

Electric Vehicle Batteries: A Scoping Review Assessing Their Compositions, Specifications, and Characteristics

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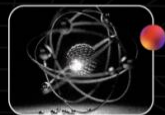
Abstract: This article presents an investigative analysis of the chemical compositions of batteries used in hybrid and electric vehicles, focusing on their technical characteristics, commercial applications, and environmental implications. The motivation stems from global decarbonization goals and the energy transition, which drive the development and adoption of electrified vehicles. The study highlights different battery chemistries, such as LFP (Lithium Iron Phosphate), NMC (Nickel Manganese Cobalt), LCO (Lithium Cobalt Oxide), and emerging technologies such as lithium-oxygen batteries. The methodology adopted is a Scoping Review, structured in accordance with the PRISMA-ScR guidelines, including steps such as defining the research question, review objectives, search protocol, study selection, and analysis. Searches were conducted in well-established databases such as Science Direct, Scopus, and Scielo, using descriptors related to high-voltage battery composition. The initial analysis revealed the predominance of lithium-ion-based chemistries, despite challenges such as capacity degradation over time and environmental limitations. The article also discusses the importance of end-of-life battery management, emphasizing the potential for reuse in stationary energy storage systems and the associated challenges.

1. Introduction

In recent decades, agreements and targets established by public agencies have been strongly directed toward reducing emissions and mitigating the depletion of the ozone layer [1]. Incentives for both the population and industry regarding electric vehicles—aimed at fleet electrification targets and the energy transition—have emerged as a potential contribution to achieving decarbonization goals [2]. Some examples of the most common chemistries include Lithium Iron Phosphate (LFP), known for its safety and longer lifespan, and Nickel Manganese Cobalt (NMC), which provides better energy storage capacity and is generally lighter [3].

Batteries can be manufactured with different proportions of active materials, resulting in

distinct performance and properties. For instance, NMC532 and NMC811 differ in the percentage of each component, as indicated by the numbers at the end [3]. However, other chemistries are being studied and evaluated for commercial application, such as Sodium-Ion batteries [4]. Another promising model under development is the Potassium-Ion Battery (KIB), which stands out for its favorable cost-benefit ratio and the abundance of potassium reserves [5]. Nevertheless, electrified vehicles still represent a small share of the market, facing certain challenges and resistance [6], stemming from factors such as high purchase costs and consumer concerns about driving range between charging cycles, as well as the options available when these batteries reach the end of their life cycle and lose functionality [7].



From this perspective, waste management has been increasingly emphasized in research [8]. Such studies can guide the development of processes, investments, and expansion plans for recycling infrastructure and the reuse of components by industries and automakers.

A critical review by Sharma, Sharma, and Mishra evaluated recent progress in lithium-ion batteries, highlighting challenges, applications, and future prospects. The authors address aspects such as safety, energy efficiency, cost, and environmental impact, in addition to discussing the technological innovations required to overcome these limitations. The research points to the need for developing new battery chemistries and more efficient recycling technologies to support the energy transition toward a circular economy [9]. The reuse of batteries in stationary applications, such as Energy Storage Systems (ESS), has been considered one of the most promising strategies within the circularity framework. However, this approach presents significant operational and technical challenges. From the refurbisher's perspective, the lack of standardized battery systems, the absence of standardized operational histories, and difficulties in assessing the State of Health (SoH) are substantial barriers [10].

The high heterogeneity in battery composition limits efficiency in component recovery processes. Furthermore, the economic viability of second-life applications depends heavily on the cost-benefit ratio compared to new storage technologies [10].

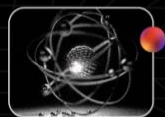
Conventional recycling processes are energy-intensive and lack efficiency in recovering high-purity metals [11]. Therefore, it is imperative to invest in hydrometallurgical and direct processes that offer lower environmental impacts and higher selective recovery of metals.

Without effective recycling policies and technologies adapted to handle complex waste, the energy transition could compromise the security of resource supply [11]. In this context, this study aims to analyze the composition of high-voltage automotive batteries currently available on the market, along with future trends and technologies. Based on specific parameters, the most suitable composition for each application can be determined, indicating the most efficient configuration while accommodating various consumer needs.

Additionally, the study examines proposals and alternatives for the proper disposal or reuse of these batteries after their service life, such as cell reuse or battery refurbishment [12], thereby ensuring appropriate destination of components and preventing potential harm to people and the environment.

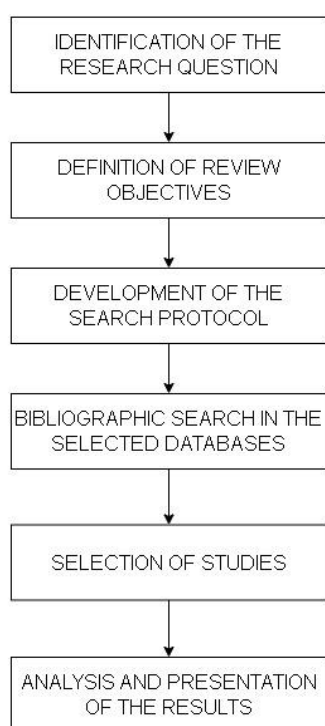
2. Methodology

For the present work, an adapted Scoping Review was proposed, with the objective of mapping the existing scientific literature on the composition of high-voltage batteries used in hybrid and electric vehicles and their respective characteristics. The choice of this type of review is justified by the



need to obtain a broad, systematic, and organized view of the available literature, especially in an interdisciplinary or still diffuse field, in which studies may adopt different methodological approaches and terminologies. The methodology adopted follows the principles established in the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) guidelines.

Figure 1: Methodological process steps



The Scoping Review will be structured into the following stages:

2.1. Identification of the research question

Initially, a guiding research question was defined. This structure allows the focus of the review to be delimited without excessively restricting the results, ensuring the comprehensiveness

characteristic of this type of review. The formulation of the question will guide all subsequent phases of the process.

This stage aimed to define the guiding research question to direct the studies and searches in the databases on the topic. Thus, the research question was: What are the main materials that compose the batteries of hybrid and electric vehicles, as well as their challenges and possibilities related to their compositions and applications?

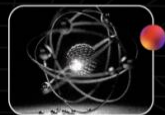
2.2. Definition of the review objectives

Based on the central research question, the objectives of the review were defined as:

- (i) to identify which approaches, technologies, or strategies have been used in the field under study;
- (ii) to map the main authors, institutions, and journals that publish on the topic; and
- (iii) to identify existing gaps that may guide future research.

With those objectives during the reserach, was possible to investigate the materials used in battery cells, undestanding more about their specifications; identify the technical and functional characteristics of these compositions; and understanding how these compositions impact the performance and applicability of batteries in vehicles.

2.3. Development of the search protocol



A protocol will be prepared containing the inclusion and exclusion criteria for studies, the databases to be consulted, and the search strategies. This protocol was registered and used as a guide throughout the process.

In this stage, search protocol began with the definition of key words to be used in databases: (HV Battery), (HV Battery + Chemistry), (HV Battery chemistry + Composition), (HV Battery chemistry + Storage). Those key words utilized were chosen based on the relation with the theme and also the ones that could gather articles broadly to enable scope delimitation.

Next, the databases selected for the searches were defined: Science Direct, Scopus, and Scielo, chosen for their credibility nationally and internationally in the scientific field and number of publications.

2.4. Bibliographic search in the selected databases

The search strategy was developed based on Boolean operators and key terms derived from the research question. Searches will be recorded and documented with the date, search terms used, and the number of results.

With key words and databases defined, it was possible to reach the following number of results in the selected databases (Table 1).

Table 1: Publications per descriptor according to databases

Descriptors	Science Direct	Scielo
HV Battery	10398	415
HV Battery + Chemistry	3603	43
HV Battery chemistry + Composition	2608	12
HV Battery chemistry + Storage	2095	12

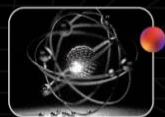
2.5. Selection of studies

The selection was carried out by screening titles and abstracts, as well as the full reading of texts that met the established criteria.

One of the first filters used to refine the related works was the chronology. A selection criterion was that the articles should have been published within the last 10 years, one of the most common academic practices [13].

Table 2: Publications per key words according to databases after chronology refinement

Descriptors	Science Direct	Scielo
HV Battery	7334	206
HV Battery + Chemistry	2611	20
HV Battery chemistry + Composition	1962	3
HV Battery chemistry + Storage	1631	5



After this time-based refinement, studies were further screened by their titles and abstracts to ensure alignment with the theme of battery composition, with emphasis on active/main materials.

2.6. Analysis and presentation of the results

The extracted data were analyzed in a descriptive manner and through narrative synthesis. The presentation included a categorization of the studies based on recurring themes, types of approach, application contexts, and identified perspectives. The main findings, convergences, divergences, and gaps were highlighted.

3. Results and Discussion

Although the selection stage is still being refined to reach a final number of works most relevant to the proposed theme, it is possible to identify the most common applications in terms of active materials in high-voltage batteries and to understand how they influence characteristics and applicability in hybrid and electric vehicles. Batteries for electric vehicles can be made with different types of materials, each with strengths and weaknesses, as well as advantages and disadvantages. These technologies have varying levels of maturity—some are already widely available in the market, while others are still being developed.

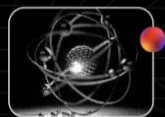
Table 3: Comparative table of batteries compositions

Composition	Energy Density	Cost	Maturity
Li-ion	High	Moderate	Very high
NMC / NCA	Very high	High	Very high
LCO	High	High	Moderate
LFP	Moderate	Low	Very high
Li-O ₂	Very high	Very high	Low

Composition	Advantages	Disadvantages
Li-ion	High efficiency; consolidated technology	Degradation over time; thermal risk
NMC / NCA	High range and performance; popular in commercial EVs	High cost; environmental and social risk due to the use of cobalt
LCO	High volumetric density; good conductivity	Poor thermal stability; short service life
LFP	High stability and safety; long service life	Lower autonomy; lower energy density
Li-O ₂	Disruptive potential; reduced weight	Low stability; still in the experimental stage

Lithium-ion batteries are the most widely used in modern electric vehicles due to their high energy density, reliable performance, and relative flexibility in composition. However, despite their popularity, lithium-ion batteries suffer gradual degradation over time, which directly affects their lifespan and the vehicle's range. This degradation can be caused by factors such as high operating temperatures, deep charge cycles, or undesirable chemical reactions within the cell.

Some commonly used compositions are the NMC and NCA family, which use nickel, manganese, and cobalt. They offer good range and



performance, making them widely used in medium- and long-range electric cars. However, because they use metals such as cobalt, they are more expensive and pose environmental concerns. In addition, they can be sensitive to heat and, under extreme conditions, have a higher risk of degradation ([14],[15]).

Another composition often used in batteries is lithium cobalt oxide, known as LCO. This model has been widely used in cell phones and laptops and can also serve as a reference in terms of energy density. Even though it provides a high amount of energy in a small volume, these batteries are less safe at high temperatures and can degrade more quickly if charged beyond recommended limits. The heavy use of cobalt also makes this technology expensive and less sustainable ([16],[17]).

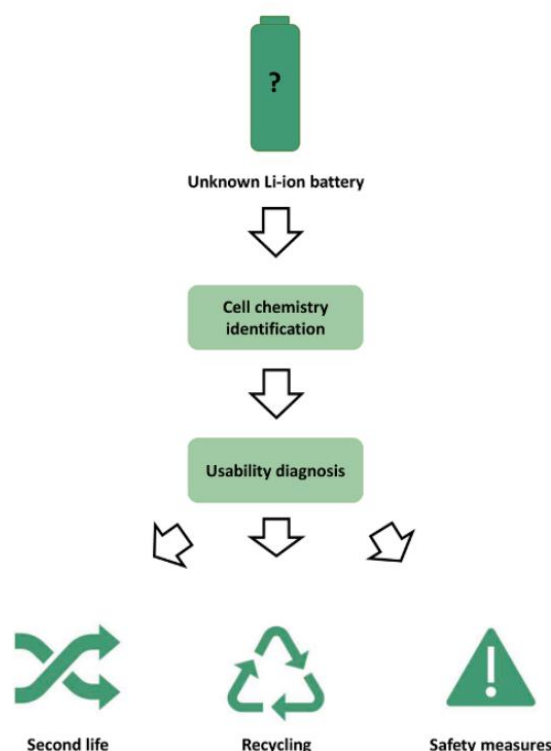
Lithium iron phosphate batteries, or LFP, are currently very popular, especially in vehicles used in urban environments. They are safer, more stable, and less expensive due to the use of iron instead of rarer metals. Although they have a shorter range compared to other chemistries, they compensate with a longer lifespan and lower fire risk. For this reason, they are widely used in electric buses and commercial vehicles, being considered a reliable option for daily use [18].

There are also lithium-oxygen batteries, which are still under research and have the potential to store more energy than current batteries. This type of battery uses oxygen from the air to generate electricity, making it extremely light and theoretically powerful. However, it faces

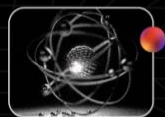
technical challenges such as charging difficulty, component instability, and short lifespan. Therefore, even with promising laboratory results, it is not yet ready for commercial use in electric vehicles [19].

Those analysis of battery composition are critical for identifying their materials, applications and functionalities. With these concepts, it is possible to better understand battery technology and also discuss about possible scenarios for their usability [3]. In figure 1, it is possible to highlight second life and recycling scenarios, as well as safety measures.

Figure 1. Identification of Li-ion battery cell chemistry and usability



In this specific case, authors utilized this approach with Li-ion chemistry batteries, but



battery can be composed with different materials and distinct percentages of each chemistry. Understanding those compositions would better guide second life usage such as merging them with other energy storage equipments and more.

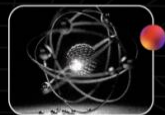
4. Final Considerations

Through this research, it was possible to analyze some of the main chemical compositions of battery cells used in hybrid and electric vehicles. Although this is an initial perspective, it provides context on the key technologies currently in use as well as possible proposals being studied for future market implementation.

The intention is to further deepen the bibliographic review, refining research databases and applying additional stages after its completion—such as benchmarking in the automotive sector for batteries used in electric vehicles—and developing a framework capable of interactively describing the characteristics that would be best applied for each composition in different applications and scenarios. Also, investigate second life possibilities of those componentes, possibly merging them with Other energy storage equipment and devices, as well as understanding how they can be recycled or reutilized/resignedified.

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