.

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

Erdi Tosun: Conceptualization, Writing-original draft, Supervision **Sinan Keiyinci**: Conceptualization, Writing-original draft, Investigation **Ali Cem Yakaryılmaz**: Investigation, Formal analysis, Writing - review & editing **Şafak Yıldızhan**: Investigation, Formal analysis, Writing - review & editing **Mustafa Özcanlı**: Conceptualization, Writing - review & editing

Nomenclature

C	:	Carbon
EUCAR	:	European Council for Automotive R&D
EV	:	Electric vehicle
GHG	:	Greenhouse gas
HEV	:	Hybrid electric vehicle
ICE	:	Internal combustion engine
LiB	:	Lithium-ion battery
Li^+	:	Lithium ion
$LiClO_4$	:	Lithium perchlorate
$LiPF_6$	:	Lithium hexafluorophosphate
$Li_4Ti_5O_{12}$	:	Spinel lithium titanate
Li_2TiO_3	:	Lithium titanate
LCO	:	$LiCoO_2$ (cathode) graphite (anode)
LLO	:	Lithium-rich layered oxide
LMO	:	$LiMn_2O_4$ (cathode) graphite (anode)
LPO	:	$LiFePO_4$ (cathode) graphite (anode)
LTO	:	$LiMn_2O_4$ or $LiNiMnCoO_2$ (cathode) Li_2TiO_3 (anode)
NCA	:	$LiNiCoAlO_2$ (cathode) graphite (anode)
NMC	:	$LiNiMnCoO_2$ (cathode) graphite (anode)
PEV	:	Plug-in electric vehicle
PHEV	:	Plug-in hybrid-electric vehicles
Si	:	Silicon
USABC	:	United States Advanced Battery Consortium

References

[1] Poornesh K, Nivya KP, Sireesha K. A Comparative study on Electric Vehicle and Internal Combustion Engine Vehicles. Proc – Int Conf Smart Electron Commun ICOSEC 2020. 2020;1179–1183. https://doi.org/10.1109/ICOSEC49089.2020.9215386

[2] Xu C, Steubing B, Hu M, Harpprecht C, van der Meide M, Tukker A. Future greenhouse gas emissions of automotive lithium-ion battery cell production. Resour Conserv Recycl. 2022;187:106606. https://doi.org/10.1016/j.resconrec.2022.106606

[3] Kurtulmuş ZN, Karakaya A. Review of mechanical, electrochemical, electrical, and hybrid energy storage systems used for electric vehicles. International Journal of Automotive Science and Technology. 2024;8:44-51. https://doi.org/10.30939/ijastech..1357392

[4] Ekici YE, Tan N. Charge and discharge characteristics of different types of batteries on a hybrid electric vehicle model and selection of suitable battery type for electric vehicles. International Journal of Automotive Science and Technology. 2019;3:62-70. https://doi.org/10.30939/ijastech..527971

[5] Goud PVS, Chary ASVP. Evaluation of electrification of 4W light commercial vehicle. Engineering Perspective. 2023;3:9-17. http://dx.doi.org/10.29228/eng.pers.69296

[6] Kilic A. Charging techniques, infrastructure, and their influences. Engineering Perspective. 2023;3:68-74. http://dx.doi.org/10.29228/eng.pers.73000

[7] Zeng X, Li M, Abd El-Hady D, Alshitari W, Al-Bogami AS, Lu J, et al. Commercialization of Lithium Battery Technologies for Electric Vehicles. Adv Energy Mater. 2019;9:1–25. https://doi.org/10.1002/aenm.201900161

[8] Ehsani M, Gao Y, Longo S, Ebrahimi K. Modern Electric, Hybrid Electric, and Fuel Cell Vehicles. CRC Press; 2018. https://doi.org/10.1201/9780429504884

[9] Barré A, Deguilhem B, Grolleau S, Gérard M, Suard F, Riu D. A review on lithium-ion battery ageing mechanisms and estimations for automotive applications. J Power Sources. 2013;241:680–689. https://doi.org/10.1016/j.jpowsour.2013.05.040

[10] Siddiqui SET, Rahman MA, Kim JH, Sharif S Bin, Paul S. A Review on Recent Advancements of Ni-NiO Nanocomposite as an Anode for High-Performance Lithium-Ion Battery. Nanomaterials. 2022;12:1–33. https://doi.org/10.3390/nano12172930

[11] Yoshino A. The birth of the lithium-ion battery. Angew Chemie - Int Ed. 2012;51:5798–5800. https://doi.org/10.1002/anie.201105006

[12] Le PA. A general introduction to lithium-ion batteries: From the first concept to the top six commercials and beyond. J Electrochem Sci Eng. 2023;13(4):591–604. https://doi.org/10.5599/jese.1544

[13] Goodenough JB, Whittingham MS, Yoshino A. Lithium-ion batteries. The Royal Swedish Academy of Sciences, Press release, 2019.

[14] Baazouzi S, Feistel N, Wanner J, Landwehr I, Fill A, Birke KP. Design, Properties, and Manufacturing of Cylindrical Li-Ion Battery Cells—A Generic Overview. Batteries. 2023;9:309. https://doi.org/10.3390/batteries9060309

[15] Wu B, Yang Y, Liu D, Niu C, Gross M, Seymour L, et al. Good Practices for Rechargeable Lithium Metal Batteries. J Electrochem Soc. 2019;166(16):A4141–A4149. https://doi.org/10.1149/2.0691916jes

[16] Chen Y, Kang Y, Zhao Y, Wang L, Liu J, Li Y, et al. A review of lithium-ion battery safety concerns: The issues, strategies, and testing standards. J Energy Chem. 2021;59:83–99. https://doi.org/10.1016/j.jechem.2020.10.017

[17] Raijmakers LHJ, Danilov DL, Eichel RA, Notten PHL. A review on various temperature-indication methods for Li-ion batteries. Appl Energy. 2019;240:918–945. https://doi.org/10.1016/j.apenergy.2019.02.078.

[18] Mekonnen Y, Sundararajan A, Sarwat AI. A review of cathode and anode materials for lithium-ion batteries. Conf Proc - IEEE SOUTHEASTCON; 2016;2016-July:1–6. https://doi.org/10.1109/SECON.2016.7506639.

[19] Ziegler MS, Trancik JE. Re-examining rates of lithium-ion battery technology improvement and cost decline. Energy Environ Sci. 2021;14:1635–1651. https://doi.org/10.1039/d0ee02681f.

[20] Orangi S, Manjong N, Clos DP, Usai L, Burheim OS, Strømman AH. Historical and prospective lithium-ion battery cost trajectories from a bottom-up production modeling perspective. J Energy Storage. 2024;76:109800. https://doi.org/10.1016/j.est.2023.109800.

[21] Georino D. Battery prices are falling again. ERA Review. 2024;16(2):24-26.

[22] Wen J, Zhao D, Zhang C. An overview of electricity powered vehicles: Lithium-ion battery energy storage density and energy conversion efficiency. Renew Energy. 2020;162:1629–1648. https://doi.org/10.1016/j.renene.2020.09.055

[23] Cao X, Ma C, Luo L, Chen L, Cheng H, Orenstein RS, Zhang X. Nanofiber materials for lithium-ion batteries. Advan Fib Mater. 2023;5:1141-1197. https://doi.org/10.1007/s42765-023-00278-4

[24] Goud VM, Satyanarayana G, Ramesh J, Pathanjali GA, Sudhakar DR. An experimental investigation and hybrid neural network modelling of thermal management of lithium-ion batteries using a non-paraffinic organic phase change material, Myristyl alcohol. J Energy Storage. 2023;72:108395. https://doi.org/10.1016/j.est.2023.108395

[25] Abo-Khalil AG, Abdelkareem MA, Sayed ET, Maghrabie HM, Radwan A, Rezk H, Olabi AG. Electric vehicle impact on energy industry, policy, technical barriers, and power systems. Int J of Therm.2022;13:100134. https://doi.org/10.1016/j.ijft.2022.100134

[26] Chen WH, Hsieh IYL. Techno-economic analysis of lithium-ion battery price reduction considering carbon footprint based on life cycle assessment. J Clean Prod. 2023;425:139045. https://doi.org/10.1016/j.jclepro.2023.139045

[27] Haram MHSM, Lee JW, Ramasamy G, Ngu EE, Thiagarajah SP, Lee YH. Feasibility of utilising second life EV batteries: Applications, lifespan, economics, environmental impact, assessment, and challenges. Alexandria Eng J. 2021;60:4517–4536. https://doi.org/10.1016/j.aej.2021.03.021

[28] Kumar R, Goel V. A study on thermal management system of lithium-ion batteries for electrical vehicles: A critical review. J Energy Storage. 2023;71:108025. https://doi.org/10.1016/j.est.2023.108025

[29] Hasan HA, Togun H, Abed AM, Biswas N, Mohammed HI. Thermal performance assessment for an array of cylindrical lithium-ion battery cells using an Air-Cooling system. Appl Energy. 2023;346:121354. https://doi.org/10.1016/j.apenergy.2023.121354

[30]Zhang Z, Yu W, Li H, Wan W, Zhang W, Zhuo W, Liu Q. Heat transfer characteristics and low-temperature performance of a lithium-ion battery with an inner cooling/heating structure. Appl Ther Eng. 2023;219:119352. https://doi.org/10.1016/j.applthermaleng.2022.119352
[31]Wang KX, Li XH, Chen JS. Surface and interface engineering of electrode materials for lithium-ion batteries. Adv Mater. 2015;27:527–545. https://doi.org/10.1002/adma.201402962
[32]Wu J, Zheng M, Liu T, Wang Y, Liu Y, Nai J, Zhang L, Zhang S, Tao X. Direct recovery: A sustainable recycling technology for spent lithium-ion battery. Energy Stor Mat. 2023;54:120-134. https://doi.org/10.1016/j.ensm.2022.09.029
[33]S. Rangarajan S, Sunddararaj SP, Sudhakar AVV, Shiva CK, Subramaniam U, Collins ER, et al. Lithium-Ion Batteries—The Crux of Electric Vehicles with Opportunities and Challenges. Clean Technol. 2022;4(4):908–930. https://doi.org/10.3390/cleantechnol4040056.
[34]Tolomeo R, De Feo G, Adami R, Osséo LS. Application of life cycle assessment to lithium ion batteries in the automotive sector. Sustain. 2020;12(11):4628. https://doi.org/10.3390/su12114628
[35]Li X, Sengupta T, Mohammed KS, Jamaani F. Forecasting the lithium mineral resources prices in China: Evidence with Facebook Prophet (Fb-P) and Artificial Neural Networks (ANN) methods. Res Policy. 2023;82:103580. https://doi.org/10.1016/j.resourpol.2023.103580
[36]Squalli J. Environmental hypocrisy? Electric and hybrid vehicle adoption and pro-environmental attitudes in the United States. Energy. 2024;293:130670. https://doi.org/10.1016/j.energy.2024.130670
[37]Masias A, Marcicki J, Paxton WA. Opportunities and Challenges of Lithium Ion Batteries in Automotive Applications. ACS Energy Letters. 2021;6:621-630. https://dx.doi.org/10.1021/acsenergylett.0c02584
[38] Theodore AM. Progress into lithium-ion battery research. Journal of Chemical Research. 2023;47(3):17475198231183349. https://doi.org/10.1177/17475198231183349
[39] Monroe, D. Building a better battery. MRS Bulletin, 2020;45: 246–247. https://doi.org/10.1557/mrs.2020.81