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Original Article

Risk Management Safety Assessment Over the Life-Cycle of Lithium-Ion Batteries in EV

Deepak Shukla[1], Vijay Shankul[2]

[1,2]*Fire Technology & Safety Engineering Department, IPS Academy Institute of Engineering Science, A.B. Road Rajendra Nagar Indore, Madhya Pradesh, India.*

[1]*Corresponding Author : diipakjishukla@gmail.com*

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Abstract - *LiB's have become the preferred energy storage solution for Powering EV's due to their high energy density and long lifecycle. However, these batteries also pose certain risks, such as thermal runway fire and explosion incidents, if not properly managed, resulting in the release of flammable gases that pose fire and explosion hazards for the compartment housing the cells. The LiB's has raised concerns about their safety and management throughout the lifecycle from their encompassing manufacturing, maintenance, and disposal. In this research, develop an effective Plan to ensure the safe operation and optimal performance of LiB's in EV's throughout their lifecycle at every stage. The environmental impacts of LiB's that characterize as the key to sustainable EV deployment, which enables a resource-efficient and economically feasible recycling system for LiB's and makes planning for future recovery more challenging, as also Review and analysis of the recent LiB's incidents. The findings of this paper offer valuable insights for stakeholders involved in the production and implementation of LiB's in EV's to contribute to the ongoing efforts to enhance the safety and reliability of critical components in sustainable transportation. Ultimately, it is concluded that adequate training for users and emergency responders and establishing protocols for safe handling and disposal.*

Keywords - *Lithium-ion Batteries (LiB's), Safety assessment, Battery Energy Storage System (BESS), Electric Vehicles (EV's), Thermal runway.*

1. Introduction

The world's lightest and softest metal, lithium, is highly reactive, flammable and also corrodes quickly in air. As well as lithium is one of the most important minerals in the digital and EV age. This mineral is a key component in rechargeable batteries that power numerous Electric Vehicles. Demand for lithium is increasing manifold as the focus shifts towards clean energy, meeting India's and other countries' net-zero emission commitments. Lithium-ion batteries play a crucial role in ensuring their safety and managing the associated risks throughout their life cycle in powering electric vehicles and serve as the primary energy storage solution in these vehicles. While lithium-ion batteries have revolutionized the automotive industry, their safety assessment is of utmost importance due to the unique working conditions and challenges faced by EVs. [1]. These challenges include vibrations, extreme temperatures, water exposure, fast charging, and more. To design a safer and more reliable LiB-based energy system for EVs, it is necessary to have a deep and comprehensive understanding of the safety issues associated with LiB's, especially in relation to accidents such as car crashes, object intrusion, overcharge, over-discharge, water exposure, overheating, battery leakage, and electrical system failure [2]. Furthermore, the high energy densities and long lifespan of lithium-ion batteries, coupled with their flammable organic electrolyte, pose fire hazards. Methods employed to ensure battery safety include both external and internal protection mechanisms [3]. External protection mechanisms involve designing the battery pack to have a strong and durable casing that can withstand impacts, vibrations, and other external factors. Additionally, the use of electronic devices such as temperature sensors and pressure valves can help in monitoring and controlling the charging and discharging characteristics of the battery pack. Internal protection mechanisms include the use of advanced cell designs that incorporate features like built-in thermal internal protection mechanisms, including the use of battery management systems that actively monitor and manage the voltage, temperature, and current of individual cells within the battery pack. Efficient thermal management control is vital for the safe and reliable operation of lithium-ion batteries in electric vehicles throughout their lifetime [2]. To address the challenges of thermal runway, which is a critical safety concern in lithium-ion batteries, researchers have developed various safety management strategies [4]. These strategies include detection, prediction, and protection mechanisms to prevent thermal runway and mitigate its consequences. A lithium-ion battery's service life is 4-5 years or at least 1900-

2000 charging cycles. However, a lithium-ion battery can survive up to 2900-3000 cycles if used and maintained properly. This is equivalent to a lead-acid battery lasting three times as long. When a battery's capacity drops to 78-80% of its rated capacity, manufacturers often consider the battery to have reached the end of its useful life. The rapid advancement of electric mobility has led to the widespread adoption of lithium-ion batteries in electric vehicles in India. The Government of India should be encouraged to emulate successful initiatives in material recovery and establish a more robust industry for recycling lithium-ion batteries. Moreover, collaboration between battery designers, policymakers, and recyclers is essential to incorporate design for recycling principles [5]. The plan should also consider the safety standards and regulations in the car industry, which have been refined over 130 years. India is the 4th largest vehicle market in the world. Though the current automobile market is dominated by fossil fuel-based vehicles, the Indian government has set up ambitious targets and enacted conducive policies to ensure that electric vehicles replace fossil fuel-based vehicles as the primary mode of transport. After a thorough analysis of the research paper, a variety of gaps in the current approaches identified to the risk management system, new technologies focus on hydrometallurgy and also the need for robust educational and legal processes to manage risks. These gaps pose significant obstacles to maximizing the efficiency, lifespan, safety and sustainability of LiB's. The Major problem is the lack of standardized testing protocols and standardized battery management systems. Each manufacturer develops its proprietary battery management system, led to inconsistencies in monitoring, control, and optimization strategies. At the same time, various organizations and regulatory bodies have established guidelines for LiB safety, but there is no universal set of standards. This fragmentation hinders interoperability and complicates aftermarket servicing and recycling efforts; consistency makes it difficult to assess the safety of batteries across different applications and industries. Without standardized testing protocols, manufacturers employ different methods, leading to inconsistent results and potentially overlooking critical safety issues. LiB installed in EVs undergoes repeated charge and discharge cycles during operation. At the same time, modern EVs equipped with advanced battery management systems to mitigate risks of incidents of thermal runway and battery fires still occur. The high energy density of LiB's makes them prone to overheating, especially under extreme conditions such as rapid charging, overcharging, or physical damage. These safety concerns not only endanger the occupants of EVs but also pose hazards to first responders and bystanders in the event of accidents or battery failures. The charging station and grid capacity must expand to accommodate the growing demand for electricity.

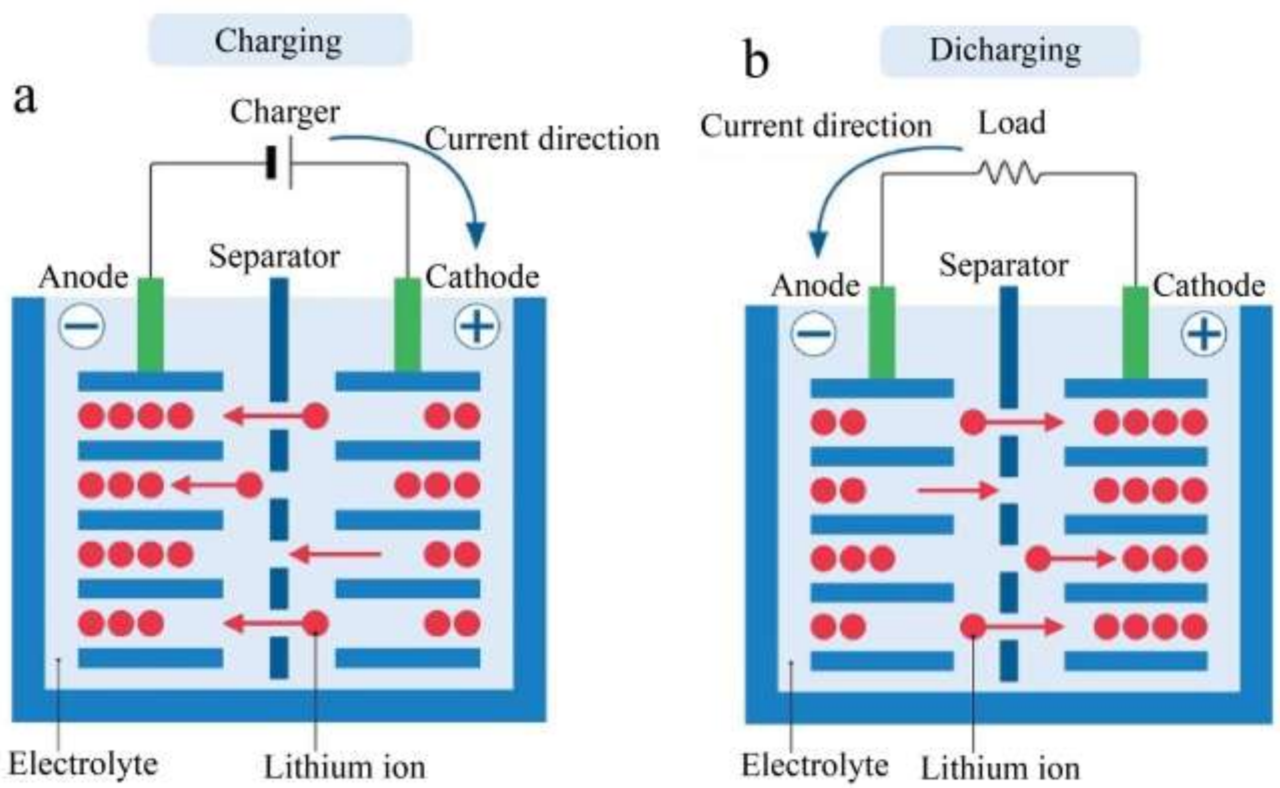

Fig. 1 Working Principle of Lithium-Ion Batteries (a) When LiB Charging (b) When LiB Dis-charging

Without adequate infrastructure, EV owners may resort to fast charging at home, putting additional stress on residential electrical systems and increasing the likelihood of electrical fire and grid instability. Secondly, they often overlook the potential risks of battery aging and degradation. Their performance and safety characteristics can deteriorate, increasing the likelihood of safety incidents such as thermal runways. Furthermore, focuses on individual components of the LiB's are comprised of multiple components, including electrodes, electrolytes and separators.

The safety of LiB's requires understanding how these three components interact and identifying potential failure modes at the system level. These batteries have limited consideration of external factors, recycling infrastructure and environmental conditions. As EV adoption continues to grow, so does the volume of spent batteries reaching the end of their usable life. Effective recycling is essential to recover valuable materials, minimize environmental impact, and reduce reliance on finite natural resources.

However, the existing facilities often lack the capacity and efficiency to handle the influx of retired batteries. Advanced recycling technologies, such as hydrometallurgical and pyrometallurgical processes, can improve resource recovery rates and enable closed-loop recycling systems. The reliance on finite and geopolitically sensitive raw materials, such as lithium, cobalt, magnesium, phosphate, nickel and aluminum, poses a significant sustainability challenge for the Automobile Industry. The extraction and processing of these materials entail environmental degradation, water pollution, human rights abuses, and supply chain vulnerabilities. Additionally, the extraction process consumes vast amounts of energy, contributing to greenhouse gas emissions and exacerbating climate change. Developing alternative battery chemistries offers a more sustainable and ethical solution by reducing reliance on scarce resources and toxic materials.

1.1. Why Focused on Safety Assessment?

It is crucial due to the inherent risks associated with lithium-ion batteries in electric vehicles [6], and these risks include over-voltage, high temperature, overcurrent or power, and thermal runway. In order to ensure the safe and reliable operation of electric vehicles, that should cover the design and manufacturing processes, as well as the operation and maintenance of the batteries. Evaluation of the safety features and materials used in the EV Battery design, testing and Analysis, Implementation of Risk Mitigation Strategies, Establishing Guidelines and standards, and monitoring the safety performance in real-world conditions minimize the risk of accidents and incidents and also enhance the overall safety of electric vehicles. Several important steps need to be taken:

1.4.1. Identify and analyze potential risks and hazards associated with lithium-ion batteries in electric vehicles.

1.4.2. Develop and implement advanced state estimation techniques to accurately characterize the battery and detect any abnormalities or deviations.

1.4.3. Implement intelligent and adaptive balancing techniques to address cell variations and optimize the performance of the battery pack.

1.4.4. Implement Robust safety management strategies, such as thermal modeling, battery management systems and testing, to identify potential thermal runway risks that can monitor, control the performance and mitigate them effectively in real-time.

1.4.5. Evaluate protocols and establish guidelines for safe handling, storage, regular inspection, maintenance, testing and disposal of lithium-ion batteries throughout their lifecycle, including proper recycling practices to minimize environmental impact.

1.4.6. It helps to ensure the safe, reliable and sustainable use of lithium-ion batteries in electric vehicles, reducing the risk of accidents and promoting the adoption of electric vehicles as a clean and efficient mode of transportation.

1.4.7. A reporting and monitoring system to track incidents, accidents, and failures related to lithium-ion batteries in electric vehicles in order to identify and address any potential safety issues promptly.

2. Material & Method

2.1. EV Batteries Energy Storage System- Second Life

In today's rapidly changing world, the significance of accurate weather forecasts cannot be overstated. In line with the goal of increasing sustainable practices and reducing waste, the concept of a second life for electric vehicle batteries has emerged. The concept of a second life for electric vehicle batteries refers to repurposing used EV batteries for other applications after they have reached their end-of-life in electric vehicles [7]. These repurposed batteries can still have significant energy storage capacity and be used in applications such as stationary energy storage for renewable energy systems. BESS plays an important role in today's energy mix as well as commercial and industrial applications enable electric grids to become more flexible and resilient. It allows energy grid operators to store generated energy by solar and wind at times when those resources are abundant and discharge that energy at a later time when needed. Therefore, this lithium-based battery is growing rapidly and widely deployed over 85-90% of the market. They must have a BMS (battery management system) that acts as the brain of the battery system, with primary functions being to safeguard and protect the battery from damage in various operational scenarios. To achieve this, the battery operates within predetermined ranges from several critical parameters, including state of charge, state of health, voltage, current and temperature. More Sophisticated BMS uses a framework that allows real-time monitoring and protection of the battery not just at the cell level but at the module, string and system level. BMS constantly monitors the status of the battery and uses special algorithms to analyze the data, control the battery environment and balance it. This is critical for the thermal management system to prevent thermal runway and also ensures the safety and longevity of the lithium-based battery. The HAVC regulates the internal environment by moving air between the inside and outside of the system's enclosure, maintaining an optimal operating temperature, and good air distribution helps prolong the life cycle of the battery system. Therefore, it is crucial to minimize hazards and ensure the safety of vehicle operation, charging stations, critical issues such as overcharging, overheating, and cell unbalancing, individuals, the environment [8], and from their second life applications throughout their entire lifespan [9].

Table 1. Comparison of electric vehicles with other Fuel-Driven vehicles

	Petrol	CNG	Diesel	EV
Ex- Shroom Price (Rupee)	8.29 lakh	8.84 lakh (CNG kit in Petrol Car)	9.59 lakh	14.24 lakh
Claimed Mileage/ Range	17.4 km/ litre	20 km/ kg	22.4 km/ litre	312 km
Running cost Per Month	5375	2342	3484	392 (charging station) 697 (Home Charge)
Annual Maintenance Cost	6500-7000	7000-8000	9500-10,000	5.102
Annual Third-Party Insurance Premium	3221	3281	3221	1855 (> 30kwh) 2838 (30-65 kwh) 6707 (<65 kwh)
Annual Comprehensive Insurance Premium	7096	7681	6496	14439
Car Life	15 years	15 years	10 years	8-10 years
Carbon Emission (g Co2/km)	117 (<1000cc)	63 (<800cc)	105 (<1000cc)	Nil; 70 (30kwh)
Running Cost Per Km	5.97	3.85	5.55	0.43
Fuel Prices (Rupee/ km)	108.67	93.93	92.52	8

2.2. Longevity, Reliability and Potential Failures of LiB's

Due to the increasing concerns about global warming, greenhouse gas emissions, and the depletion of fossil fuels, electric vehicles have gained significant popularity due to their performance and efficiency in recent decades [7]. Lithium-ion batteries have emerged as the preferred choice for powering electric vehicles due to their lightweight, fast charging, high energy density, low self-discharge, and long lifespan [10]. The manufacturing and supply chain of lithium-ion batteries must also be taken into consideration, as any issues or flaws in the production process can contribute to battery malfunctions and safety risks. In order to reduce safety risks and promote the circular economy of lithium-ion batteries, it is necessary to establish proper handling and recycling systems for retired batteries development of robust and efficient recycling processes to address the environmental concerns associated with their disposal. This will not only mitigate the potential risks of improper disposal or handling but also maximize the value of the materials and resources within the batteries [11]. It is important to consider external factors that may impact the safety and performance of lithium-ion batteries, such as temperature variations, mechanical stress, and other environmental conditions [12]. By identifying potential failures and implementing appropriate safety measures, the risks associated with lithium-ion batteries can be minimized, ensuring a more sustainable and reliable energy storage solution. This assessment should encompass the production, use, and end-of-life stages of the batteries, considering factors such as manufacturing processes, operational safety measures, transportation, storage, and recycling procedures.

2.3. Enhancing EV Safety through Battery Management

The use of machine learning techniques in predicting the operating conditions of lithium-ion batteries has provided opportunities for enhancing the safety management of energy storage systems, including electric vehicles [13]. To ensure safe operation and maintenance, mitigate potential risks of the thermal runway, and optimize the performance and longevity of battery energy storage power plants, it is crucial to effectively monitor the health and safety of large-scale battery systems. This can be achieved by implementing machine learning techniques to analyze real-time data on the voltage, current, and temperature of individual battery cells. This approach allows for early evaluation and warning of battery safety characteristics, helping to mitigate potential risks of thermal runway caused by battery abuse. The crucial aspects for ensuring their profitable application in the automotive industry include lower costs, lower safety risks, higher specific energy density, and longer lifetime under everyday conditions. Additionally, by accurately assessing the safety of lithium-ion batteries throughout their lifecycle, we can enable second-life applications of these batteries after their usage in electric vehicles.

2.4. Categorization of Hazard & Risks of EV Battery

The categorization of hazards and risks associated with EV batteries is an essential step in the risk management process. This categorization helps to identify the potential dangers and evaluate the likelihood and severity of incidents. By categorizing hazards and risks, appropriate control measures can be implemented to mitigate the identified risks [14]. Some possible categories of hazards and risks associated with EV batteries include:

2.4.1. Thermal Runway and Overheating

Lithium-ion batteries are susceptible to thermal runway, which can result in fires or explosions.

2.4.2. Electrochemical Reactions and Internal Short Circuits

The chemical reactions occurring within lithium-ion batteries can lead to the formation of gas, electrolyte leakage, and internal short circuits.

2.4.3. Improper Handling and Disposal

Improper handling and disposal of lithium-ion batteries can lead to environmental contamination and pose health risks.

2.4.4. Inadequate Manufacturing Processes

Faulty manufacturing processes can lead to defects in the batteries, which may result in decreased performance and potential safety hazards.

2.4.5. Inadequate Charging and Discharging Processes

Improper charging and discharging of lithium-ion batteries can lead to capacity loss, decreased performance, and potentially catastrophic failures.

2.4.6. Inadequate Electrical and Thermal Management

Improper electrical and thermal management can lead to overcharging, overheating, and thermal runways.

2.4.7. Transportation and Storage Risks

During transportation and storage, lithium-ion batteries can be exposed to conditions that may impact their safety, such as extreme temperatures or mechanical stress.

2.4.8. Safety Protocols and Training for Users

It is important to educate users on safe handling, charging, and storage practices to minimize the risk of accidents or incidents.

2.5. Health Problem

Exposure to toxic metals such as lithium, cobalt, and nickel, as well as flammable electrolytes that contain flammable solvents found in lithium-ion batteries, can pose a risk to human health. Exposure to these materials can pose health risks to workers involved in manufacturing, maintenance, and recycling processes, as well as to individuals who come into contact with batteries during use or disposal if proper safety measures are not in place. This can lead to safety hazards such as fires and explosions, which can result in serious injuries or even fatalities and prevention of adverse health effects. To mitigate this risk, it is important to implement strict safety protocols and guidelines for handling lithium-ion batteries throughout their lifecycle. These protocols should include proper training for workers, the use of personal protective equipment, proper Ventilation in battery manufacturing, the establishment of safe handling and proper waste management (disposal practices) and recycling processes in place to prevent the release of hazardous materials into the environment [15]. Furthermore, research into advanced recycling technologies is necessary to recover valuable materials from spent lithium-ion batteries and minimize environmental impact [16]. Additionally, regular monitoring and testing of battery cells can help identify any potential risks or malfunctions early on, allowing for prompt intervention and prevention of adverse health effects.

2.6. Fire & Explosion Hazard

Fire and explosion risks in lithium-ion batteries are a major concern due to their flammable electrolytes and the potential for thermal runaway. These risks can be attributed to various factors such as internal short circuits, thermal runways, overheating, overcharging, physical damage, or manufacturing defects and external factors like high temperatures or physical damage.

2.7. Environmental Hazard

Hazards to the natural environment can arise from the extraction of key minerals used in battery production [17]; potential environmental contamination during the manufacturing process itself can result in air and water pollution if proper control measures are not in place. Inadequate disposal or recycling methods lead to the release of harmful chemicals and heavy metals into the environment [18] at the end of the battery's life, which significantly impacts the natural environment [19]. This includes the extraction of raw materials, such as lithium and cobalt, which can contribute to deforestation, water pollution, and habitat destruction [17]. Furthermore, the extended implication on the environment and national economy for battery systems, including lithium-ion batteries, remains uncertain.

The potential for thermal runway, fire and explosion hazards, and hazards to the natural environment are significant concerns in the lifecycle of lithium-ion batteries in electric vehicles. Key risks and hazards in the lifecycle of Lithium-ion batteries in Electric Vehicles include fire and explosion hazards and environmental impacts due to mining and production of key minerals with improper disposal or recycling methods [19]. Sustainability in the transportation sector [3]. Furthermore, ongoing research and advanced characterization techniques will contribute to a better understanding of the failure mechanisms and degradation of lithium-ion battery materials [3].

2.8. End of EV Batteries First Life

The handling process of the end of the first life of EV batteries is an important step in the successful deployment of the second life, as well as presents challenges and risks in terms of disposal and recycling. Appropriate disposal methods for lithium-ion batteries need to be developed to avoid negative environmental impacts [20]. Recycling methodologies for EV lithium-ion batteries must also be explored and implemented to ensure sustainable waste management. Additionally, the increasing demand for electric vehicles and the subsequent growth in retired or dead lithium-ion batteries creates challenges for battery recycling, which is the most common chemistry used in the industry. Appropriate disposal methods and recycling technologies need to be developed to effectively manage the waste stream of lithium-ion batteries. This growth creates a number of challenges related to the recycling of batteries [20]. Based on the conducted estimations of EV penetration level until 2030, a prediction of the waste stream of lithium batteries for the next 10 years shows the need to apply various solutions for effective waste management through educational programs, infrastructure improvements, and legislative framework adjustments [20]. Furthermore, the reusage of end-of-life batteries in non-automotive applications, such as stationary storage systems, can contribute to a circular economy and minimize environmental impacts [20]. EV batteries reached the end of their first life several options can be considered.

2.9. Ensuring the Long-Term Safety of EV Lithium-ion Batteries

One important aspect of ensuring the long-term safety of electric vehicles is the development of technologies and processes for recycling, remanufacturing, and reusing lithium-ion batteries. Efforts are being made to develop technologies and processes for recycling, remanufacturing, and reusing lithium-ion batteries in electric vehicles. The aim is to minimize the environmental impacts of the batteries throughout their life cycle and reduce the need for primary production of raw materials. Additionally, engineers involved in the development of next-generation lithium-ion batteries must integrate considerations for easier and more economical recycling, as well as minimizing environmental impacts. This includes having a good understanding of battery components, skills in electrochemistry and physic-chemistry, and knowledge of separation science and chemical engineering. One key aspect of ensuring long-term safety in the lifecycle of lithium-ion batteries in electric vehicles is implementing a comprehensive risk management safety assessment. This assessment should consider hazards and risks related to thermal runway and overheating, electrochemical reactions and internal short circuits, improper handling and disposal, inadequate manufacturing processes, and transportation and storage risks. It is also crucial to establish safety protocols and provide training for users, educating them on the proper handling, charging, and storage practices for lithium-ion batteries.

Furthermore, it is important to estimate the potential return volumes of end-of-life batteries and consider factors such as battery performance development, future battery chemistry, and reuse and recycling costs. This will help evaluate the feasibility of reverse supply chains and ensure efficient and sustainable recycling practices as well as address these challenges, cooperation between the forward and reverse supply chains is essential. By working together, companies can improve decision-making processes and optimize production and recycling planning. In today's rapidly changing world, the significance of accurate weather forecasts cannot be overstated for ensuring the long-term safety of electric vehicles with lithium-ion batteries is a critical aspect throughout their lifecycle. This includes considering various factors, such as the risk of capacity loss, decreased performance, and potential catastrophic failures due to charging. It is important to monitor electrical and thermal management systems that regulate the charging, discharging, and temperature of the batteries. Specific materials tailored for different batteries should be designed, and more efficient methods of detecting and monitoring the internal health conditions of lithium-ion batteries should be developed [21].

2.10. Incident Associated with End of EV Batteries Life

The transformation of the transport sector from reliance on fossil fuel combustion towards electric mobility (e-mobility) powered by renewable energy is pivotal when striving to mitigate greenhouse gas emissions in the sector. Aside from reducing transport emissions, electric mobility also causes considerably less air and noise pollution and reduces dependency on petroleum imports. Hence, it offers a pathway towards a more sustainable mobility option overall. There may be instances when a Lithium-ion battery has reached the end of its first life and is no longer able to meet the demands of an EV because the electric vehicle industry and second-life vehicle industry is in its early stage, the mass collection of real-world EV batteries (Lithium-ion batteries) incidents does not extend to every conceivable failure mechanism or its possibility. Therefore, a precautionary approach draws together a body of knowledge relating to EV battery incidents on a border of adjacent areas and predicts the potential challenges over the lifecycle of Lithium-ion batteries.

2.10.1. BESS Incidents

On 18/Sept./2023, at approximately 5:15 pm, a battery storage unit caught fire at the Terra-Gen Energy Storage System Facility in San Diego County, California, U.S. States. The facility is a standalone 139 MW, 560 megawatt-hour energy storage project that houses lithium-ion batteries in racks within enclosures and produces enough electricity to power up to 140,000 homes for four hours on a single charge. The fire originated inside a solar battery storage container when a battery storage unit caught fire due to exceeding temperature, which led to a thermal runway. These batteries store and discharge electricity, which is then converted from DC to AC by an inverter transformer located nearby. The energy is delivered to the SDG&E Valley Center substation, approximately one-third of a mile away. Although fire officials said the blaze was put out in about 45 minutes and extinguished by the site's internal fire prevention system. As a precautionary measure, Public Safety personnel have issued an evacuation order for the small number of homes and businesses within ¼ mile of the site where the facility is located were evacuated, and shelter-in-place orders were in effect within a half-mile of the site. They can proceed to Valley Center High School [22].

Table 2. Lithium-Ion Batteries Globally Incident Record

Years	Venting	Swelling	Fire	Explosion	Heat
1995-2015	38	17	507	158	34
2016	18	1	402	130	7
2017	32	2	553	65	16
2018	38	17	507	158	34
2019	34	1	686	76	5
2020	25	3	590	74	6
2021	55	7	1149	142	9
2022	42	1	2121	132	12
2023	11	0	1334	78	4

Fig. 2 Battery energy storage system fire incident in Terra-Gen at Sen Diego

2.10.2. Road Accidents

On 16/ April /2023 in Katraj Pune, Maharashtra fire incident involving the Tata Nexon EV XZ+ was fairly new, being introduced by Tata Motors. Tata Nexon EV XZ+ was registered in July 2022, as revealed by the government data. The lower-spec Nexon EV Prime has a 30.2kWh lithium-ion battery mated to a 129PS/245Nm electric motor. In contrast, the higher-spec Nexon EV Max has a 40.5kWh lithium-ion battery paired with a 143PS/250Nm electric motor. The claimed range is 312km Nexon EV Prime and 453km for the Nexon EV Max. The Tata Nexon EV price starts at Rs 14.49 lakh (ex-showroom), with the range-topping variant available for Rs 19.54 lakh (ex-showroom). While all passengers in the EV escaped the incident unhurt, the instance triggered an investigation taken by the team of technical experts from Tata Motors into what caused the fire. It has now been ascertained that a thermal incident caused the fire in the left headlamp area after an unauthorized repair was made from the workshop on the electric SUV.

Official Statement from Tata Motors: Over an extended period of time, this led to a short and trapped heat. The fitment and repair process at the unauthorized workshop had shortcomings, which caused an electrical malfunction in the headlamp area, leading to the thermal incident. The affected area is concentrated only in the zone of repairs carried out. We remain engaged with the customer to offer all the support needed [25].

3. Findings and Analysis

3.1. Safety Assessment of Lithium-ion Batteries

The safety assessment of lithium-ion batteries in electric vehicles is a critical aspect of risk management. This assessment involves evaluating the potential hazards and risks associated with lithium-ion batteries at each stage of their lifecycle, including design, manufacturing, operation, and disposal practices.

3.1.1. During the Design Phase

It is important to consider the chemical composition of the battery and its potential risks. This information can be obtained from the Safety Data Sheet provided by the battery manufacturer. In addition, the design should incorporate safety features such as thermal management systems and robust casing material to prevent thermal runway and minimize the risk of fire or explosion.

3.1.2. During the Manufacturing and Assembly Process

Regular inspections and quality control Measures should be implemented to identify any defects or abnormalities that could potentially compromise the safety of the battery. This will ensure that only high-quality and properly constructed batteries are released to the market.

3.1.3. During the operation of electric vehicles

Continuous monitoring of battery performance is crucial [1]. This involves monitoring factors such as temperature, voltage, and current to identify any abnormalities or signs of degradation that could increase the risk of safety incidents. These protocols should include clear procedures for identifying and responding to battery malfunctions, as well as appropriate training for first responders. Rapid detection and intervention are of utmost importance in ensuring safe and reliable operation, particularly when multiple batteries are connected in series or parallel. Therefore, diagnosing and prognosticating short circuits are of great significance in improving EV safety. This work reviews the current state of the art in diagnosing and prognosticating short circuits in lithium-ion batteries.

3.1.4. During the Disposal Phase

Proper handling and recycling are essential to minimize environmental impact and potential safety hazards.

The Safety Assessment plan for Lithium-ion Batteries following steps should be taken:

3.1.5. Evaluate the safety features and materials used in the battery design, including the cathode, anode, electrolyte, and separator, to identify potential risks and hazards.

3.1.6. Testing and analysis of the battery components under various operating conditions to assess their performance and safety characteristics.

3.1.7. Develop and implement risk mitigation strategies to address identified hazards and risks, such as battery management systems, implementing thermal management systems, improving cell design, control the temperature of the battery cells and developing safety protocols for handling and maintenance.

3.1.8. Establish clear guidelines and standards for battery manufacturing, installation, and operation to ensure consistency and adherence to meet safety protocols and requirements and adherence to international regulations.

3.1.9. Regularly reporting, monitoring systems and assessing the safety performance of lithium-ion batteries in real-world conditions, including conducting post-market surveillance and gathering feedback from users.

3.1.10. Additionally, it is important to collaborate with relevant stakeholders, such as battery manufacturers, electric vehicle manufacturers, regulatory bodies, and research institutions, to exchange knowledge and best practices in order to continuously improve.

3.1.11. Develop stringent quality control measures and standards and ensure safety training and education for users and operators of electric vehicles to promote the safe handling and operation of lithium-ion batteries.

3.1.12. Ensure proper labeling and documentation of lithium-ion batteries to facilitate tracking, identification, and recall processes in case of any safety concerns or defects.

Steps of safety Assessment carried out:

3.1.13. Assessment of the possible Battery risks

The possible Battery risks associated with the facility or activity shall be identified and assessed.

3.1.14. Assessment of safety functions: All safety functions associated with a facility or activity shall be specified and assessed.

3.1.15. Assessment of site characteristics: An assessment of the site characteristics relating to the safety of the facility or activity shall be carried out.

3.1.16. Assessment of the provisions for Battery protection: It shall be determined in the safety assessment for a facility or activity whether adequate measures are in place to protect people and the environment from the harmful effects of batteries.

3.1.17. Assessment of engineering aspects: It shall be determined in the safety assessment whether a facility or activity uses, to the extent practicable, structures, systems and components of robust and proven design.

3.1.18. Assessment of human factors: Human interactions with the facility or activity shall be addressed in the safety assessment, and it shall be determined whether the procedures and safety measures that are provided for all normal operational activities, in particular those that are necessary for the implementation of the operational limits and conditions, and those that are required for responding to anticipated operational occurrences and accident conditions, ensure an adequate level of safety.

3.1.19. Assessment of safety over the lifetime of a facility or activity: The safety assessment shall cover all the stages in the lifetime of a facility or activity in which there are possible battery risks.

3.1.20. Assessment of defence in depth: It shall be determined in the assessment of defence in depth whether adequate provisions have been made at each of the levels of defence in depth.

3.1.21. Scope of the safety analysis: The performance of a facility or activity in all operational states and, as necessary, in the post-operational phase shall be assessed in the safety analysis.

3.1.22. Deterministic and probabilistic approaches: Both deterministic and probabilistic approaches shall be included in the safety analysis.

3.1.23. Criteria for judging safety criteria: For judging, safety shall be defined for the safety analysis.

3.1.24. Uncertainty and sensitivity analysis: Uncertainty and sensitivity analysis shall be performed and taken into account in the results of the safety analysis and the conclusions drawn from it.

3.1.25. Use of computer codes: Any calculational methods and computer codes used in the safety analysis shall undergo verification and validation.

3.1.26. Use of operating experience data: Data on operational safety performance shall be collected and assessed.

3.1.27. Documentation of the safety assessment: The results and findings of the safety assessment shall be documented.

3.1.28. Independent verification: The operating organization shall carry out an independent verification of the safety assessment before it is used by the operating organization or submitted to the regulatory body.

3.1.29. Management of the safety assessment: The processes by which the safety assessment is produced shall be planned, organized, applied, audited and reviewed.

3.1.30. Use of the safety assessment: The results of the safety assessment shall be used to specify the program for maintenance, surveillance and inspection; to specify the procedures to be put in place for all operational activities significant to safety; and for responding to anticipated operational occurrences and accidents; to specify the necessary competences for the staff involved in the facility or activity; and to make decisions in an integrated, risk-informed approach.

3.1.31. Maintenance of the Safety Assessment: The safety assessment shall be periodically reviewed and updated.

3.2. Lithium-ion Battery Recycling – an Emerging Field of Concern & Waste Treatment Facilities

Waste from electronic and electrical equipment is one of the fastest-growing waste streams, with its volume expected to increase by a third from 2013 to 2017. With the rapidly increasing demand, the issue of waste management and recycling has become a major concern due to the high volume, complexity, and variety of materials found in electric vehicle batteries. To date, the recycling industry for lithium-ion batteries is lagging behind due to the growing consumer demand for electronic devices and the transition towards electric transportation. Approximately 95% of lithium-ion batteries end up in landfills instead of being recycled. This improper disposal of lithium-ion batteries can have a negative impact on the environment and resources, including the proper disposal of hazardous materials, the efficient recovery of valuable resources, and the reduction of environmental impacts.

Moreover, lithium-ion batteries contain various toxic substances, including the lack of established and efficient recycling processes, limited recycling infrastructure, the release of hazardous materials during improper disposal, and the potential for environmental contamination if not properly managed, making them hazardous if not handled properly. The development of proper waste treatment facilities specifically designed for lithium-ion battery recycling is crucial to develop and commercialize new recycling processes that are capable of recovering valuable materials more efficiently. One of the key emerging concerns in lithium-ion battery recycling facilities is the need to have the capability to safely handle and process lithium-ion batteries, extract valuable materials, and properly dispose of any hazardous components and management of waste.

Another concern is the environmental impact of different recycling processes. The environmental impacts of battery recycling need to be carefully managed and minimized. This includes reducing energy consumption, reducing greenhouse gas emissions, and implementing processes that have the least impact on the environment. In order to ensure environmental sustainability, it is important to develop more efficient recycling processes that minimize the environmental impact of lithium-ion battery recycling. These concerns emphasize the need for improved recycling technologies including inadequate regulatory oversight, supply chain risks, and the need for advancements and facilities that can effectively handle the increasing volume of lithium-ion batteries entering the waste stream. One potential solution to address the emerging concerns in lithium-ion battery recycling is the implementation of a circular economy approach, and there is a need for further policy development, regulatory oversight to ensure proper recycling, proper record-keeping systems, development of advanced waste treatment facilities, and promoting accurate information and disposal practices. In a circular economy, the emphasis is placed on minimizing waste, maximizing resource efficiency, and promoting the reuse and recycling of materials.

3.3. Safety Measures During Battery Operation and Maintenance

This includes proper training for operators and maintenance personnel, as well as following strict safety guidelines or measures for proper handling, installation, and maintenance procedures during battery operation and maintenance Phase. These measures include: -

3.3.1. Implementing proper handling and storage procedures for lithium-ion batteries to prevent damage or accidental short-circuiting.

3.3.2. Regular inspections and maintenance checks to identify any signs of degradation or potential safety hazards.

3.3.3. Training and educating users and maintenance personnel about proper handling and safety protocols.

3.3.4. Implementing robust safety protocols for charging and discharging lithium-ion batteries to prevent overcharging, which can lead to overheating and potential safety hazards.

3.3.5. Strict safety standards and guidelines implementation are crucial for risk management and safety assessment throughout the lifecycle of lithium-ion batteries in electric vehicles.

3.3.6. Regular risk assessments and evaluations should be conducted to identify any new or emerging risks associated with lithium-ion batteries in electric vehicles.

3.3.7. Developing and enforcing safety regulations and standards for the manufacturing, testing, and transportation of lithium-ion batteries to ensure their compliance with industry best practices and minimize the risk of fire, explosion, and other safety hazards.

3.3.8. Proper labelling and marking on lithium-ion batteries to provide clear instructions and warnings for safe use and handling. Testing and certification processes for lithium-ion batteries to ensure they meet safety standards and performance requirements.

3.3.9. Effective communication and reporting channels for incidents or potential safety concerns related to lithium-ion batteries in electric vehicles.

3.4. Severity, Exposure and Probability Risk Assessment Model

3.4.1. Severity

Scored 1 to 5. Entails analyzing the Potential consequences of a risk event occurring. In lithium-ion batteries, severe consequences could include thermal runway leading to fire or explosion, resulting in property damage, injuries, or even fatalities. Assessing severity involves considering factors such as the magnitude of potential harm, the extent of damage, and the likelihood of cascading effects on the vehicle, occupants, and surrounding environment. Severity Score Classification are as follows:

1 = None or Slight
2 = Minimal
3 = Significant
4 = Major
5= Catastrophic

3.4.2. Exposure

Scored 1 to 4. Involves identifying and quantifying which risk is present or likely to occur. Exposure factors may include the frequency and duration of battery usage, environmental conditions (e.g., temperature, humidity), and operational parameters (e.g., charging/discharging rates, depth of discharge).

Understanding exposure helps prioritize risks and allocate resources effectively, focusing on areas with higher exposure levels to mitigate potential hazards. Exposure Score Classification are as follows:

1 = None or Below Average
2 = Average
3 = Above Average
4 = Great

3.4.3. Probability

Scored 1 to 5. Evaluates the likelihood of a risk event occurring based on various factors such as historical data, empirical evidence, expert judgment, and simulation models. Probability may include manufacturing defects, material degradation, external impacts, improper handling, and unforeseen operational scenarios.

By assessing probability, stakeholders can gauge the likelihood of different risk scenarios and implement preventive measures accordingly, such as enhancing quality control processes, implementing robust safety protocols, and incorporating fail-safe mechanisms. Probability Score Classification is as follows:

1 = Impossible or Remote Under Normal Conditions
2 = Unlikely Under Normal Conditions
3 = 50/50 Chance
4 = Greater than 50 % Chance
5 = Very Likely

3.4.4. Calculation of Risk

The value of risk computed to evaluate the effectiveness of Severity, Exposure, Probability Risk Assessment of LiB's in Electric vehicles and Risk of Execution.

Risk = Severity X Probability X Exposure

Compute the Risk value at each Hazard Identified. The Value Substantial to Very High Range Need to be Controlled. The Assessment & Calculation Sheet is mentioned below (Table 3).

4. Recommendation

4.1. Health & Safety Measures

4.1.1. Risk Management of Lithium-ion Batteries

It involves comprehensive risk assessments, implementing safety measures, and continuously monitoring battery performance to detect any potential hazards or abnormalities to ensure their safe and reliable operation. This process should identify and address potential hazards, defects, and abnormalities in the electric vehicle batteries.

It should consider various factors, including the design and development phase, manufacturing and assembly processes, operational phase, and emergency response protocols and implement their precautionary measures to mitigate risks [1].

This process includes regular inspections and maintenance during manufacturing to ensure the safety and reliability of batteries, as well as monitoring battery performance during operation, detecting signs of degradation or malfunction, and establishing protocols and procedures for responding to safety incidents, including proper training for personnel and the availability of appropriate safety equipment.

4.2. EV Safety Regulatory

The safety of lithium-ion batteries is foremost, which has revolutionized the electric vehicle industry and also increased the adoption of electro-mobility in our society, allowing for efficient and reliable transportation without the use of fossil fuels. As these batteries become increasingly integrated into our daily lives, ensuring their safety and compliance with international standards is of paramount importance. In this study, we delve into the world of lithium-ion battery standards, current safety standards, safety testing, transportation regulations, storage, and responsible recycling and disposal practices are essential components of ensuring that lithium-ion batteries can power our vehicles while minimizing risks to both people and the environment.

The various international standards and regulations for safety testing of lithium-ion batteries in automotive applications under various abusive environments. Safety tests are presented and analyzed, including mechanical, electrical, environmental, and hazards of a chemical nature. The intention of this study is to compile the most relevant standards and regulations to identify shortcomings and areas for future improvement. These regulations are vital for ensuring the safety of both those handling the batteries and the public.

By adhering to these measures, we can enjoy the benefits of this technology with confidence in its safety and sustainability. The Society of Automotive Engineers rolls out some of the global regulations, Automotive Industry Standards by Central Motor Vehicles Rules regulations from AIS 038 to AIS 156, IS 16348, ISO 26262, ISO 12405 and United Nations Economic Commission for Europe Regulations R100, R101, R85, R136 for EV.

5. Conclusion

Ensuring the safe and reliable operation, proper design, manufacturing, testing, transportation, operation, and maintenance procedures of lithium-ion batteries in electric vehicles requires a comprehensive approach. It is also essential to minimize hazards, ensure safe functioning, and maintain overall safety. Ensuring the safe and reliable operation, proper design, manufacturing, testing, transportation, operation, and maintenance procedures of lithium-ion batteries in electric vehicles requires a comprehensive approach. It is also essential to minimize hazards, ensure safe functioning, and maintain overall safety.

Proper training, strict safety guidelines, risk assessment, mitigation strategies, thermal management, monitoring techniques, regular inspections and maintenance are all important measures to ensure the safety of lithium-ion batteries throughout their lifecycle in electric vehicles, necessary to identify. These measures are essential to prevent potential hazards such as thermal runway, electrolyte decomposition, flammability, and other safety concerns.

Table 3. Severity, Probability and Exposure calculation & Assessment sheet

Sr. No.	Activity/ Process	Hazard	Consequences	Severity (S)	Probability (P)	Exposure (E)	Risk Value = (S X E X P)
At Lithium-Ion Batteries Manufacturing Process							
1.	**Mixing**	1. Chemical Hazard 2. Dust Inhalation 3. Electrolyte Spillage 4. Physical Injuries 5. Static Charge	Respiratory Distress, Health Impairment, Illness, Burn or Fire, Injuries	3	3	2	18
2.	**Coating**	1. Chemical Hazard 2. Powder Hazard 3. Electrical Hazard 4. Noise Exposure 5. Fire & Explosion Hazards	Respiratory Problems, Skin Irritation, Health Impairment, Illness, Burn or Fire, Injuries, deafness, Shock and Electrocution	3	3	2	18
3.	**Drying**	1. Solvent Exposure 2. Electrolyte Stability 3. Over-Heating 4. Fire & Explosion Hazards	Health Impairment, Illness, Burn or Fire, Injuries	2	3	2	12
4.	**Calendering**	1. Chemical Hazard 2. Mechanical Hazard 3. Noise Exposure 4. Fire & Explosion Hazards 5. Ergonomic Hazard	Health Impairment, Illness, Burn or Fire, Injuries, Entanglement, Crushing Injury, deafness, Low back pain, Musculosketon disorder	3	3	3	27
5.	**Slitting**	1. Mechanical Hazard 2. Sharp Object 3. Fire & Explosion Hazards 4. Chemical Hazard	Lacerations, Puncture Wounds, Health Impairment, Burn or Fire, Injuries, Entanglement, Crushing Injury,	3	2	2	12
6.	**Vaccum Drying**	1. Explosive Atmosphere 2. High Temperature 3. Environment Impact 4. Chemical Hazard	Health Impairment, Equipment Malfunction, Overheating, Burn, Explosion, Pollution	3	3	3	27
7.	**Separating**	1. Chemical Hazard	Health Impairment	3	2	1	6
8.	**Stacking Or Winding**	1. Chemical Hazard 2. Mechanical Hazard 3. Electrical Hazard 4. Heat Generation 5. Ergonomic Hazard	Health Impairment, Illness, Burn or Fire, Injuries, Entanglement, Crushing Injury, Shock and Electrocution, Low back pain, Low back pain, Musculosketon disorder	2	4	2	16
9.	**Packaging**	1. Chemical Hazard 2. Mechanical Hazard 3. Electrical Hazard 4. Fire or Explosion Hazard 5. Environment Hazard	Respiratory Problems, Skin Irritation, Health Impairment, Entanglement, Crushing Injury, Burn or Fire, Injuries, Environment pollution, Shock and Electrocution	2	3	3	18

10.	**Electrolyte Filling**	1. Chemical Hazard 2. Corrosion 3. Toxicity 4. Fire or Explosion Hazard	Health Impairment, Neurological damage, Organ Failure, Respiratory Problems, Skin Irritation, Health Impairment, Burn or Fire, Injuries	2	2	2	8
11.	**Roll Pressing (Pounch Cells)**	1. Dust & Particulate Matter Generation 2. High Temperature 3. Electrical Hazard 4. Mechanical Hazard 5. Chemical Hazard 6. Ergonomic Hazard	Respiratory Problems, Skin Irritation, Health Impairment, Entanglement, Crushing Injury, Equipment Malfunction, Burn or Fire, Injuries, Shock and Electrocution, Low back pain, Musculosketon disorder	3	3	2	18
12.	**Formation**	1. Particulate Matter Generation 2. Heat Generation 3. Electrical Hazard 4. Mechanical Hazard 5. Chemical Hazard 6. Fire & Explosion Hazard	Respiratory Problems, Skin Irritation, Health Impairment, Entanglement, Crushing Injury, Equipment Malfunction, Burn or Fire, Injuries, Shock and Electrocution	3	3	2	18
13.	**Degassing**	1. Toxic Gas Emission 2. Equipment Malfunction 3. Chemical Hazard 4. Fire & Explosion Hazard	Respiratory Problems, Skin Irritation, Health Impairment, Burn or Fire, Physical Injuries	3	3	3	27
14.	**Aging**	1. Electrolyte Leakage 2. Environment Hazard 3. Electrical Hazard 4. Mechanical Hazard 5. Chemical Hazard 6. Ergonomic Hazard	Respiratory Problems, Skin Irritation, Health Impairment, Entanglement, Crushing Injury, Environment Pollution, Burn or Fire, Injuries, Shock and Electrocution, Low back pain, Musculosketon disorder	3	3	2	18
15.	**Grading, EOL Testing**	1. Noise Exposure 2. Environment Hazard 3. Thermal Runway 4. Mechanical Hazard 5. Chemical Hazard	Respiratory Problems, Skin Irritation, Health Impairment, Deafness, Environment Pollution, Burn or Fire, Injuries, Emission Toxic Gases	3	3	3	27
16.	**Storing, Packing (and Transport)**	1. Electrical Hazard 2. Chemical Hazard 3. Fire & Explosion Hazard	Respiratory Problems, Skin Irritation, Health Impairment, Burn or Fire, Shock and Electrocution	3	2	2	12
At Lithium-Ion Batteries Used in Electric Vehicles (First Life)							
1.	**Charging**	1. Short-Circuit 2. Over-Heating 3. Over-charging	Chemical Burn, Fire, Battery Damage,	3	3	3	27

		4. Electrical Hazard 5. Electrolyte Leakage	Environment Pollution, Shock and Electrocution				
2.	**Discharging (Driving)**	1. Thermal Runway 2. Over-Heating 3. Over-discharging 4. Voltage Fluctuation 5. Environmental Hazard	Thermal Runway, Fire, Battery Damage, Environment Pollution	3	3	2	18
3.	**Regenerative Braking**	1. Heat Generation 2. Over-charging 3. System Integration	Thermal Runway, Fire, Battery Damage or Failures, Over- Heating, Malfunction	3	4	2	24
4.	**Regular Maintenance**	1. Thermal Runway 2. Corrosion 3. Over-charging 4. Mechanical Damage	Thermal Runway, Fire, Battery Damage or Failures, Electrolyte Damage, Short-circuit	2	2	3	12
5.	**End of first Life**	1. Thermal Runway 2. Chemical Exposure 3. Electrolyte Release	Health Impairment, Thermal Runway, Fire, Battery Damage or Failures, Environment Damage	3	3	3	27
At Lithium-Ion Batteries Recycling							
1.	**Collection & Sorting**	1. Chemical Exposure 2. Fire Hazard 3. Mechanical Hazard 4. Electrical Hazard	Health Impairment, Burn or Fire, Electric Shock, Electrocution Injuries	3	3	2	18
2.	**Discharge & Disassembly**	1. Thermal Runway 2. Chemical Exposure 3. Mechanical Hazard 4. Electrical Hazard	Health Impairment, Burn or Fire, Electric Shock, Electrocution Injuries	3	3	3	27
3.	**Wet Shredding**	1. Thermal Runway 2. Chemical Exposure 3. Mechanical Hazard 4. Toxic Fumes 5. Environment Hazard	Health Impairment, Burn or Fire, Electric Shock, Electrocution Injuries, Explosion, Ecological Damage	3	2	3	18
4.	**Friction Washer**	1. Chemical Exposure 2. Mechanical Hazard 3. Noise 4. Heat Generation	Health Impairment, Burn or Fire, Injuries, Explosion, deafness, Entanglement,	2	2	2	8
5.	**Light & Heavy Fraction**	1.Chemical Exposure 2. Fire & Explosion Hazard 3. Air & Water Pollution 4. Occupational Health	Health Impairment, Burn or Fire, Electric Shock, Air Pollution, Explosion, Ecological Damage	3	2	2	12
6.	**Black Mass Tank**	1. Chemical Exposure 2. Fire & Explosion Hazard 3. Corrosion 4. Environment Hazard	Health Impairment, Burn or Fire, Injuries, Explosion, Ecological Damage, Battery Damage, Skin Irritation, Respiratory Issues	2	3	2	12

7.	**Filtration**	1. Chemical Exposure 2. Electrolyte Contamination 3. Particulate Matter 4. Environment Hazard 5. Heavy Metal Exposure	Health Impairment, Burn or Fire, Injuries, Explosion, Ecological Damage, Battery Damage, Skin Irritation, Respiratory Issues, Water Pollution	2	2	2	8
8.	**Liquid Diluted Electrolyte**	1. Chemical Exposure 2. Fire & Explosion Hazard 3. Corrosion 4. Environment Hazard	Health Impairment, Burn or Fire, Injuries, Explosion, Ecological Damage, Battery Damage, Skin Irritation, Respiratory Issues	2	3	3	18
9.	**Moist Black Mass**	1. Flammability 2. Toxicity 3. Corrosion 4. Environment Hazard	Health Impairment, Burn or Fire, Injuries, Explosion, Ecological Damage, Battery Damage,	3	4	2	24
10.	**Vaccum Dryer**	1. Chemical Exposure 2. Fire Hazard 3. Material Contamination 4. Electrical Hazard	Health Impairment, Burn or Fire, Electric Shock, Electrocution Injuries, Cross Contamination	2	3	2	12
11.	**Leaching (Feed Preparation & Process)**	1. Chemical Exposure 2. Fire Hazard 3. Mechanical Hazard 4. Electrical Hazard 5. Environmental Hazard 6. Corrosion	Health Impairment, Burn or Fire, Electric Shock, Electrocution Injuries, Respiratory Issues, Water Pollution, Battery Damage, Ecological Damage	3	3	2	18
12.	**Crystallization**	1. Chemical Exposure 2. Environmental Hazard	Health Impairment, Respiratory Issues, Water Pollution, Ecological Damage	2	2	1	4
13.	**Impurity Removal**	1. Chemical Exposure 2. Fire Hazard 3. Environmental Hazard 4. Corrosion	Health Impairment, Burn or Fire, Respiratory Issues, Water Pollution, Battery Damage, Ecological Damage	2	3	1	6
14.	**Extraction**	1. Chemical Exposure 2. Fire & Explosion Hazard 3. Environmental Hazard 4. Metallic Contamination 5. Airborne Particulates	Health Impairment, Burn or Fire, Explosion, Respiratory Issues, Water Pollution, Battery Damage, Ecological Damage	3	3	2	18

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