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ELECTROCHEMICAL RECHARGEABLE BATTERY TECHNOLOGIES: A COMPARATIVE STATE-OF-THE-ART REVIEW

Ciprian POPA[1] & Andrei-Darius DELIU[2*]

[1]Romanian Naval Academy "Mircea cel Bătrân", Faculty of Marine Engineering, 1 Fulgerului Street, 900218, Constanța, Romania, ORCID ID 0009-0001-8630-7729, e-mail address: ciprian.popa@anmb.ro
[2*]National University of Science and Technology Politehnica Bucharest, Faculty of Electrical Engineering, 313 Splaiul Independentei Street, 060042, Bucharest, Romania, corresponding e-mail address: andrei_darius.deliu@stud.electro.upb.ro

Abstract: Electrical energy storage plays a critical role in modern industrial, transport, and power-system applications, particularly in the context of renewable-energy integration and grid-support services. Among available storage technologies, electrochemical batteries are especially important because they enable reversible conversion between electrical and chemical energy and provide a practical solution for a wide range of operating requirements. This paper presents a comparative technical analysis of the main rechargeable battery technologies, with emphasis on their electrochemical structure, operating principles, and application-related performance. The study examines the fundamental characteristics of electrochemical cells and battery packs, including nominal voltage, capacity, energy rating, and series-parallel configuration. It then reviews the main rechargeable chemistries currently used in practice, namely lead-acid, nickel-cadmium, nickel-metal hydride, lithium-ion, lithium-polymer, and sodium-based batteries. The analysis highlights the principal advantages and limitations of each technology in terms of energy density, cycle life, charging behaviour, safety constraints, environmental impact, and engineering applicability. The results indicate that no single battery chemistry is universally optimal, and that technology selection must be based on application-specific trade-offs involving cost, performance, durability, safety, and system-integration requirements.

Key words: Electrochemical energy storage, energy density, lead-acid batteries, lithium-ion batteries, nickel-based batteries, rechargeable batteries.

1. INTRODUCTION

Electrical energy is highly practical for generation, transmission, and end-use, yet it remains inherently difficult to stockpile at grid scale. In practice, the overwhelming share of electricity produced by utility plants is delivered and consumed almost instantaneously. Even so, a range of technologies can store energy at smaller scales by converting it into other domains-most commonly electrical, mechanical, chemical, or magnetic forms. These options are often compared using metrics such as energy density and typical discharge duration [1], [2], [3], [4], [5].

Among storage solutions, electrochemical batteries are widely employed in both consumer devices and industrial installations because they enable reversible conversion between electrical and chemical energy. The conversion efficiency for each direction (electrical → chemical or chemical → electrical) is typically on the order of ~ 85%, although this value depends on the specific chemistry and operating conditions. Electrochemical batteries are generally classified into two main categories [1], [5], [6], [7], [8], [9]:

1. Primary batteries (non-rechargeable). In these devices, electricity is produced through an electrochemical reaction that proceeds essentially in one direction. Once the active materials are depleted and the cell reaches end-of-discharge, the battery is not restored and is normally discarded. Primary cells are attractive where high energy density, both gravimetric (Wh/kg) and volumetric (Wh/L), is required for single-use applications.
2. Secondary batteries (rechargeable). Secondary cells operate via reactions that are largely reversible. After a battery has been discharged, it can be charged again by applying direct current from an external power source, which reverses the electrochemical reaction and stores energy in chemical form. When the battery is used again, this process goes in the opposite direction, converting the stored chemical energy back into electrical energy. Since some of the energy is lost as heat during both charging and

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discharging, the overall round-trip efficiency depends on the efficiency of each step. In practice, with each process typically operating at around 85% efficiency, the total round-trip efficiency is usually in the range of 70–75%, depending on the battery chemistry involved [5].

At the transmission and distribution level, utility-scale batteries support a broader set of grid services, including buffering variable output from wind and photovoltaic plants, enabling smart-grid functionalities and resilient communications/cyber-secure operation, strengthening system adequacy and dynamic stability to mitigate voltage instability and large-scale outages, enhancing power quality for both utility networks and downstream consumers, and contributing to decarbonization-oriented programs by lowering emissions, improving overall energy efficiency, and delivering co-benefits for environmental performance [1], [2], [3], [5].

Table 1. Overview of selected electrical, mechanical and magnetic energy-storage options [5]

Storage option	Dominant stored-energy domain	Typical discharge / storage timescale in applications	Qualitative specific energy $kWh \cdot kg^{-1}$
Electrostatic capacitor	Electric field	sub-second (millise-conds to seconds)	low
Inductive storage (coil)	Magnetic field	sub-second (millise-conds to seconds)	medium
Electrochemi-cal battery	Chemical (electro-chemical)	long-duration (days to months)	medium
Flywheel system	Mechani-cal (rotational kinetic)	long-duration (days to months)	high
SMES (superconduct-ting magnetic energy storage)	Magnetic field	long-duration (days to months)	very high

A representative electrochemical cell, whether primary or rechargeable, consists of a positive and a negative electrode, electrically isolated by a separator, and an electrolyte that provides ionic conduction between the electrodes. The electrode assemblies are interfaced with external terminals integrated into the cell casing. Depending on the chemistry, a single cell typically operates at a low nominal potential, commonly in the range of ~1.2 to 3.6 V [5], [10], [11], [12].

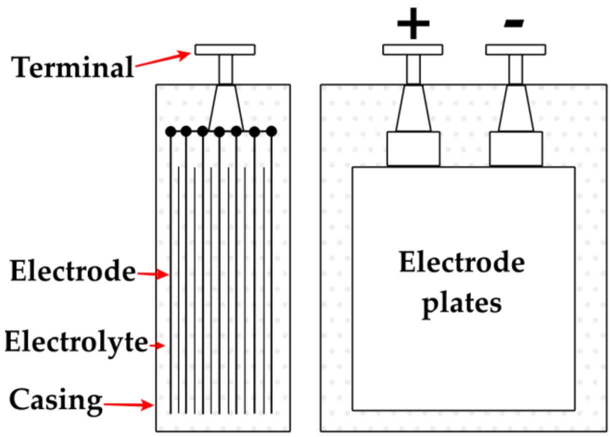

Figure 1 Architecture of the electrochemical cell

The charge storage capability of a cell is expressed as its capacity, *C*, usually reported in ampere-hours (Ah). Since 1A = Cs^{-1}, it follows that 1Ah = 3600C of transferable charge. Accordingly, a cell with capacity *C* can ideally supply *C* amperes for 1 hour, or equivalently C/n amperes for n hours, under a constant-current discharge assumption. In first approximation, Ah capacity scales with the effective electrode area (and associated active material utilization), whereas the cell voltage is primarily chemistry-determined and is not governed by electrode area [5].

A battery pack is formed by interconnecting multiple cells in series and/or parallel to meet required voltage and current levels. Increasing the pack voltage is achieved by adding cells in series, while increasing deliverable current (and capacity) requires additional cells in parallel. Practical battery ratings are commonly specified using the average discharge voltage and the Ah capacity available until the terminal voltage reaches a defined cutoff. The corresponding energy capability is typically expressed in watt-hours (Wh), obtained as the product of the representative voltage and the Ah rating, representing the energy that can be delivered to a load from a fully charged state under the specified conditions [5], [9], [13], [14], [15].

2. MAIN TYPES OF RECHARGEABLE BATTERIES

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Rechargeable battery technologies currently represent a well-established component of both industrial infrastructure and consumer electronics. In parallel, advanced electrochemical storage systems are being continuously improved to satisfy the requirements of a broad spectrum of applications, such as electric mobility, spacecraft systems, utility-scale load balancing, and renewable energy conversion systems, particularly those based on wind and solar resources, which are characterized by fluctuating power generation. The most widely recognized rechargeable battery chemistries are as follows [5], [9], [16], [17], [18]:

- Lead-acid (Pb-acid)
- Nickel-cadmium (NiCd)
- Nickel-metal hydride (NiMH)
- Lithium-ion (Li-ion)
- Lithium-polymer (Li-poly)
- Sodium battery

Table 2. Representative discharge cell voltages of common rechargeable battery chemistries [5]

Battery chemistry	Representative applications	Nominal discharge voltage (V)	Key observa-tions
Lead-acid	Commonly employed in industrial systems, road vehicles, and marine applications	2.0	Conside-red one of the most economi-cal battery technolo-gies
Nickel-cadmium (NiCd)	Frequently used in portable power equipment	1.2	May be affected by the memory effect during repeated cycling
Nickel-metal hydride (NiMH)	Widely applied in automotive systems	1.2	Perfor-mance can be influenced by temperatu-re variations
Lithium-ion (Li-ion)	Typically used in laptops, mobile phones, and aerospace equipment	3.6	Regarded as safe under normal operation and does not contain metallic lithium
Lithium-polymer (Li-polymer)	Common in computers, mobile devices, and spacecraft-related applications	3.0	Includes metallic lithium in its construc-tion

The average discharge voltage varies according to the type of electrochemical system, as indicated in Table 2. In addition, Figure 2 presents a comparison of the energy densities of different battery technologies in terms of both specific energy (Wh/kg) and volumetric energy density (Wh/L). The selection of a suitable battery chemistry for a particular application depends on the optimization of performance, physical dimensions, and cost. The principal structural and functional characteristics of these electrochemical systems are examined in the subsequent discussion [5].

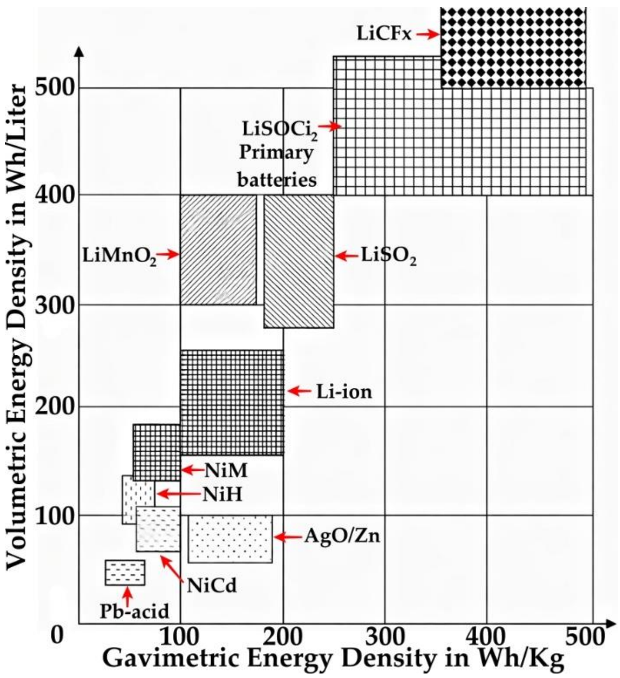

Figure 2 A comparative study on the energy density of different cell technologies [5]

2.1 Lead-acid

Rechargeable lead-acid batteries remain among the most extensively used electrochemical storage systems due to their technological maturity and favorable cost-to-

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performance ratio [19], despite their relatively low gravimetric and volumetric energy density. During discharge, the electrochemical reactions lead to the formation of water and lead sulfate, which results in dilution of the sulfuric acid electrolyte and a corresponding decrease in electrolyte specific gravity as the state of charge declines. When the battery is recharged, these reactions proceed in the opposite direction, regenerating metallic lead at the negative electrode and lead dioxide at the positive electrode, thereby restoring the cell to its charged condition [5], [20], [21].

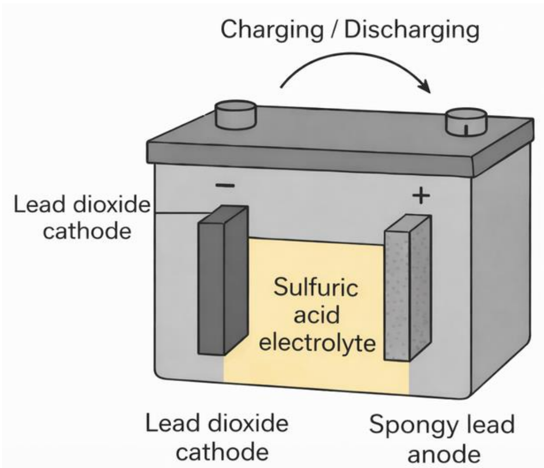

Figure 3 Lead-acid batteries [9]

Lead-acid batteries are manufactured in several configurations designed for different operating requirements. Shallow-cycle types are primarily intended for applications such as automotive and marine engine starting, where the battery must deliver a high current pulse over a short period. By contrast, deep-cycle designs are better suited to repeated charge-discharge operation and are therefore preferred in most energy storage installations. Another important variant is the sealed gel-cell battery, in which additives convert the electrolyte into a gelled, non-spillable medium. Owing to this construction, such batteries can be installed in inclined or inverted positions. However, their comparatively higher cost has restricted their broader use in specialized fields such as military avionics [5], [9], [20], [21], [22].

Table 3. Technical benefits and limitations associated with lead-acid battery technology [23]

Technical advantages
• Economical production due to mature and comparatively simple manufacturing processes • Reduced cost per unit of stored energy • High specific power and strong capability for delivering elevated discharge currents • Stable operation across a broad temperature range, including both low- and high-temperature conditions • In many conventional configurations, complex cell-level or block-level battery management systems are not essential
Technical limitations
• Low specific energy, resulting in limited gravimetric energy performance • Long recharge duration; full charging typically requires extended time intervals • Requirement for storage in a charged state in order to minimize sulfation effects • Restricted cycle life, particularly under repeated deep-discharge operation • Periodic water replenishment is necessary in flooded lead-acid designs • Transport and handling constraints are more significant for flooded battery configurations • Environmental concerns related to lead content and disposal requirements

2.2 *Nickel-cadmium (NiCd)*

Nickel-cadmium (NiCd) batteries represent a well-established rechargeable battery technology. In this system, nickel hydroxide functions as the positive active material, while cadmium serves as the negative electrode material. The electrodes are typically isolated by polymer-based separators and immersed in an alkaline electrolyte, commonly potassium hydroxide, within a metallic enclosure. Owing to their sealed construction and lower mass relative to conventional lead-acid systems, NiCd batteries were historically adopted in a wide range of portable rechargeable consumer devices [5], [9].

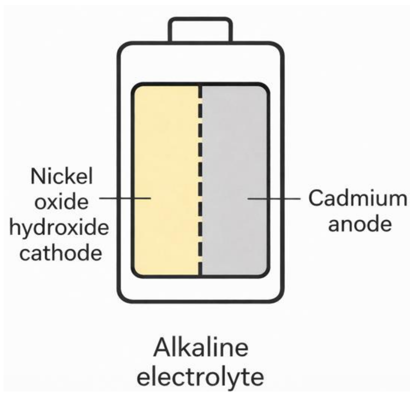

Figure 4 Nickel-cadmium (NiCd) batteries [9]

Compared with lead-acid batteries, NiCd systems generally provide superior tolerance to temperature variation and a longer service life under deep cycling conditions. Nevertheless, their application has declined because of two major limitations. First, they are susceptible to the memory effect, which can reduce the available capacity under certain operating conditions.

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Second, the toxic nature of cadmium has led to increasing environmental and regulatory concerns. As a result, NiCd technology has gradually been displaced in laptop computers and other high-value portable electronic products by nickel-metal hydride and lithium-ion batteries [5].

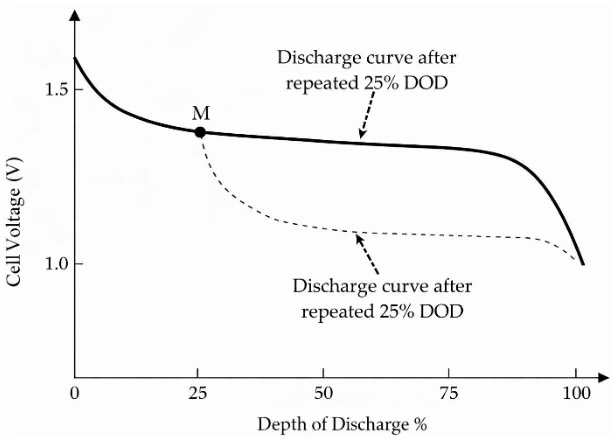

Figure 5 The Memory Effect in Nickel-Cadmium (NiCd) battery [5]

NiCd batteries are known to exhibit a so-called memory effect, meaning that their electrochemical behavior may adapt to a repeatedly imposed charge-discharge regime. When the battery is cycled many times over only a limited portion of its total capacity, for example up to approximately 25% of full discharge, it tends to retain that operating range as a reference condition. If the cell is later discharged beyond this previously repeated limit, the terminal voltage may decline sharply below its normal profile, creating the impression that the battery has lost part of its usable capacity [5].

This behavior can be interpreted as a temporary reduction in accessible energy caused by long-term shallow cycling. Recovery of the original capacity can often be achieved through a reconditioning procedure, sometimes referred to as battery exercising. In practice, this involves occasionally discharging the cell to a very low voltage level and then recharging it completely to its nominal full-charge voltage. The memory effect is generally considered characteristic of NiCd batteries, whereas most other rechargeable battery chemistries do not display this phenomenon to the same extent [5].

Table 4. Principal technical merits and limitations of nickel-cadmium battery technology [23]

Technical merits
• High structural and electrochemical robustness, with the ability to sustain a large number of charge-discharge cycles when maintained appropriately • Capability to accept very high charging rates with comparatively low degradation stress • Strong tolerance to demanding load conditions and relatively stable behavior under misuse or non-ideal operation • Long storage life; cells may remain in a discharged state and be restored to operation after suitable conditioning • Straightforward storage and transport requirements in comparison with some other battery systems • Reliable low-temperature performance, making the technology suitable for cold-environment operation • Favorable economic performance in terms of cost per cycle over the service lifetime • Availability in a broad spectrum of cell formats, capacities, and performance categories
Technical limitations
• Lower specific energy than more recent rechargeable battery technologies, which reduces suitability for weight- and volume-constrained systems • Pronounced memory effect, which may require periodic deep discharge or reconditioning to recover usable capacity • Use of cadmium, a hazardous toxic metal, creates significant environmental and disposal constraints • Elevated self-discharge rate, leading to noticeable energy loss during storage and the need for recharging before use • Low nominal cell voltage, approximately 1.20 V, necessitates the connection of numerous cells in series to obtain higher pack voltages

2.3 Nickel-Metal Hydride Batteries

Nickel-metal hydride (NiMH) batteries were developed as an advanced alternative to nickel-cadmium (NiCd) systems, with the primary objective of improving energy storage capability while reducing the environmental drawbacks associated with cadmium-based electrodes. From an electrochemical standpoint, NiMH technology preserves several operating principles of NiCd batteries, but replaces the cadmium-containing negative electrode with a hydrogen-absorbing metal alloy. This design modification not only mitigates toxicity-related concerns, but also contributes to a higher specific energy and a less pronounced memory effect during repeated cycling [5], [9].

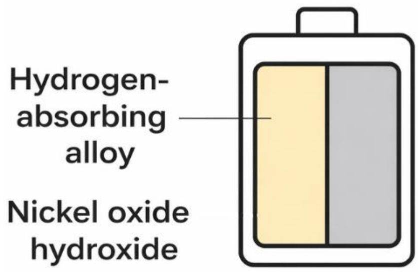

Figure 6 Nickel-metal hydride (NiMH) batteries [9]

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One of the principal advantages of NiMH batteries is their improved energy density compared with NiCd cells, which makes them more suitable for applications where mass and volume are important design constraints. In addition, the reduced memory effect enhances their practical usability under partial charge-discharge operation. For these reasons, NiMH batteries were widely adopted in portable electronics, hybrid vehicles, and various industrial devices, particularly during the period preceding the large-scale dominance of lithium-ion technology [5].

Despite these advantages, NiMH systems also exhibit several technical limitations. Their peak power capability is generally lower than that of comparable NiCd batteries, which can restrict their use in applications requiring very high transient current delivery. Moreover, NiMH batteries typically present a relatively high self-discharge rate, leading to progressive capacity loss during storage when compared with more advanced lithium-based systems. Another important drawback is their sensitivity to overcharging, since excessive charging may accelerate degradation processes, increase internal temperature, and shorten service life if charge management is not properly controlled [5].

NiMH batteries have been used in automotive, industrial, and consumer electronics because they offer a practical balance between cost, safety, and performance. However, as lithium-ion technology has become more advanced, offering higher energy density, lower self-discharge, and better overall performance in demanding applications, NiMH batteries have gradually become less important in both the market and research. Even so, they still remain a suitable choice in certain applications where reliability, reasonable cost, and well-established manufacturing processes are valued more than achieving the highest possible energy density [5].

Table 5. Main engineering advantages and limitations of nickel-metal hydride battery technology [23]

Technical advantages
• Higher energy density than several conventional rechargeable chemistries, enabling either extended operating duration or reduced battery-pack volume for a given energy requirement • Elimination of cadmium-related manufacturing, handling, and end-of-life constraints, thereby improving environmental acceptability and regulatory compliance • Easier substitution in systems originally designed for nickel-cadmium cells because of the substantial design and functional similarities between the two technologies • Favorable operational capability in low-temperature environments, including applications around subzero conditions

Technical limitations
• Restricted cycle durability under repeated deep-discharge operation, particularly at elevated current demand; performance degradation becomes more pronounced under severe cycling conditions • Sensitivity to high-rate discharge; although capable of supplying substantial current, frequent operation under heavy load accelerates aging and shortens service life • Greater charging complexity, as NiMH cells generate more heat during charging and generally require more controlled charging protocols than NiCd systems • Increased self-discharge during storage relative to NiCd batteries, resulting in more rapid capacity loss when the battery is not in use • Trickle-charge management is more critical, since improper charge maintenance can promote thermal stress and long-term degradation • Chemical modifications introduced to reduce self-discharge may improve storage retention, but can also be associated with compromises in energy density

The electrochemistry of the nickel–metal hydride (NiMH) battery is based on [9]:

- Positive electrode: The cathodic active material is commonly nickel oxyhydroxide (NiOOH).
- Negative electrode: The anodic side is generally based on a metal alloy capable of reversibly absorbing hydrogen, usually denoted MH.
- Electrolyte: Ionic transport takes place through an aqueous potassium hydroxide (KOH) solution.

2.4 Lithium-Ion battery technology

Lithium-ion technology constitutes a relatively recent but highly influential development in the field of rechargeable batteries. Its widespread adoption is mainly due to its high specific and volumetric energy density, which markedly exceeds that of lead-acid systems. This performance benefit arises in large part from the low atomic mass of lithium and from the comparatively high nominal voltage of Li-ion cells. Because each cell provides a higher voltage than lead-acid, NiCd, or NiMH cells, fewer units are required in series to reach a prescribed battery voltage, thereby reducing pack complexity and potentially lowering assembly-related costs [5], [9], [24].

Despite these advantages, Li-ion batteries are associated with important electrochemical and safety constraints. Interfacial reactions between the electrode surfaces and the electrolyte lead to the formation of passivation layers that influence long-term cycling behavior. In addition, these batteries are particularly vulnerable to overcharge, overheating, and other battery-management deficiencies. Consequently, Li-ion systems

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require sophisticated charging strategies and integrated protection electronics to ensure safe and reliable operation [5], [24], [25].

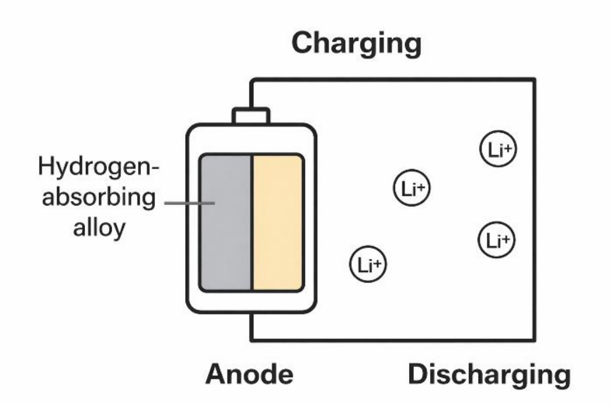

Figure 7 Lithium-Ion batteries [9]

In electric-vehicle applications, Li-ion batteries must simultaneously satisfy high power demand, sufficient energy storage capacity, long cycle life, and acceptable cost. Their high energy and power density make them attractive for such uses, but also intensify thermal management requirements because substantial heat may be generated within a compact volume. Although early large-scale Li-ion battery systems were characterized by high cost, ongoing technological progress has been directed toward improving durability, safety, and affordability [5], [24], [25].

Table 6. Principal engineering advantages and limitations of lithium-ion battery technology [23]

Technical advantages
• High specific energy combined with strong power-delivery capability, particularly in power-oriented cell configurations • Extended cycle life and favorable calendar life under properly controlled operating conditions, with minimal routine maintenance requirements • High usable capacity, low internal impedance, and efficient charge transfer reflected in favorable Coulombic efficiency • Relatively straightforward charging strategy compared with some alternative advanced chemistries, together with comparatively short charge duration
Technical limitations
• Requirement for dedicated protection electronics to prevent hazardous operating conditions, including thermal runaway under electrical or thermal abuse • Accelerated degradation at elevated temperature and under prolonged storage at high state of charge or high terminal voltage • Rapid charging is severely constrained or impractical at subzero temperatures due to increased risk of lithium plating and performance deterioration • Large-scale transport and distribution are subject to strict safety and regulatory requirements, particularly for high-energy shipments

The selection of the cathode material plays a decisive role in determining battery performance, giving rise to multiple Li-ion chemistries, each tailored to particular application requirements [9], [22]:

- Anode: In most lithium-ion cells, the negative electrode is commonly based on graphite, often represented as LiC_6.
- Cathode: The positive electrode is generally composed of a lithium-containing metal oxide, such as $LiCoO_2$, $LiFePO_4$, or NMC-type materials.
- Electrolyte: Ionic conduction is ensured by a lithium salt, for example $LiPF_6$, dissolved in an organic solvent medium.
- Separator: The two electrodes are kept apart by a microporous polymer separator that prevents electrical contact while allowing ion transport.
- Lithium ions: During discharge, Li^+ ions migrate from the anode toward the cathode.

2.5 *Lithium-Polymer batteries*

Lithium-polymer (Li-polymer) batteries constitute a variant of lithium-based electrochemical storage systems in which the electrolyte is incorporated into a polymer matrix rather than being present exclusively as a conventional free-flowing liquid. In this configuration, the polymer medium performs a dual function by enabling ionic transport while also acting as a separator between the electrodes. This structural approach permits the development of compact and lightweight cells with improved packaging flexibility, which is one of the principal reasons for the growing interest in this technology [5].

From a construction standpoint, lithium-polymer cells are generally based on layered architectures in which lithium-containing active materials are combined with thin polymer electrolyte films. The use of a solid or gel-like polymer electrolyte can contribute to an increase in specific energy because the electrolyte and separator functions are integrated into a single component, thereby reducing inactive material within the cell. In addition, the replacement of a fully liquid electrolyte with a polymer-based medium may reduce leakage risk and improve mechanical adaptability, especially in applications where thin, lightweight, or custom-shaped battery formats are required [5], [26].

Another important advantage of lithium-polymer technology is related to interfacial stability. Compared with traditional liquid-electrolyte systems, the interaction between lithium and a polymer-based electrolyte may be less aggressive under controlled operating conditions, which can be beneficial for reducing certain parasitic reactions and improving safety characteristics. However, the practical performance of these batteries strongly depends on electrolyte formulation, ionic conductivity, temperature, and cell design. As with other lithium-based systems, careful control of charging conditions and thermal behavior remains essential to ensure reliability and long-term durability [5], [27].

Lithium-polymer batteries have attracted considerable attention in transportation and portable electronics because of their high energy density and design versatility. In electric-vehicle applications, their low mass and potential for efficient space utilization make them particularly attractive for extending driving range compared with heavier conventional battery technologies. The ability to manufacture cells in thin and flexible geometries also supports their use in compact electronic devices, aerospace subsystems, and other applications where strict mass and volume constraints apply [5].

Despite these advantages, lithium-polymer technology also presents several engineering challenges. The ionic conductivity of solid or polymer-rich electrolytes may be lower than that of liquid electrolytes, particularly at reduced temperatures, which can limit rate capability and overall power performance. In addition, production cost, material stability, and long-term cycling behavior remain critical considerations for large-scale deployment. For these reasons, current research continues to focus on improving polymer electrolyte conductivity, interfacial compatibility, thermal stability, and manufacturing scalability [5].

Overall, lithium-polymer batteries are regarded as a promising direction in advanced electrochemical energy storage, particularly where a combination of high specific energy, reduced weight, and geometric flexibility is required. Their future development is closely linked to progress in solid-state and hybrid polymer-electrolyte systems, which may further enhance both safety and performance in next-generation battery applications [5].

2.6 Sodium battery technology

Sodium-based batteries are among the most recent electrochemical storage technologies to enter advanced energy markets. They have been developed primarily for applications in which high power capability, operational durability, and suitability for large-scale energy storage are required. In particular, sodium-metal halide systems have demonstrated relevance for hybrid rail transport, heavy-duty vehicles, and stationary backup storage associated with renewable energy installations [5].

This electrochemical technology is especially appropriate for operating regimes that combine short bursts of high power with the need for sustained energy delivery over longer periods. Such characteristics are advantageous in transportation systems requiring strong starting or traction support, as well as in wind and solar power installations where storage is needed to improve continuity and operational stability. Although sodium-based batteries may involve higher system complexity in certain designs, they remain a promising option for high-capacity applications due to the abundance of sodium resources and their potential cost advantages [5].

4. CONCLUSIONS

This study shows that electrochemical batteries continue to be among the most important energy-storage solutions for modern industrial, transport, and power-system applications, mainly because they can efficiently convert electrical energy into chemical energy and back again. The analysis also confirms that battery performance depends on several key factors, including cell chemistry, nominal voltage, capacity, energy density, cycle life, and operating safety constraints. In addition, the design of the battery pack plays a major role in determining the final voltage, current, and energy capability of the system.

The comparison highlights that lead-acid batteries are still a practical option for low-cost and high-power applications, even though they have relatively low energy density and limited durability under deep cycling. NiCd batteries offer strong robustness and fast-charging capability, but their use is limited by the memory effect and the environmental concerns associated with cadmium. NiMH batteries provide a better balance between energy density and environmental acceptability, although they are affected by self-discharge and charging-related thermal issues. Among all the technologies reviewed, lithium-ion batteries currently offer the best overall combination of energy density, voltage level, and flexibility of use, although they require advanced protection and thermal-management systems. Lithium-polymer and sodium-based batteries also appear to be promising solutions, especially for lightweight designs and large-scale energy-storage applications.

Overall, the study makes it clear that no rechargeable battery technology is ideal for every application. Each chemistry has its own strengths, limitations, and areas of suitability. For this reason, the choice of a battery system must always be based on the specific requirements of the intended application, whether the priority is low cost, high energy density, high power capability, long service life, environmental compatibility, or grid support. Future progress in electrochemical energy storage will depend on continued advances in active materials, electrolyte systems, thermal management, battery-pack engineering, and intelligent control methods, with strong emphasis on safety, sustainability, and long-term performance.

5. FUNDING

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