

Perspective

# Outlook of Lithium-Ion Battery Regulations and Procedures to Improve Cell Degradation Detection and Other Alternatives

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**Abstract:** This article constitutes a relatively new perspective that has emerged from the need to reduce environmental pollution from internal combustion engine vehicles (ICEVs) by reinforcing the fleet of electric vehicles (EVs) on the road. Future requirements to exclusively use zero-emission vehicles have resulted in the necessity of enhancing the testing and monitoring process for EVs in order to release reliable devices. The unpredictable response of lithium-ion batteries (LIBS), future lack of raw materials, and inconsistencies in the present regulations must be reviewed and understood in order to develop enhanced batteries. This article aims to outline the future perspective of nonconventional vehicles monopolizing the roads by year 2035 in order to eradicate CO<sub>2</sub> emissions by year 2050.

**Keywords:** lithium-ion; regulation; rechargeable energy storage system; electric vehicles



**Citation:** Cortada-Torbellino, M.; El Aroudi, A.; Valderrama-Blavi, H. Outlook of Lithium-Ion Battery Regulations and Procedures to Improve Cell Degradation Detection and Other Alternatives. *Energies* **2023**, *16*, 2458. <https://doi.org/10.3390/en16052458>

Academic Editors: Konstantinos G. Arvanitis, Christos-Spyridon Karavas, Athanasios Karlis and Dimitrios Piromalis

Received: 17 January 2023

Revised: 13 February 2023

Accepted: 1 March 2023

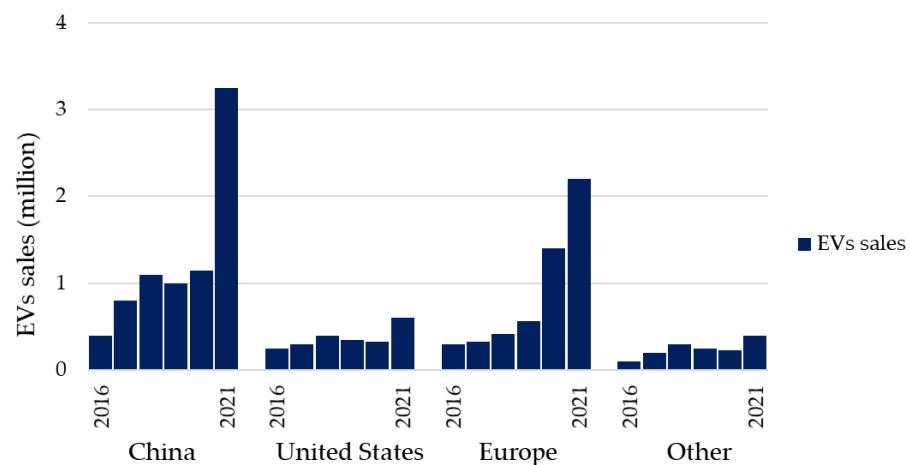
Published: 4 March 2023



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## 1. Introduction

The growing appeal for sustainable means of transport in order to reduce carbon emissions has driven electric vehicles (EVs) to their highest levels of popularity. As can be seen in Figure 1, which shows the EV sales in some countries in recent years [1], the market for EVs has increased exponentially due to the fact of a growing general awareness regarding global warming caused by internal combustion engine vehicles (ICEVs) and reductions in the price of EVs through governmental grants. In fact, EVs became 9% of all global vehicle sales in 2021 [1]. The demand to acquire battery-powered vehicles that are able to provide the same levels of comfort, safety, and competitive prices as ICEVs has brought a new challenge to scientists and vehicle manufacturers.



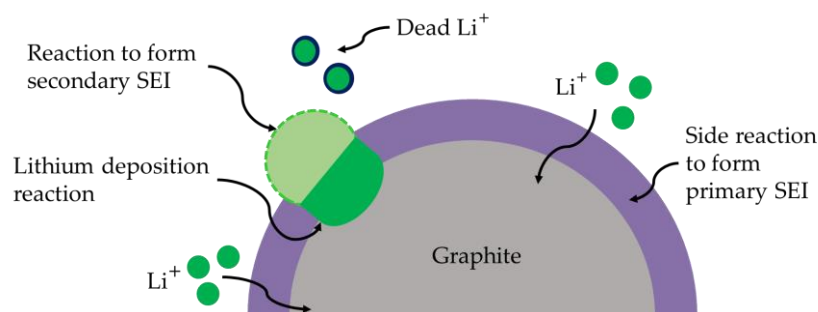
**Figure 1.** EVs sales in selected countries/regions during 2016–2021.

The current solution to fulfilling the requirements of EVs is the use of lithium-ion batteries (LIBS), which essentially consist of two electrodes: a negative electrode, known as the anode, usually made of graphite, and a positive electrode made of lithium metal oxide, known as the cathode. Both components are separated by a membrane, known as a separator, and immersed in electrolyte [2]. Improvements in technology over the past decade have demonstrated the feasibility of LIBS, as they are able to offer high specific energy (the specific energy is a measurement unit that defines the energy from the battery in comparison to its weight. It is usually expressed in Wh/kg.), long cycle life, high output voltage, and low self-discharge rates at affordable prices [3,4].

However, one of LIBS' drawbacks is their aging mechanism, which can result in severe levels of degradation that can alter the battery applicability due to the fact of the deterioration of properties. The main sources of degradation are usually lithium plating, dendrites growth, and solid electrolyte interphase (SEI) [5].

On the one hand, lithium plating is the formation of metallic lithium around the anode during the charging process. The constant aggregation of lithium on the anode can develop into sharp dendrites that can fissure the separator and cause a short circuit. These phenomena also induce the permanent loss of lithium, which becomes electrically disconnected when it is disposed on the farthest dendrite layer from the anode [6].

On the other hand, SEI is the effect of lithium chloride covering the electrodes, which is a direct effect of the reaction between the electrolyte and the metal [7]. The SEI formation is the main source of anode degradation and consumes active materials and electrolyte. The result of this phenomenon consists of a lower capacity and higher internal resistance [5,6]. Despite the SEI having positive effects, such as protecting the electrode or reducing the internal resistance, an excess of it can reduce lithium diffusion, which increases power fading and causes chemical instability after numerous charging cycles or when exposed to higher temperatures. The process of SEI formation is presented in Figure 2.



**Figure 2.** Scheme of SEI formation.

Degraded cells have become an issue of great importance, because the alteration of mechanical and chemical properties, together with the continuous gathering of secondary reactions that can alter the chemical stability (the chemical stability refers to the lack of chemical reactions that are not intended to occur inside the cell) of the cell, can cause battery failure [8,9]. Despite LIBS already containing self-degrading mechanisms, structural damage can also appear from mechanical, electrical, or thermal abuse scenarios.

Cells that are involved in hazard situations, such as drastic temperature changes or an inappropriate charging process, can suffer from a short circuit [8–10], eventually leading to thermal runaway, which can cause a fire or the explosion of the system due to the high activity of the electrodes and the flammability of the electrolyte. Thermal runaway finds its origin in the exothermic reactions that produce more heat than the one that can be dissipated [11,12].

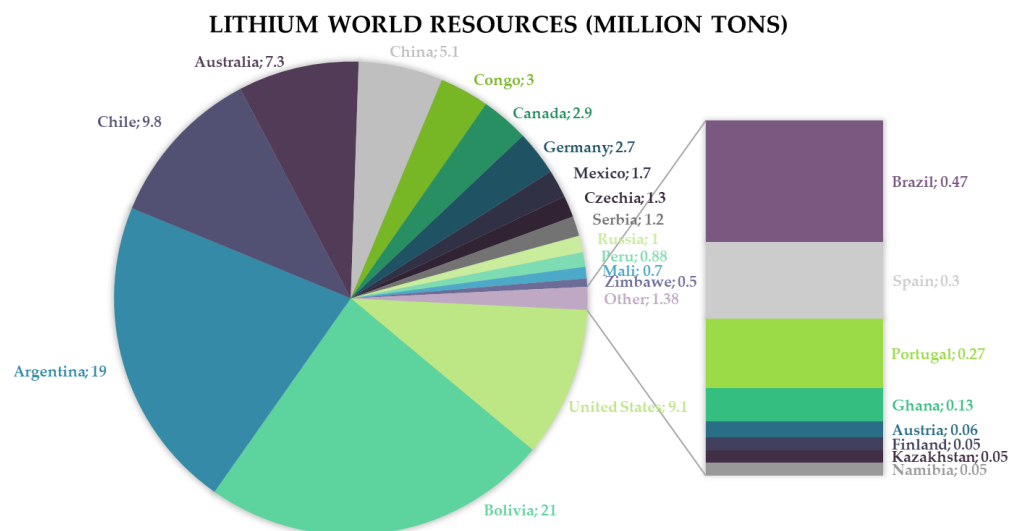
EV accidents are a substantial source of abuse mechanisms that can contribute to cell deterioration, as they usually do not cause imminent failure but can lead to a deficient system. For instance, a Chevrolet Volt, in 2016, ignited weeks after being involved in a side crash because of short circuit issues. A similar situation occurred in 2013–2014 when,

despite being a much smaller crash, a direct strike to the battery's protective structure due to the fact of road debris caused a Tesla to ignite. Such experiences with the risks associated with EVs has led to the implementation of safety requirements and regulations, aiming to preserve electric devices after a vehicle crash and to protect a vehicle's occupants from electric shock [13].

Although these regulations are widely accepted, the tests and procedures lack consistency. The techniques employed to assess ICEVs have existed for decades, and despite EVs and ICEVs being very similar on the outside, it is important to highlight that they differ in their internal structure and power motion. Therefore, safety targets should be different for each type of vehicle. A review of the current tests must be addressed in the near future in order to renew the employed regulations and provide safer devices [14].

Another well-known problem with LIBS is that the lithium resources on earth are limited. Lithium can be obtained from seawater, brine, or minerals. The extraction process directly affects the cell price. The easiest method to obtain lithium is through brine extraction, which due to the fact of its simplicity highly reduces the battery cost. With current technology, extraction from other substances, such as seawater, could increase the price of lithium and, thus, the battery would be more expensive. There is already an increase in the demand for LIBS, and this can become a problem if new reserves are not discovered in the future [15–17]. Figure 3 shows the current lithium resources according to [17].

A number of alternative approaches to overcome a future lack of lithium have been developed. Recent research is focused on exploring recycling methods for the reuse of LIBS, whereas other research is focused on developing lithium-free batteries, with the implementation of other resources such as sodium.



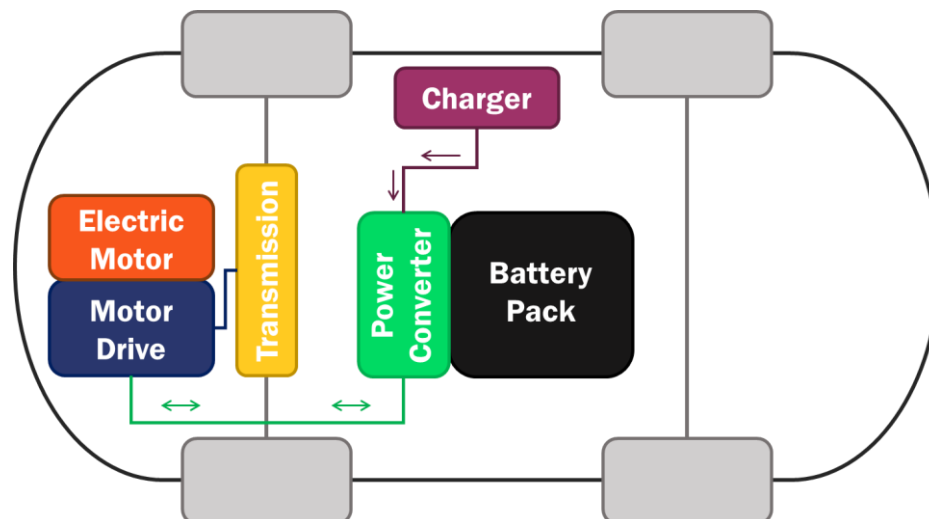
**Figure 3.** Lithium world resources in millions of tons.

## 2. Electric Vehicle Components and Vehicle Inspection

The working principle of EVs is entrenched in their kinematics simplicity, as the only moving component is the electric motor. Compared to ICEVs, which require the movement of the majority of their components, the maintenance of EVs is low. In fact, EVs and ICEVs happen to be very similar on the outside; however, the inside arrangement is not the same, as over 50% of their components are different [18].

The fundamental components of EVs are illustrated in Figure 4. The battery pack, which is the main feature of EVs, comprises a series of cells that are grouped into modules, with lithium-based batteries being the preferred technology. To power an EV, the direct current (DC) stored in the battery is converted into alternating current (AC) using an inverter [19], while the controller changes the AC frequency in order to adjust the vehicle speed. The internal mechanisms of EVs essentially employ static components, which

require little or no maintenance. Nevertheless, daily usage of the vehicle or an inappropriate charging process can contribute to a component's failure due to the appearance of torque nonlinearity, property degradation, or the influence of an unbalanced voltage or current [20,21].



**Figure 4.** Scheme of an EV's working system.

In order to control the alterations from the operational range of the battery, EVs employ another essential component, which is the battery management system (BMS). It is responsible for gathering cell data, such as the current, temperature, and voltage, and predicting their future response, state of charge (SOC), state of health (SOH), and state of energy (SOE). Moreover, the BMS detects unsafe temperatures or battery deficiencies [22,23], employing a series of algorithms based on machine learning, neural networks, regression, and probability. However, these techniques can be complex and usually require a considerable amount of storage to manage the collected data.

Despite the fact that a cell's irregular degradation makes it difficult to obtain an accurate lifespan for EVs, the field of degradation and component failure of ICEVs has been further developed, as it employs well-understood methods to ensure their safety on the road. Member States of the European Union must follow the safety procedures described in Directive no. 2014/45/EU. This directive aims to submit different types of vehicles to a roadworthiness test in order to improve road safety and to detect irregular vehicle components that could endanger road users. Each Member State is in charge of developing the testing procedure according to the recommended methods established in Directive no. 2014/45/EU [24,25].

For example, in Spain, this inspection is known as the vehicle technical inspection (ITV). The ITV standard is similar to other European standards; it evaluates the current state of vehicles that are on the road by analyzing the passive safety components, such as seatbelts, or other components, such as lighting equipment, braking system, steering, wheels, suspension system, chassis, and chassis attachments. Vehicle emissions are also inspected. The majority of the tests consist of a visual inspection, which essentially aims to detect corroded, broken, or damaged components in order to determine if a vehicle is in the correct condition to circulate [24,26].

This inspection has been widely adopted with reasonable modifications for EVs. For instance, the emissions test and noise inspection have been replaced by a more accurate inspection of the high-voltage connections. Even though the latest updates are significant improvements, no specific inspection is performed on the rechargeable energy storage system (RESS), because only a visual assessment of the battery fixations, presence of leakage, deteriorated elements, such as fuses and switches, or inappropriate ventilation system is performed.

This aspect of the review suggests that future ITVs should comprise a deeper inspection of the RESS, which should consist of assessing parameters such as the electrolyte level, electrolyte density, cell voltage, temperature, and capacity, as a reduction of the voltage or electrolyte could cause a short circuit. This practice would entail safer devices, as it would allow the detection of critical individual cells or battery packs that could be replaced if the safety conditions are not guaranteed [27].

Moreover, performing regular maintenance procedures, such as checking the ventilation filters and the charging port or cleaning the RESS parts that are exposed to dust, mud, or other harsh external conditions, could also help to detect and fix early signs of degradation that could eventually cause the failure of the system. The implementation of both procedures would increase the safety of devices and their lifespan.

### 3. Current Standards and Regulations for RESS

Knowledge and experience gained over the years has led the automotive industry to define accurate safety targets for ICEVs and their components during the vehicle development phase. However, since EVs have been recently introduced on the market, the knowledge of this technology is very limited. Therefore, in order to acquire further information, a series of abuse tests have been developed. The employment of abuse tests on RESS aims to examine their response when involved in worst-case scenarios. The data obtained from the tests can be employed to improve the RESS and gain more knowledge regarding the unpredictable behavior of the battery components. Furthermore, these tests are also essential to ensure the safety of the device [28].

Over time, extensive investigations on electrical, mechanical, or thermal abuse have been performed. Recent research has demonstrated that daily circumstances, for instance, driving at high speed over an object on the road or driving over a curbstone, can cause indentation to the battery's protections, resulting in alterations to the battery's chemical stability [29]. Therefore, in order to protect vulnerable road users and occupants, different organizations, such as EVERS SAFE, have started to develop a series of projects that aim to understand crash effects on EVs, investigate and comprehend how batteries would respond under different scenarios, and detect dangerous operation points in the system [30].

Different regulations regarding the safety targets of EVs have been implemented in a variety of countries. Each of them has been properly adapted to their specific needs. For instance, in Europe, vehicles should be able to pass with success when submitted to crash tests defined by the United Nations Economic Commission for Europe (UNECE). However, vehicles from the USA are regulated by tests defined by the Federal Motor Vehicle Safety Standards (FMVSS). Batteries from EVs are also regulated by UN 38.3, which simulates different transport conditions, such as temperature changes, and impacts [31]. UN 38.3 together with ECE Regulation 100, BS 62660, and Warwick Manufacturing Group/Millbrook Proving Ground (WMG/MBK) can be employed to test the response of batteries under vibration energy [32–36].

Since data obtained from different vehicle crash assessments have provided sufficient knowledge to corroborate that ICEVs and EVs are different, new regulations regarding high-voltage safety and battery safety in crash accidents have also been implemented and developed by different regulatory bodies, such as the Society of Automotive Engineers (SAE) and the US Advanced Battery Consortium (USABC) [37]. Regulation UN-R100 covers EVs and RESS in Europe. Post-crash requirements regarding the safety of electric vehicles have also been added to UN-R94 and UN-R95.

Apart from regulation tests, some standards have been implemented to assess basic safety performance, such as ISO 6469, SAE J2929, or IEC 62133. Other tests are specially designed to cover mechanical, thermal, and electrical damage, such as ISO 12405, IEC 62660, or SAE J2464 [13]. Regarding vibrations, SAE J2380 has been described as the most representative of real-life vibration profiles, as it has been correlated with the vibrations obtained from 100,000 miles and can be useful for assessing cell degradation [38].

To pass each test, the battery system should not suffer from any sign of deformation, temperature or resistance increases, voltage changes, or the appearance of gas or smoke. Moreover, those tests require a period of observation of one hour to perform a visual inspection. Some of the main tests employed to assess daily scenarios that can physically alter LIBS are mechanical shock tests, which consist of applying an acceleration profile to a battery loaded at half SOC while working at ambient temperature. The aim is to analyze the robustness of the battery module when submitted to the sudden appearance of forces or abrupt changes in vehicle motion [39]. Another mechanical abuse test is the drop test, which aims to represent the fall of the device during the assembly process. It can be dropped on a textured plate surface or a cylinder steel object in order to represent an impact with cylinder elements such as a telephone pole [40].

The penetration test consists of inserting a mild steel pointed rod perpendicular to the electrodes through the battery module. Different nail diameters and penetration depths can be employed to perform this test, which is considered one of the most severe, as it involves the combination of mechanical, electrical, and thermal abuse scenarios to induce an internal short circuit (ISC) [40,41]. Another severe test is the crush/crush test. A crush test consists of causing enough force onto the battery until it is completely deformed, whereas a crash test is the collision of a vehicle. Then, this test aims to simulate a vehicle collision through an extreme deformation of the RESS, by crushing the device between a flat plate and a textured crush plate employing a force of around 100 kN horizontally, and perpendicular to the travel direction of the RESS [39].

The rollover test is usually performed after crush/crash test, as it aims to represent the overturn of a vehicle after an accident. To perform this test, the battery module is rotated one complete revolution for one minute in a continuous slow-roll fashion. Next, it is rotated on full revolution employing increments of 90° [39]. Finally, the immersion test can be executed in order to represent a situation of flooding and assess the chemical stability and the consequences of having the electrical energy storage system covered with salt water for at least two hours or until any anomaly can be visibly detected [40].

#### 4. LIBS Degradation

Previous regulations and standards aim to reproduce scenarios that are able to damage the battery system and eventually cause thermal runaway. As mentioned before, there is no present procedure to monitor the RESS, despite the fact that research has demonstrated that daily circumstances can increase cell degradation easing the appearance of thermal runaway.

Different studies conclude that before reaching the failure mode, abuse tests can cause degradation and alternate property of different cell components. Degradation signs do not cause imminent failure but make the cells more susceptible to fail when involved in a continuous abuse condition. It has also been proved that certain parameters must be considered when assessing the safety of lithium-ion cells, such as their integrity, impact position, SOC, or the cell chemistry, because the combination of these factors increases the chances of reaching thermal runaway [42].

The safety performance of battery cells can be directly related to the SOC, as it symbolizes the remaining quantity of energy in the battery [43]. Cells loaded at a high SOC have larger amounts of stored energy, which causes higher explosive scenarios, as heat propagation occurs faster, and the maximum temperature is higher [44]. Therefore, cells that are completely discharged are less likely to suffer from thermal runaway, since their maximum temperature is not high enough to damage the system [45]. It has been reported in the literature that SOC and cell deformation can alter cell stiffness, which is the main source of mechanical failure and voltage drop. The voltage drop has been associated to a reduction in the gap between the anode and the cathode, caused by the compression and deformation of the cell. Therefore, it is essential to take under consideration the deformation rate when assessing cell performance, as it can lead to electrical failure [46].

An ISC is the most common result of cell abuse and the main originator of thermal runaway, as it causes irregular heating. The heat propagates through different cells, causing fire to the device [47]. This phenomenon arises from material alterations occasioned by the stress and strain that developed during mechanical abuse tests [48]. The permanent alteration of cell materials can cause irreversible damage and, thus, internal structure failure [49–51]. If mechanical abuse also breaks or damages the separator, an ISC will also take place, as both electrodes would be in direct contact [52]. The nail penetration test directly changes the internal structure of a cell [53,54]. Cell integrity failures may also arise from the relative movement of the jellyroll or the overhanging of parts, such as the separator or the electrodes, which can also result in an ISC [55].

Another failure mode for lithium-ion cells is electrolyte and gas leakage [56]. Each of the previously seen tests can break the cell cover, allowing the electrolyte to flow outside of the cell, causing severe deteriorations effects, such as an increase in the internal resistance and self-discharge, together with a capacity decrease [57].

Finally, despite being less severe, other signs of degradation can be observed in cells that have been subjected to impact, shock tests, or mechanical deformation, such as an increase in the ohmic resistance, decrease in the charging capacity, external case deformation, or a loose electrode assembly. When cells are under compression forces, some cracks are likely to occur. The appearance of cracks should not affect the functioning of the cells as long as no contact between the anode and cathode occurs [45,46,51,58]. The appearance of internal deformation can also alter the initial state of the battery [59].

Signs of degradation, such as an increase in the internal resistance or decrease in the capacity, can also occur due to the fact of vibrations, which do not cause significant changes to the open circuit voltage (OCV), but the results before and after submitting LIBS to vibration energy exhibit a reduction in the natural frequency (the natural frequency is the range of frequencies at which an object naturally vibrates) and amplitude changes to cells loaded at different SOC. Again, the results of testing the cells at different SOC levels confirm that this is a key factor in cell degradation, as higher capacity fade occurs in cells loaded at higher SOC compared with cells at lower SOC. Changes in material properties, such as fracture, cracking, or delamination, can occur after vibrations [60]. Internal cracking can reduce cell capacity. Overall, a great deterioration in cell components can lead to a reduction and degradation of their electric characteristics [61,62]. Then, despite research that has confirmed that vibrations can cause cell degradation, this degradation trend is not uniform.

The consensus of the research is that those degradation signs do not show imminent failure, but the occasioned small alterations can eventually reduce the SOH of the battery [63].

## 5. Conclusions and Outlook

The massive growth of EVs sales is moving towards the objective of reaching a total vehicle decarbonization by year 2050. The recent introduction of EVs to the vehicle market has contributed to an improvement in knowledge and compilation data, which can help the automotive industry improve the RESS from EVs. However, the present review has provided arguments to confirm that substantial changes must be executed before removing ICEVs from the roads.

LIBS are highly susceptible to suffer from alterations due to the fact of periodic usage or being involved in any atypical situation such as vehicle accidents. The latest research provides potential arguments that expose that alteration of cells' physical integrity can modify their properties. Hence, mechanical abuse is as hazardous as electrical and thermal abuse, as it can give rise to irreversible side reactions due to the fact of structural and electrochemical damage. Nevertheless, according to the literature, the severity of mechanical abuse is dependent on the working state of the battery. Using a high SOC increases the amount of heat that is generated during an ISC and allows heat to spread faster. Using a lower SOC, the cell is less likely to reach a higher temperature, so the

chances of generating heat are lower. The outcome of the research concludes that harsh circumstances result in faster degradation, which despite not causing imminent failure can eventually collapse the system.

It is well known that the late detection of cells working under degraded conditions confronts the risk of the RESS suffering from thermal runaway or explosion. Therefore, it is recommended to protect the RESS using a precise BMS and improved safety testing procedures [22,64]. It is important to employ the BMS to monitor and predict cell behavior through different algorithms while the vehicle is working, as it greatly reduces the chances of failure. Nevertheless, its accuracy when estimating future scenarios decreases due to the fact of battery aging, as the internal structure of the cell changes and alters the SOC, SOH, and SOE [23].

Although adjusting the accuracy of the modeling data to enhance the BMS assessment process would not address the issue of unpredictable aging [9], it is proposed to handle BMS deficiencies implementing aging detection methods to identify early signs of degradation, such as cracking, electrolyte decomposition, unstable solid electrolyte interphase (SEI), material loss, resistance increase, or lithium plating [65–67].

Machine learning is one of the main technologies used to estimate cells' functioning stage. The accuracy of this method requires longstanding and computationally expensive data; hence, a combination of physical models and numerical simulations data should be implemented in order to improve the estimating capacity of the model, reducing the computational cost [68,69]. The voltage profile should also be integrated in machine learning algorithms in order to improve aging prediction. Changes in the OCV are indicator signs of degradation and are directly related to the SOH and the SOC [70,71].

A potential solution to overcome this problem is the use of ultrasonic waves, as the use of acoustics can be an effective nondestructive method to detect structural changes in the cell and characterize their current state. An ultrasonic wave can be used to characterize the internal structure of a cell in order to define the initial cell stiffness. This can be monitored through sound waves in order to predict battery states or detect material alterations [72,73]. Another defect detection model that can be integrated in the BMS is Sim-YOLOv5s. This model is an improved version of YOLOv5s and is able to identify cell defects in the LIBS' shell, through a single-stage target detection algorithm that employs computer vision models to detect failed elements on the steel shell of cylinder cells. This procedure must employ a camera to acquire images from the tested cells in order to gather the required information [74]. Modeling improvements can be complimented using temperature control heat sensors and cooling systems in order to overcome potential temperature inconsistencies to mitigate internal resistance increase, recognizing heat sources inside and out of the RESS [75–77].

Regulation tests employed during early development stages should also be reviewed, as they lack consistency and are not representative of real scenarios. For example, performing a visual inspection during an established period of 1 h is insufficient to certify the safety of a cell. Another test that has generated some controversy is nail penetration, as it directly provokes an ISC. Many researchers doubt its accuracy, as it lacks resemblance to legitimate situations [42].

The response of different tested cells confirms the hypothesis that it is necessary to invest in developing better regulations that not only identify weak points of LIBS but also represent real damaging scenarios in order to improve the safety assessment of RESS and align safety standards. A critical aspect that must be reconsidered is the mechanical damage detection process, which is not severe enough, as sometimes cells do not show visual alteration, but the damage on the inside can be severe enough to reach a failure state. This affirmation is remarkably critical, as the current post-test assessment is not restrictive enough and allows cells to pass some standard tests while being highly damaged on the inside [78].

Given the adversities and arbitrary performance of cells, it is not enough to simply rely on predicting methods and testing procedures during the development phase to avoid



RESS failure. Therefore, it is proposed to approach these problems by implementing regular inspection tests to assess the RESS and the BMS in order to confirm that both components are safe and working under normal conditions after a certain working period.

ICEVs are constantly checked with procedures such as ITV, but as mentioned before, this inspection lacks assessment tests specially designed for RESS. In fact, EVs are being submitted to ITV, even though this inspection contains a series of tests that could actually damage the RESS or stimulate early signs of degradation. For instance, the suspension system test, which causes high vibrational energy to the RESS despite the existing evidence that vibrations enhance cell degradation [79].

The present ITV should be revised in light of adapting it to EVs and their needs in order to ensure the safety of vehicle occupants and road users through inspection procedures that would allow for the early detection of highly degraded cells.

An advanced method that could be implemented to overcome this issue consists of the assessment of RESS through 3D X-ray microscopy, which allows the visualization of a battery's internal morphology without disassembling it [80]. The result of the 3D X-ray is a voxel (i.e., 3D pixel) image of the battery insides. This image favors the examination of electrode thickness, defects, or irregular composition. This is also useful for verifying structural changes due to the fact of aging or degradation. Despite the fact that there is no plausible evidence to confirm that this method could be directly implemented in the BMS while the EV is working, it is a potential tool to use during the maintenance or inspection process, as it would allow for a better assessment of not only the RESS but also battery pack assemblies, electronic connections, or welding points. Then, to accomplish the future goal of only driving EVs, it is crucial to invest time and research on how to implement new tools that not only reduce the chances of RESS failure but also detect signs of cell degradation.

A further problem that is expected to occur is related to the massive demand for lithium. Currently, LIBS are the most advanced chemistry used in RESS, and the growth of EVs will cause exponential lithium consumption. However, lithium resources are limited, and there are not many feasible alternative procedures to reproduce this raw material. Different works have exposed that this problem can be solved throughout the implementation of recyclable methods to reuse lithium from old batteries.

A key aspect of lithium recycling is the cost of the process and the environmental impact. The employment of expensive methods would raise the battery price and, consequently, the vehicle price. Furthermore, the pollution generated from this performance must be minimum; otherwise, the recycling action would be disadvantageous. Thus, both aspects are key to developing a positive lithium recovery process.

The most common recycling methods that have recently emerged aim to obtain lithium-ions through different processes, such as deformation-driven resintering (DDR) or the electrochemical relithiation [81]. DDR severs deformation by applying high levels of pressure to the cell, which breaks the components into small pieces. Once the particles are obtained, supplementary lithium ( $\text{Li}_2\text{CO}_3$ ) is employed to absorb lithium-ions. This process causes the loss of some lithium due to the supplementary lithium employed and is only suitable for solid-state cells [81,82].

The relithiation process can be performed by submerging a used cathode into a lithium solution, which causes recrystallization. Recrystallization can be performed employing molten salt, which fastens lithium-ion diffusion and promotes contact between salts and used materials. Although this technique is still being developed, it is not very precise in terms of restoring the initial crystal structure [81,83].

However, the recycling process can result in a negative aspect, which is the insertion of counterfeit LIBS on the market, usually through online platforms. The usage of uncertified batteries can cause hazardous scenarios, such as fire or explosion, as they can suffer from jellyroll alterations, a lack of active energy storage materials, or fewer safety features. New regulations should be implemented to monitor the battery supply chain in order to avoid the usage of defective cells [84].

An alternative to the recycling process is to approach the future lack of lithium using new chemistries in order to acquire better technology that can offer higher capacity, higher life cycle, and fewer side reactions, which could hinder the functioning capacity of the device. However, many questions remain to be addressed regarding new chemistries such as their degradation and electric response under hazardous scenarios.

In order to achieve the total green transport objective, EVs play an essential role. However, different aspects of RESS must be further investigated with the aim of manufacturing better devices. Despite huge steps having been taken to expand energy densities and safety, to address the increase in lithium consumption, new chemistries or new recycling processes and further research are required. A review and upgrade of RESS regulations must be performed in the near future, as the EV fleet is increasing, and no procedures exist to monitor and detect hazardous cells.

**Author Contributions:** Conceptualization, M.C.-T., A.E.A., and H.V.-B.; validation, A.E.A. and H.V.-B.; investigation, M.C.-T.; writing—original draft preparation, M.C.-T.; writing—review and editing, M.C.-T., A.E.A., and H.V.-B.; supervision, A.E.A. and H.V.-B.; project administration, A.E.A. and H.V.-B.; funding acquisition, A.E.A. and H.V.-B. All authors have read and agreed to the published version of the manuscript.

**Funding:** This work was sponsored by the Spanish *Ministerio de Ciencia e Innovación*, under grants PID2020-120151RB-I00 and PID2019-111443RB-I00.

**Data Availability Statement:** Not applicable.

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

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