

# Battery Energy Storage Technologies in Electric Vehicles: An Overview and Perspective on the Future

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## ABSTRACT

The electrification of transportation has brought forth a diverse landscape of battery technologies for powering electric vehicles (EVs). This review explores various types of batteries used in EVs and their implications for the future of sustainable mobility. The evolution of battery technology, from conventional lead-acid to advanced lithium-ion, sodium-ion, zinc-air, and graphene batteries, is examined in terms of energy density, charging capabilities, environmental impact, and cost-effectiveness. A comparative analysis highlights the strengths and limitations of each battery type, addressing key factors such as range, charging speed, lifespan, and sustainability. This comprehensive exploration underscores the pivotal role of battery technology in shaping the performance, range, and adoption of EVs. By delving into these distinct battery chemistries and their applications in electric vehicles, this review provides insights into the potential of each technology to contribute to cleaner and more energy-efficient transportation systems. Ultimately, this knowledge aids in steering the transition towards a sustainable and electrified future in the automotive industry.

**Keywords**— Electric vehicle; Battery; Energy Storage; Lead acid ;lithium ion

## I. INTRODUCTION

The advent of electric vehicles (EVs) marks a seismic shift in the transportation landscape, heralding a departure from conventional combustion engines to embrace novel battery-powered propulsion systems propelled by electric motors. This transformative mode of mobility finds its classification in three distinct iterations: pure electric vehicles (PEVs), hybrid electric vehicles (HEVs), and fuel cell electric vehicles (FCEVs) [1-3]. This pivotal transition aligns harmoniously with the global automotive panorama, which currently resonates with an intensified wave of innovation. The urgency to address imperatives such as energy security and environmental sustainability serves as a potent catalyst, driving extensive research and development endeavors in the realm of electric car technology [4-5].

In this dynamic context of transformation, China has emerged as a prominent protagonist, seizing the reins of the electric mobility narrative. Established in 2004, the China Electric Vehicle Association (CEVA) stands as a pivotal instrument for progress. Constituted as a collaborative entity, CEVA interweaves stakeholders from the electric vehicle industry, public institutions, and the labor force. Its standing as a national non-governmental organization underscores China's resolute commitment to nurturing an automotive future that is both sustainable and forward-looking. The collective synergy of efforts invested has borne tangible results, propelling significant strides in the advancement of both hybrid and pure electric vehicle technologies [6-7]. Notably, these efforts culminate in the achievement of limited-scale production for pure electric vehicles, embodying a testament to China's dedication to being at the forefront of transformative change [8].

Parallel to this narrative of change, Japan has embarked on an equally fervent journey of exploration into electric mobility. Japan's relentless pursuit of innovation underscores its proactive stance in not only adapting to the evolving automotive landscape but also actively shaping its contours. This underscores Japan's recognition of electric vehicles as potent agents in forging a transportation ecosystem that is sustainable, efficient, and in harmony with environmental imperatives. The nation's strategic orientation towards optimizing electric vehicle technology is emblematic of the broader global acknowledgment of the pivotal role that EVs play in shaping a greener future.

The cumulative outcomes of these multifaceted developments in electric vehicle technology are poised to recalibrate the very nature of transportation on a global scale. The segmentation of EVs into discrete categories, the unwavering commitment demonstrated by countries like China, and the innovative fervor exhibited by nations

such as Japan collectively paint an inexorable trajectory toward a transportation future that is cleaner, greener, and undeniably electrified. As these endeavors continue to unfurl, the stage is meticulously set for a transformative transition from conventional internal combustion engines. Instead, the symphony of transportation will be orchestrated by the hushed yet potent hum of electric propulsion, ushering in an era marked by diminished carbon footprints and a planet more harmonious with the needs of generations to come.

## II. Battery Technologies

The battery powers electric cars. Battery performance determines electric vehicle performance. The rapid development of electric vehicles accelerates battery development [9]. Electric vehicle development has produced many cars and batteries. The most common rechargeable batteries are lead acid, NiCd, NiMH, and Li-ion.

### A. Lead Acid Batteries

The inception of the lead-acid battery dates back to Gaston Plante's pioneering work in 1859, a creation marked by the utilization of heavy metal lead as the negative electrode, lead oxide as the positive plate, and sulfuric acid as the electrolyte. These fundamental components intertwine to orchestrate the intricate dance of charging and discharging, forming the core mechanism of this battery technology [10]

The lead-acid battery's acclaim rests on a spectrum of advantages. Its foundation in well-established technology has enabled mass production on a grand scale. This, coupled with the cost-effectiveness of its raw materials, translates into economic feasibility and low production expenses. However, the landscape of lead-acid batteries is nuanced, encompassing certain limitations. Most notably, their substantial size and weight impose challenges, contributing to heightened weight and energy consumption in electric vehicles [11]. Furthermore, the batteries exhibit a finite operational lifespan and raise concerns about environmental pollution.

Paradoxically, despite these drawbacks, the lead-acid battery steadfastly holds its ground in the market. China, in particular, has witnessed its enduring presence, as the technology commands a substantial market share. Many vehicle manufacturers in the country continue to adopt lead-acid batteries, signifying both the adaptability of this technology and its compatibility with specific applications.

The lead-acid battery's journey through time encompasses both triumphs and tribulations. Its significance, entrenched in a history spanning over a century, is a testament to its resilience and adaptability. While challenges related to weight, limited lifespan, and environmental impact persist, the lead-acid battery's ongoing relevance showcases its niche utility and continued contribution, particularly in sectors where its attributes align with prevailing requirements as shown in Fig. 1.

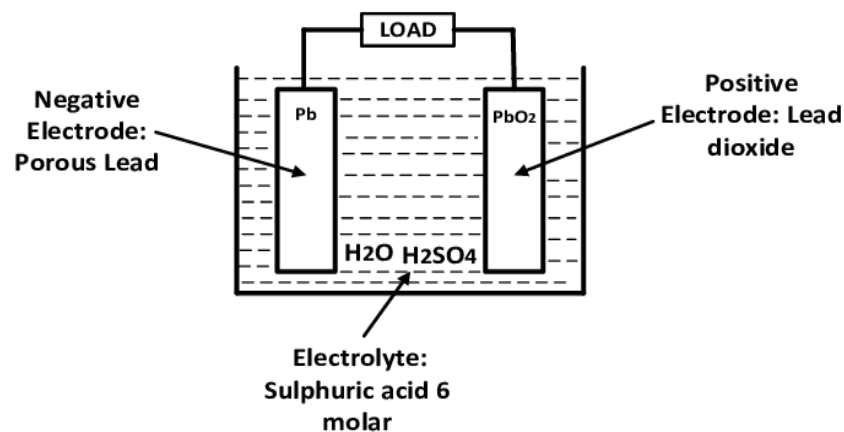


Figure 1: Lead acid battery

### B. Nickel Cadmium (NiCd) batteries

Nickel Cadmium (NiCd) batteries, often referred to as Ni-Cd batteries, are a rechargeable battery type utilizing nickel oxide hydroxide and metallic cadmium as their active components. With a history dating back to the early 20th century, they were among the earliest rechargeable batteries to gain widespread use. Their popularity was driven by attributes such as respectable energy density, reliable performance, and the ability to endure numerous charge-discharge cycles. Despite these advantages, NiCd batteries have gradually given way to newer battery technologies like nickel-metal hydride (NiMH) and lithium-ion (Li-ion) batteries.

Characterized by their durability, NiCd batteries are renowned for their capacity to endure numerous cycles of charging and discharging without substantial degradation, making them suitable for applications requiring frequent use. However, they suffer from the "memory effect," a drawback wherein incomplete discharges can result in reduced capacity due to the battery "remembering" previous charge levels. Modern NiCd batteries have mitigated this issue.

NiCd batteries excel in delivering high discharge currents, rendering them apt for scenarios necessitating bursts of power. Furthermore, they exhibit robust performance across a wide temperature spectrum, proving advantageous in both high-temperature and low-temperature environments.

Nevertheless, NiCd batteries face drawbacks, including environmental concerns. Containing cadmium, a toxic heavy metal, they pose risks to the environment and human health if not properly disposed of. This environmental impact led to restrictions on their usage in various applications.

Subsequently, NiMH batteries emerged as a more eco-friendly alternative, offering higher energy density and lacking toxic components. Furthermore, lithium-ion (Li-ion) batteries gained dominance due to their lightweight construction, higher energy density, and absence of memory effects.

While NiCd batteries are no longer prevalent in consumer electronics and various sectors, they maintain relevance in specific niches. Industrial applications, such as emergency lighting systems, leverage their durability, consistent power delivery, and temperature resilience. Despite this, their overall usage has diminished as advanced and more environmentally conscious battery technologies have risen to the forefront.

### C. Nickel Metal Hydride Batteries

Nimh batteries see limited use within China's electric vehicle market, but they are predominantly employed in hybrid cars to serve as auxiliary power sources. Categorized as alkaline batteries, nimh batteries have garnered recognition as "green energy" due to their strong safety profile and lack of environmental impact as shown in Fig. 2. These batteries exhibit high specific energy and specific density. In comparison with lead-acid batteries, nickel metal hydride (Ni-MH) batteries boast a threefold increase in volumetric energy density and a tenfold surge in power capability [12]. However, the progress of electric car battery technology centered on Ni-MH batteries faces certain constraints [13]. The cost and scarcity of nickel pose significant obstacles, hampering Ni-MH battery advancement. Additionally, the capacity of Ni-MH batteries diminishes under low temperatures [14].

Compared to lead-acid batteries, nickel metal hydride batteries have a greater energy storage capacity, but discharging them excessively can lead to permanent harm. Research on nimh batteries should prioritize addressing application-related issues. Enhancing the catalyst activity on the metal hydride electrode's surface holds promise for refining the rapid charging and discharging capabilities and overall capacity of nimh batteries. Addressing nimh battery concerns can be achieved through the use of appropriate additives, conductive adhesives, optimization of battery design, or other methods. Presently, nimh batteries remain the preferred power source for electric cars [15].

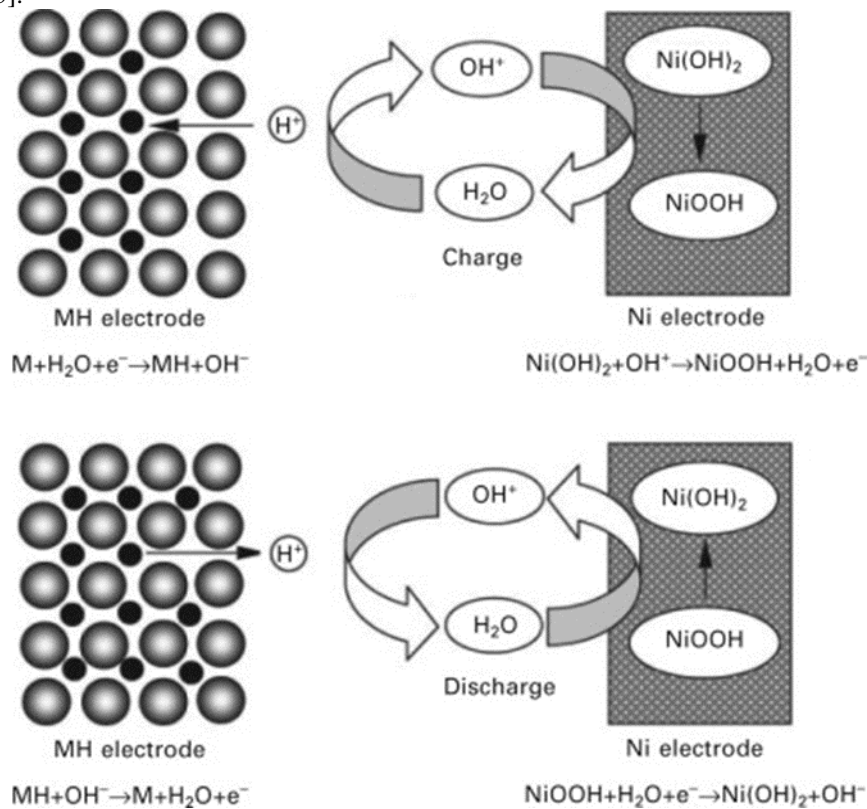


Figure 2: Nickel Metal Hydride battery overview

#### D. Lithium Ion Batteries

The traditional configuration of a lithium-ion battery involves a graphite anode, a lithium metal oxide cathode, and an electrolyte as shown in Fig. 3. This foundational arrangement forms the basis for a technology that has transformed portable energy storage. Lithium-ion batteries encompass two primary categories: lithium-ion batteries and lithium polymer batteries, each with distinct characteristics and applications. The cathode materials in lithium-ion batteries are diverse, with lithium cobalt oxide (LiCoO<sub>2</sub>), lithium nickel oxide (LiNiO<sub>2</sub>), lithium manganese oxide, and lithium iron phosphate (LiFePO<sub>4</sub>) among the key components. Correspondingly, the anode materials encompass graphite, lithium titanate, and other innovative materials.

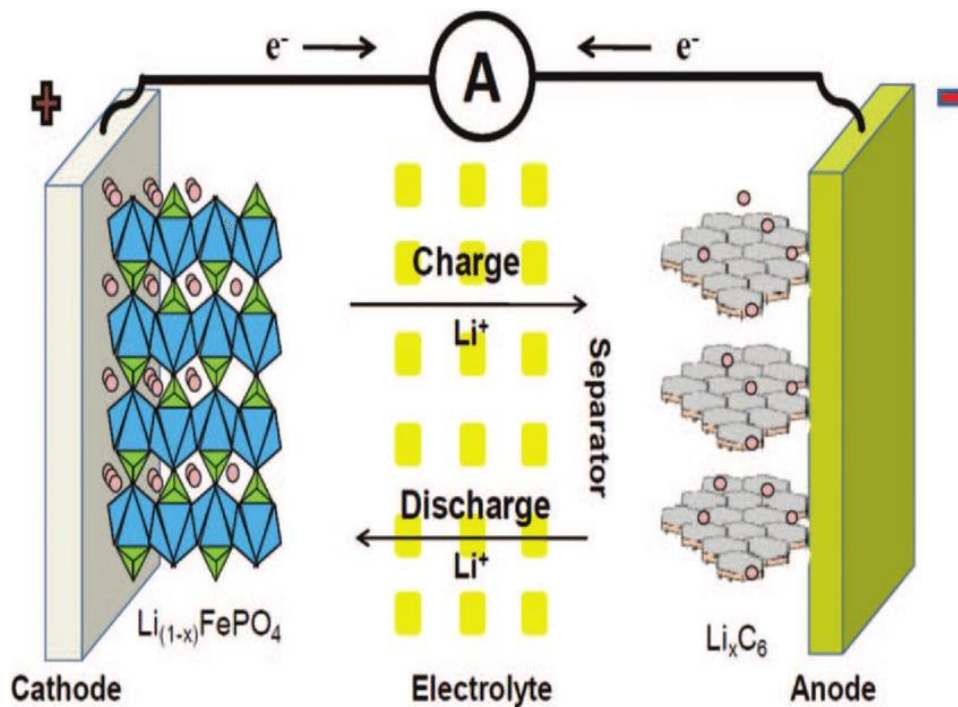
Table 1 encapsulates an insightful snapshot of the performance parameters associated with lithium-ion batteries in the context of electric vehicles [16,17]. This tabulation reveals a compelling comparative advantage over nickel metal hydride batteries. Lithium-ion batteries exhibit notably higher operating voltages and boast significantly larger specific energy capacities. Beyond these crucial attributes, lithium-ion batteries offer a diverse array of benefits. Their compact form factor, lightweight construction, prolonged cycle life, minimal self-discharge rate, impressive energy density, and potent power density collectively render them an indispensable technology. Additionally, the absence of memory effects and environmental pollutants further underscore their value proposition [18].

The ramifications of lithium-ion battery technology reverberate across multiple industries, particularly electric vehicles, where their attributes align seamlessly with the quest for efficiency and sustainability. The versatility of these batteries, evident through their categorization and their remarkable performance indicators, substantiates their pivotal role in modern energy storage. As the world seeks cleaner and more efficient modes of transportation, lithium-ion batteries are poised to continue shaping the landscape with their distinctive advantages, ushering in a new era of compact, powerful, and eco-friendly energy solutions. Table 1 gives the performance Index on Lithium Ion Battery in Electric Vehicles.

**Table 1: Performance Index on Lithium Ion Battery in Electric Vehicles**

| Battery     | Specific Energy (W·h/kg) | Volumetric Energy Density (W·h/l) | Specific Power (W/kg) | Cycle-index | Monomer Voltage/V |
|-------------|--------------------------|-----------------------------------|-----------------------|-------------|-------------------|
| NIMH        | 30~110                   | 140~490                           | 250~1200              | 500~1500    | 1.2               |
| Lithium-ion | 100~250                  | 250~360                           | 250~340               | 400~2000    | 3.7               |

There are still issues with lithium-ion batteries in electric cars. The pure electric car and hybrid electric vehicle need several batteries, making the system complex and requiring stringent safety, dependability, and consistency. Lithium ion batteries have safety, cycle life, cost, and temperature limits.



**Figure 3: Schematic of Lithium-ion battery**

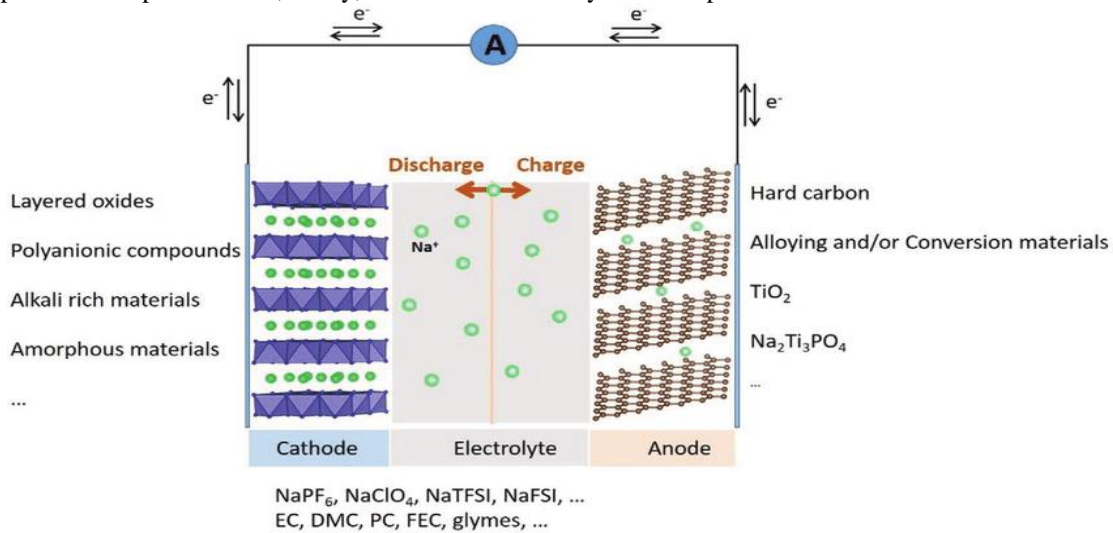
### E. Sodium Ion Batteries

Sodium-ion batteries are an emerging type of rechargeable battery technology that uses sodium ions ( $\text{Na}^+$ ) as the charge carriers instead of the more common lithium ions found in lithium-ion batteries as shown in Fig. 4. These batteries hold promise due to the abundance of sodium, which makes them potentially more cost-effective and environmentally friendly compared to lithium-ion batteries.

Sodium-ion batteries operate on a similar principle to lithium-ion batteries, involving the movement of ions between a cathode and an anode during charging and discharging cycles. The specific materials used in the cathode and anode can vary, but they are designed to facilitate the reversible insertion and extraction of sodium ions.

While sodium-ion batteries offer benefits in terms of resource availability and cost, they also face challenges. The larger size of sodium ions compared to lithium ions can affect the overall energy density and performance of the battery. Researchers are actively working to develop suitable electrode materials and improve the cycling stability of sodium-ion batteries to make them more competitive with existing battery technologies.

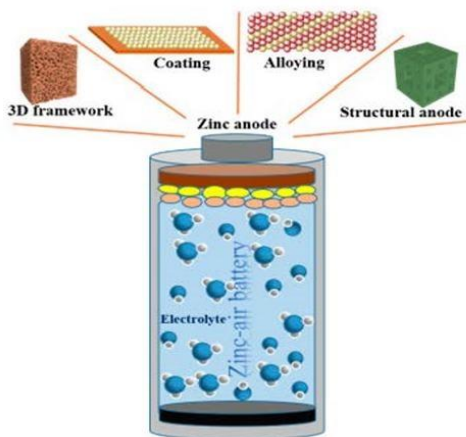
Sodium-ion batteries have potential applications in various fields, including energy storage for renewable sources, grid-level energy storage, and electric vehicles. However, further research and development are needed to optimize their performance, safety, and overall feasibility for widespread commercial use.



**Figure 4: Schematic of sodium-ion battery**

### F. Zinc-Air Batteries

Zinc-air batteries utilize atmospheric oxygen as a reactant in conjunction with zinc as fuel to produce electricity as shown in Fig. 5. This distinctive approach yields a battery type characterized by its remarkable energy density and lightweight nature. These attributes render zinc-air batteries particularly well-suited for applications requiring extended periods of power supply, including electric vehicles and grid-level energy storage solutions. However, the implementation of zinc-air batteries does come with its own set of challenges. Managing air exposure to ensure consistent performance and effective electrolyte management pose significant obstacles to the widespread adoption of this technology.



**Figure 5: Zinc air battery**

### G. Graphene Batteries

The advent of graphene batteries introduces an exciting dimension to energy storage. By incorporating graphene, an arrangement of carbon atoms forming a single layer, these batteries exhibit unparalleled electrical conductivity and heightened performance capabilities as shown in Fig. 6. Promising a combination of high energy density, rapid charging capabilities, and extended lifespan, graphene batteries have garnered substantial attention.

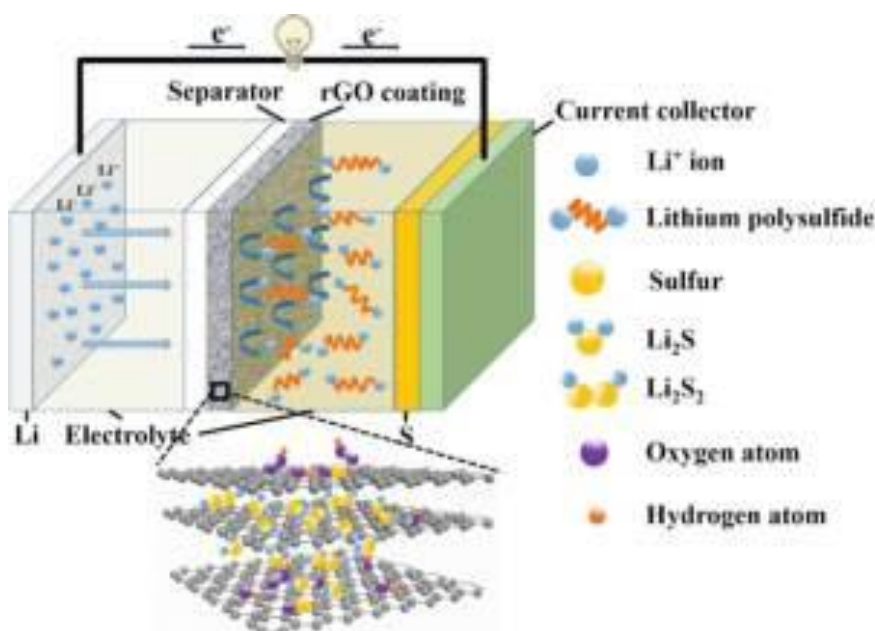


Figure 6: Graphene Batteries

Table 2: Various types of batteries and their properties

| Battery     | Cell type  | Voltage (V) | Gravimetric energy density (Wh/kg) | Volumetric energy density (Wh/L) |
|-------------|--|-------------|------------------------------------|----------------------------------|
| Lithium-ion | LiFePO <sub>4</sub> /graphite  | 3.3         | 80–150                             | 120–300                          |
|             | LiCoO <sub>2</sub> /graphite   | 3.7         | 160–210                            | 340–580                          |
|             | LiNi <sub>0.8</sub> Co <sub>0.15</sub> Al <sub>0.05</sub> O <sub>2</sub> /graphite | 3.7         | 150–300                            | 680–760                          |
|             | LiMn <sub>2</sub> O <sub>4</sub> /graphite   | 3.8         | 100–130                            | 220–400                          |
|             | LiNi <sub>1/3</sub> Mn <sub>1/3</sub> Co <sub>1/3</sub> O <sub>2</sub> /graphite   | 3.7         | 150–220                            | 580–750                          |
| Sodium-ion  | Na <sub>x</sub> V <sub>2</sub> (PO <sub>4</sub> )F <sub>y</sub> /hard carbon       | 3.4         | ~100                               | ~175                             |
|             | Na <sub>x</sub> TMO <sub>2</sub> /hard carbon                                      | 3.0         | ~115                               | ~250                             |
|             | Sodium sulfur (Na/S)   | 2.1         | 170                                | 345                              |
|             | Sodium nickel chloride   | 2.6         | 115                                | 190                              |
| Alkaline    | Alkaline zinc manganese dioxide (Zn/MnO <sub>2</sub> )                             | 1.5         | 145                                | 400                              |
|             | Alkaline nickel cadmium (NiCd)   | 1.3         | 35                                 | 100                              |
|             | Lithium iodine (Li/I <sub>2</sub> )  | 2.8         | 245                                | 900                              |
|             | Nickel metal hydride (NiMH)  | 1.3         | 75                                 | 240                              |
|             | Lead–acid (Pd/A)   | 2.1         | 35                                 | 70                               |

The incorporation of graphene's exceptional properties into battery systems enhances overall efficiency. Nevertheless, the journey towards commercializing graphene batteries is not without its difficulties. While graphene's potential is undeniable, issues surrounding production scalability and cost-effectiveness present substantial roadblocks that need to be surmounted to fully harness the transformative potential of this technology. Table 2 gives the different types of batteries and their properties.

### 3. Summary

Each of these battery types has its own advantages and limitations, making them suitable for specific applications. Ongoing research and development are aimed at improving their performance, safety, and cost-effectiveness for various uses, including electric vehicles, renewable energy storage, and portable electronics as shown in Fig. 7. Table 3 gives the various types of batteries and their properties.

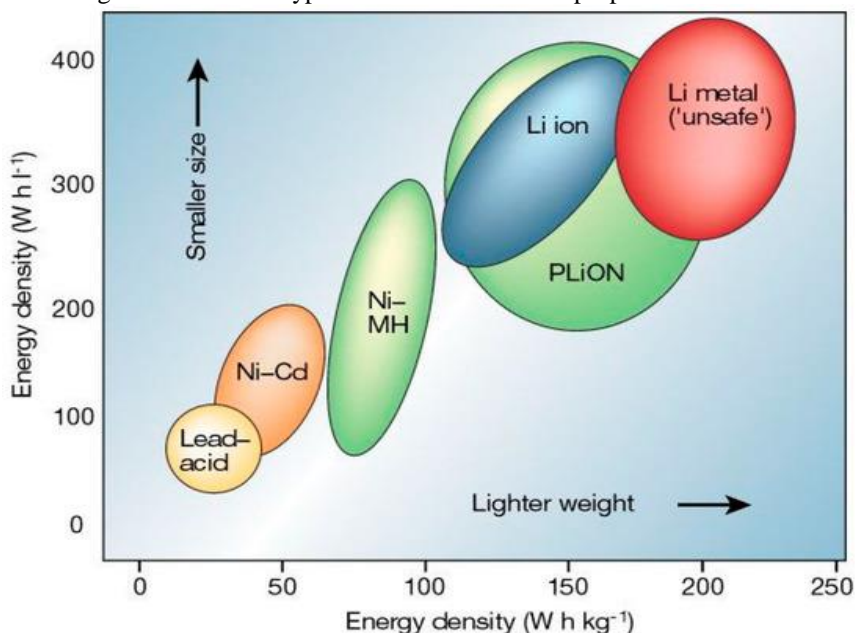


Figure 7: Battery technologies used in EVs

Table 3: Various types of batteries and their properties

| Battery Type     | Chemistry  | Energy Density                    | Weight            | Lifespan                      | Charge Time                 | Environmental Impact               | Common Use  |
|------------------|--|-----------------------------------|-------------------|-------------------------------|-----------------------------|------------------------------------|---|
| Lead-Acid        | Lead-acid  | Low                               | Heavy             | Limited                       | Moderate                    | Contains toxic materials           | Automotive starter batteries                            |
| Lithium-Ion      | Lithium-ion  | High                              | Light to moderate | Moderate to long              | Fast                        | Some concerns over resource mining | Mobile devices, laptops, EVs                            |
| NiMH             | Nickel-metal hydride                               | Moderate                          | Moderate          | Moderate                      | Moderate                    | Contains less toxic materials      | Hybrid vehicles, portable electronics                   |
| Sodium-Ion       | Sodium-ion   | Moderate (in development)         | Moderate          | Expected to be competitive    | Similar to lithium-ion      | Sodium is more abundant            | Emerging technology, grid storage                       |
| Zinc-Air         | Zinc-air   | High                              | Moderate          | Competitive                   | Similar to lithium-ion      | Zinc is abundant and less harmful  | Hearing aids, potentially EVs and grid storage          |
| Graphene Battery | Various, often lithium-ion with graphene additives | Potential for high energy density | Light             | Potential for longer lifespan | Potential for fast charging | Depends on underlying chemistry    | Emerging technology with various potential applications |

## CONCLUSION

In the realm of electric vehicles, the Lithium-Ion battery stands as the front-runner, embodying the ideal balance of key attributes. Its remarkable energy density ensures extended driving ranges, addressing the concern of range anxiety. Coupled with a relatively moderate weight, it contributes to overall vehicle efficiency. The moderate to long lifespan and rapid charging capabilities align seamlessly with the demands of modern mobility, promoting convenience and user satisfaction. While challenges related to resource mining and environmental impact persist, technological advancements are gradually mitigating these concerns. With its performance, adaptability, and continuous research into improving its characteristics, the Lithium-Ion battery asserts its dominance as the optimal choice, propelling electric vehicles into a more sustainable and promising future.

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