A Review on Second Life of Li-ion Batteries: Prospects, Challenges, and Issues

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Abstract: **High power density has made Li-ion batteries a reliable energy storage technology for electric vehicles (EV). This is contributing to the ever-increasing number of used Li-ion batteries. When these used batteries reach 80% of their nominal capacity, they are no longer appropriate for powering EVs due to reduced range. Safely disposing of these batteries is a matter of great concern to reduce the overall carbon footprint. These retired EV batteries will be employed as second life which can be potentially used in other applications such as renewable energy storage devices, telecommunication dc power supply, and grid ancillary service, etc. The battery typically accounts for 40% of the total cost of an EV. So, it is necessary to exploit the economics and energy that are required for battery production by combining recycle and reuse to extend the effective lifetime of the retired EV batteries and make the overall system profitable rather than dumping them directly. This paper provides a comprehensive overview of the present state of second-life batteries through studying all the relevant literature that has been conducted in this area. Second-life assessment of Li-ion batteries, applicable field, testing methodology, cost analysis and required business models are elaborately discussed in this paper so that it can play a pivotal role for future research in this emerging area.**

Keywords**: Electric vehicles, Li-ion battery, second life, environmental pollution.**

1.INTRODUCTION

Due to environmental and emerging energy concerns [1], the transportation industry is rapidly electrifying. For example, by 2030 Volvo cars will no longer provide vehicles powered exclusively by internal combustion engines [2], since electric vehicles (EVs) are proving to be a viable alternative to internal combustion engine-powered vehicles. Lithium-ion battery (LIB) is commonly used in transportation because of their high energy capacity (200-250 W h/kg), high columbic performance (nearly 100%), and lack of memory effect [3]. In the automotive industry, a LIB is commonly determined to be no longer suitable if its output falls below 80% of its nominal capacity [4]. In the coming years, a considerable number of batteries in EVs will be retired [5]. For instance, 250,000 metric tons of EV lithium-ion batteries (LIBs) are predicted to hit end-of-life (EOL) by 2025 [6]. In addition, in response to global climate change , the loss of fossil fuels has increased power production through the use of renewable energy sources such as solar or wind [4]. The created power fluctuates due to the intermittent and time-varying existence of renewable energy sources. These are difficult to process into the grid, which has an effect on grid performance, voltage stability, and reliability. This can be effectively mitigated if the generated energy from a renewable source is first deposited in a battery [7] , and then converted by an appropriate power electronic converter topology to achieve the necessary grid voltage, frequency, and permissible total harmonic distortion. Energy storage systems (ESS) will be in high demand in the coming years as more renewable energy systems are incorporated into the power grid. As a result, a large number of retired batteries will be required. If more recycling and reuse are not possible, a large number of retired batteries containing volatile chemical elements would be released into the atmosphere. Giving such retired batteries a second life would not only support the economy, but it will also help to minimize total battery demand, resulting in a substantial reduction in the use of extracted chemical materials [8].

The use of batteries after they have reached the end of their usable life is referred to as ''second-life," which is also a phenomenon with positive aspects such as lowering manufacturing costs and mitigating waste produced by direct disposal, as well as negative aspects such as battery collection, storage, handling, and recycling [9]. However, because of its high energy potential, using this retied battery has attracted interest. According to Bloomberg New Energy Finance, the combined capacity of used EV batteries could exceed 185 GWh/year by 2025, with around three-quarters of used EV batteries being reused[10]. The second-life battery (SLB) has the potential to generate more than 200 GWh by 2030, with a global value of more than $30 billion, according to another report [11]. In order to optimize their economic and environmental benefits, batteries with available residual values can be reused rather than recycled or disposed of. LIBs that have been retired due to low performance may be recycled to recover valuable materials or discarded during the reuse process. [12], [13].

This paper presents a critical review on the second life assessment of LIBs and discusses the testing methodology to screen the battery from the battery pack for second life use. This paper also highlights the cost issues and provides critical ideas on how economic benefits can be achieved from the reuse of battery. Additionally, this paper provides future research directions and future recommendations. The paper is structured to review the technical and economic challenges across all areas of the secondary life battery cycle from on-board diagnostics in first life application, post first life screening, remanufacturing, secondary life deployment and finally recycling. Section 2 discusses the testing methodology for battery degradation. Section 3 surveys the related works regarding how second life assessment is performed. Section 4 discusses the business model from an economic perspective. Section 5 indicates the future research direction and finally, conclusions are drawn in Section 6.

2. Testing Methodology for Identification of Battery Degradation

2.1 Degradation of lithium-ion battery:

Identifying the optimum point to retire the battery from its first life application in an EV is important to maximize the overall benefit of the battery across its first and second life. Lithium-ion batteries have a variety of ageing mechanisms, and the relationships between them are complex [14]. Braithwaite et al.[15] investigated the current-collector ageing phenomena of lithium-ion batteries, as well as the impact of current-collector wear and peeling on power and impedance. Petzl et al. [16] looked at the effects of lithium deposition on lithium-ion batteries and how lithium deposition manifests itself at low temperatures. Christensen et al. [17] investigated the possible failure mechanism of lithium-ion batteries caused by particle fracturing and electronic separation of active electrode material, and developed a mathematical model to measure the impact of lithium insertion and extraction. Lithium-ion battery aging processes were partitioned into two modes in [18], the loss of lithium inventory (LLI) and the loss of active material (LAM) and a mechanistic model was built in [19] that can synthesize a variety of aging scenarios based on these two modes. LAM occurs in both positive and negative electrodes and leads to a reduction in the material available for electrochemical activity; LLI causes a reduction of the amount of cyclable lithium available for transport between electrodes [20]. Pastor-Fernández et al. [21] added a conductivity loss (CL) degradation mode to explain the rise in ohmic resistance due to electrode interaction or electrolyte conduction degradation. Along with the 'Ohmic resistance rise', Dubarry et al. [19] described 'faradaic rate degradation', which is caused by processes such as the solid–electrolyte interphase (SEI) growth and pore blockage and occurs mainly due to electrodes not reacting with lithium ions at the same rate as they did at the start of life.

The main aging factor on negative electrodes (graphite, carbon, titanate, silicone, etc.) is the development of a robust interface on the electrolyte/electrode interface over time. This phenomenon is referred to as SEI [22]. This is normally seen at voltages below the electrolyte's electrochemical stability window [23], [24], which speeds up redox processes irreversibly breaking down the electrolyte and causing electrolyte loss [20]. This SEI layer is formed by Li metal electrodes, as well as graphite [25], [26]. Lithium diffusion within the SEI and graphite can be inhibited at low temperatures, resulting in metallic lithium plating, increased impedance, and additional cyclable lithium losses [27]. Plated Li can form more SEI by undergoing additional side reactions with the electrolyte, as seen in **Figure 1**. The remaining Li can be electrically isolated by the SEI growth, resulting in ''dead lithium" that cannot be recovered. As a result, there are reversible and permanent components of Li plating [20]. Both additional SEI growth and dead lithium cause a lack of lithium inventory and pore clogging, lowering conductivity [28]. High temperatures and currents, on the other hand, cause particle cracking and accelerate SEI growth [29]. SEI growth depletes the electrolyte solvents, lowering the electrolyte's volume and conductivity [20]. The square root of time roughly coincides with the SEI growth rate [30].

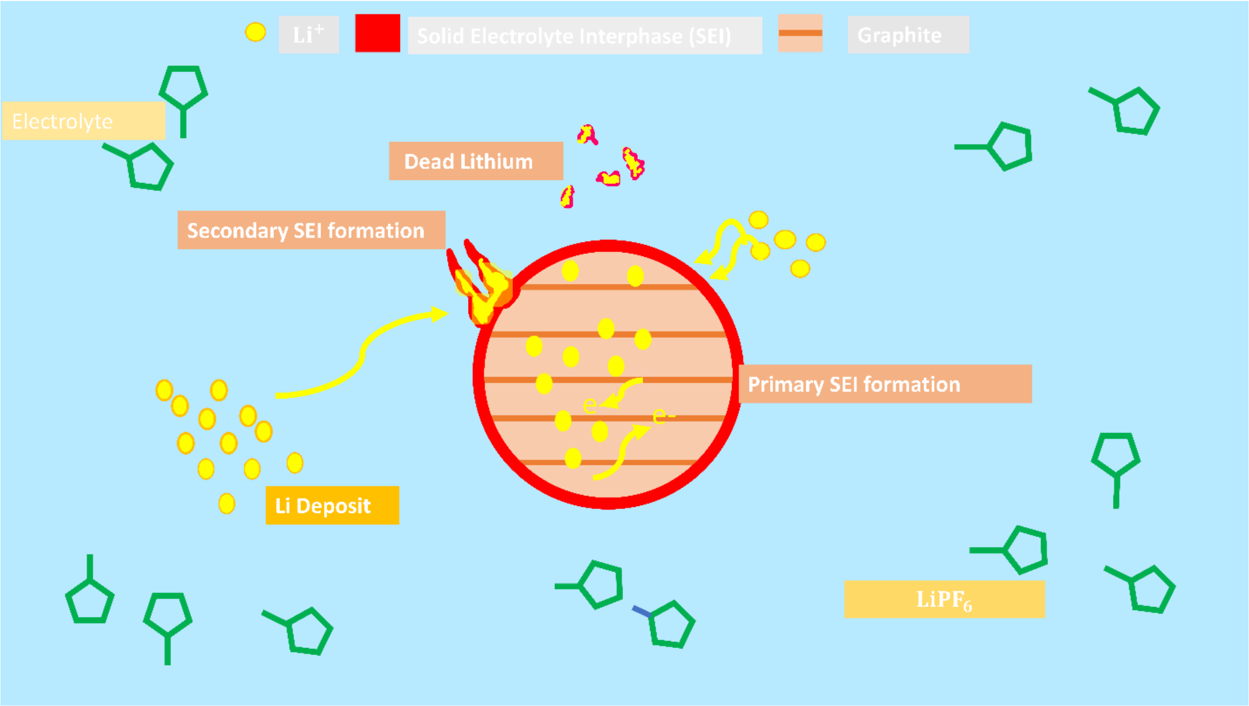


Fig.1. Lithium plating interacts with the solid-electrolyte interface [31].

2.2 Experimental techniques:

Various techniques for estimating battery ageing have been proposed in different literatures[32]–[42]. In order to assess the battery's health, several variables or notions are created to predict ageing. In much of the literature, the state of health (SOH) is the most often used metric. SOH is most commonly defined as the capacity of the battery relative to its original capacity when new but can also be based on the resistance of the battery or a combination of multiple factors for different applications. Essentially, SOH shows how a battery's present state compares to its ideal state. Aging is taken into account when calculating SOH because it is linked to changes in energy, internal resistance, and power fade [43], [44]. Ref.[45] emphasizes capacity estimation and the internal resistance estimation method for estimating SOH. The Coulomb counting procedure, which involves constantly measuring and integrating the battery current, is widely used by researchers because of its simplicity[46], [47]. SOH is determined using this method by dividing estimated capacity by rated capacity [2]. A disadvantage of conventional coulomb counting SOH estimation is that it requires the battery to be cycled across the entire 100% to 0% state of charge(SOC) range which is not always possible in an EV. The relationship between battery internal resistance, measured impedance and battery ageing can also be used to estimate battery SOH [48]. This can be achieved through utilizing transient voltage measurements caused by the variation of the current over short durations (less than 10 ms) to measure the internal resistance of the battery [49]. Internal resistance can also be measured using the Joule effect, the hybrid pulse strength characteristic test (HPPT), and other resistance measuring models [50]. The impedance of the battery pack is measured using electrochemical impedance spectroscopy (EIS)[51].

EIS applies a small alternating current/voltage perturbation to the cell over a broad frequency range to calculate the battery impedance and parameterize battery models [52]. These models are commonly based on combinations of equivalent circuit elements such as inductors, resistors and capacitors and electrochemical equivalent circuit elements such as the constant phase element and Warburg element and analyzed in the frequency domain [53]. Different elements in an equivalent circuit model (ECM) can then be attributed to electrochemical behavior in the battery, such as SEI layer or solid-state lithium diffusion, then used for SOH diagnostics. Galeotti et al. [54] showed a correlation between ECM parameters and SOH, producing diagnostic maps capable of predicting SOH with 3.73% error. Mingant et al. [55] used multivariable regression analysis based on equivalent circuit element values to estimate the SOH from EIS with 7% precision. Zhang et al. [56] applied Gaussian process machine learning to 20,000 EIS spectra to estimate capacity, remaining useful life and identify features of interested in improved SOH diagnostics.

Unlike coulomb counting, EIS measurements can be conducted in several minutes and do not require the battery to undergo a full charge or discharge cycle [54] .However, EIS response can be affected by SOC and battery temperature, leading to errors in SOH estimation. Furthermore, EIS requires accurate signal generation and analysis across a wide frequency bandwidth which would add significant cost to the battery management system. Howey et al. [57] developed a low-cost method of performing on-board EIS for SOH estimation through analyzing the battery voltage response to excitation currents generated by the motor controller. Other researchers have estimated the impedance response through analyzing signals from normal battery operation [58], [59].

An alternative to performing dedicated diagnostics tests such as EIS or charge/discharge cycles is to utilize data already measured by the battery management system. This type of analysis can be split into data driven models, such as machine learning, and parameterization of physical based models, such as Kalman filters.

A neural network (NN) is a mathematical model which parameters do not directly resemble the original model's physical or chemical structures [60]. To build the $LiFePO_4$ battery NN network structure, the NN takes the discharge current, terminal voltage, and temperature as inputs and outputs SOC. Centered on a back propagation neural network, Yang et al.[61] used maximum usable power to show the battery's SOH. The artificial neural network (ANN), which is known for its simplicity, can handle nonlinear data and does not need all of the battery's information during modeling [62]. Based on the specified environmental and load conditions, the Support Vector Machine (SVM) method, a Kernel function-based method, uses a regression algorithm to transform a nonlinear model in lower dimension to a linear model in higher dimension [49]. This approach was used to prevent the degeneracy problem in model building while maintaining particle diversity [63]. In [64], , the SVR algorithm is used to evaluate the parameters of the model during the charging/discharging state of the battery using independent variables such as current, voltage, and temperature. Nuhic et al. [65] created an SVM model to predict the SOH of a battery for electric vehicles, using two-thirds of the available data for preparation and one-third of the data for research, and estimated SOH with less than 0.0007 mean square error in real-world driving conditions.

The Kalman filter (KF), which filters parameters from erroneous and unexplained observations, is an effective method of calculating the dynamic state of the battery. This method is based on a collection of state-space mathematical equations that calls a cell dynamics discrete-time version that predicts and corrects a new state as the system operates [49]. Both input and output data are experimentally calculated in the KF process, which aids in achieving the true state's minimum mean square error assessment [66]. The extended Kalman filter (EKF) is widely used for non-linear applications since the Kalman filter (KF) is unable to deal with the non-linear properties of battery forms. EKF uses partial derivatives and first order Taylor series expansion to linearize the battery model. Mastali et al. [66] used the prismatic and cylindrical cells to incorporate both the expanded Kalman filter and the dual Kalman filter. For the determination of SOH, Gholizadeh and Salmasi [67] suggested an inclusive and unobservable model. They created a multiscale EKF that estimates the system parameter at the macroscale and the system condition at the microscale. Similarly, Xiong et al.[68] suggested the multiscale expanded Kalman filter, which had lower computational performance but higher precision estimation. Lee et al. [69] used a dual EKF in an electrochemical model to estimate battery SOC and power using the proposed OCV-SOC. Ref. [70] uses a nonlinear battery model and EKF to simulate the SOC of a lithium-ion battery. The nonlinear model is constructed using a series-connected nonlinear, open circuit voltage, and second order RC model. The linearization approach used by EKF approximates a nonlinear model by using the first or second-order terms of the Taylor series expansion to degrade the accuracy of the SOC calculation [71]. Instead of using local linearization to solve this, the unscented Kalman filter (UKF) derives the statistical distribution properties of a nonlinear system from a series of sigma points [72]. As a derivation of gradient boosting, Chen and He developed a scalable algorithm called XGBoost 'eXtreme gradient boosting' [73]. Based on discharge test data, XGBoost is used to calculate SOC under dynamic operating conditions, and the measurement has a 98.81% coefficient of determination. In Ref. [73], this thesis suggests a hybrid model that combines XGBoost and exponential smoothing.

Other approaches for estimating battery health conditions include fuzzy logic [74], incremental capacity analysis (ICA) method [75], Gaussian process regression method, Bayesian network, particle filter method [76], Thevenin model, and many others [77]–[79]. The Genetic Algorithm (GA) is an optimization method in which the variables of interest in the structure to be optimized are represented as chromosome strings. It has been successfully generalized to describe the optimal model parameters of a nonlinear structure in chemistry, physics, and mathematics. Ref. [80] used a traditional GA to define the parameters of five distinct ECMs and, as a result, estimate the SOC. In [81] , a GA is used as one of the optimization strategies to estimate the SOC by approximating the parameters of the second-order ECM equation based on SOC. Weng et al. [82] proposed SOH monitoring of lithium-ion battery modules and packs by incremental capacity peak tracking. ICA is a popular technique for lithium-ion battery SOH estimation because it can be estimated using existing sensors and can help identify underlying degradation mechanisms such as LLI and LAM. A disadvantage of ICA is that it requires constant current at low C-rates and differentiation of experimental data can amplify noise[83].

3. SECOND LIFE ASSESSMENT

3.1 Battery Screening

Owing to the inconsistency of in-pack cells, a retired battery pack is not ideal for direct reuse straight from a vehicle. While the retired batteries have enticing economic advantages, they cannot be integrated into other applications in their current state. Several considerations applicable to the aging system necessitate provisional screening procedures in order to assess battery characteristics that are appropriate. Batteries with low consistency can quickly be over discharged or over charged, resulting in heat runaway, the possibility of explosion, and other problems [84]. In the remanufacturing process, screening techniques will help detect damaged batteries in an end-of-life (EOL) pack, which can then be substituted with suitable cells. At the cell and module stage, traditional screening methods such as charge-discharge tests [85], [86], open circuit voltage (OCV) measurements [50], [87], internal resistance methods [88], statistical approaches [89], machine learning methods [84] etc. are used.

A quick and efficient screening technique was suggested based on the voltage and capacity profiles in [84]. Here, a neural network model was created to screen retired cells in large sample situations, and simulation results showed a screening error of less than 4% for large-scale retired cells. Electrochemical Impedance Spectroscopy (EIS) can be used to perform fast characterization of retired batteries, correlating state of health (SOH) to fitted equivalent circuit parameters. In [90] which screening system focused on capacity and electrochemical impedance spectroscopy (EIS) characteristics where retired EV batteries were divided into groups to satisfy the specifications of various scenarios. The battery sorting system suggested in [87] for the echeloned use of retired batteries from EVs used a combined capacity and resistance metric, the ‘effective capacity’ at specific operating conditions to sort batteries, minimize inconsistencies and optimize the life-cycle of secondary used batteries. To filter expended EV LIBs, [91] used a hybrid pulse power characterization (HPPC) technique related to capability and power ability where current pulses were used to test ion flow mobility and calculate reaction time. The classification technology's applicability was shown by experimental testing, demonstrating that it can discern the battery difference in under 80 seconds. Jiang et al. [92] used the incremental capacity analysis (ICA) approach to investigate the consistency and ageing characteristics of retired LFP batteries, concluding that the loss of Li inventory was the primary cause of capacity depletion. In [93], an effective screening system based on support vector machines (SVM) is proposed for retired $LiFePO_4$ batteries. As training and research samples, twelve retired $LiFePO_4$ battery modules are disassembled into 240 cells and their power and resistance are tested. The SVM-based OVO (one-against-one) model is trained using the filtered ICA curve based on high charging rate to easily extract power features, and the retired cells are correctly identified using this trained model. An Arduino-based device was developed in [94] to identify retired batteries based on data stored in a battery management system (BMS), which can read information such as capacity, production date, and cycle numbers. The dataset was used to train the confusion matrix screening algorithm, which was then used to choose batteries for reuse.

3.2 Battery disassembly and reassembly

After passing the required battery checks, the retired battery packs go through the 'Disassembly' phase. The disassembly procedure includes opening the battery pack casing, removing the electrical and mechanical connections between the cells, and removing auxiliary electronic parts [13]. The process, which begins with battery removal and ends with cell extraction, can take anything from 8 to 16 hours, depending on the amount of dismantling, manpower, and individual activities. Generally, the automated procedure will take less time [95]. As, there is currently no standardization for the specifications and configurations of battery packs and components, and battery device disassembly also necessitates human intervention and must be done manually [96]. In addition to the equipment and machines, [95] estimates that it would take at least two people to accomplish the job. The dismantling procedure can be followed as seen in **Figure 2**:

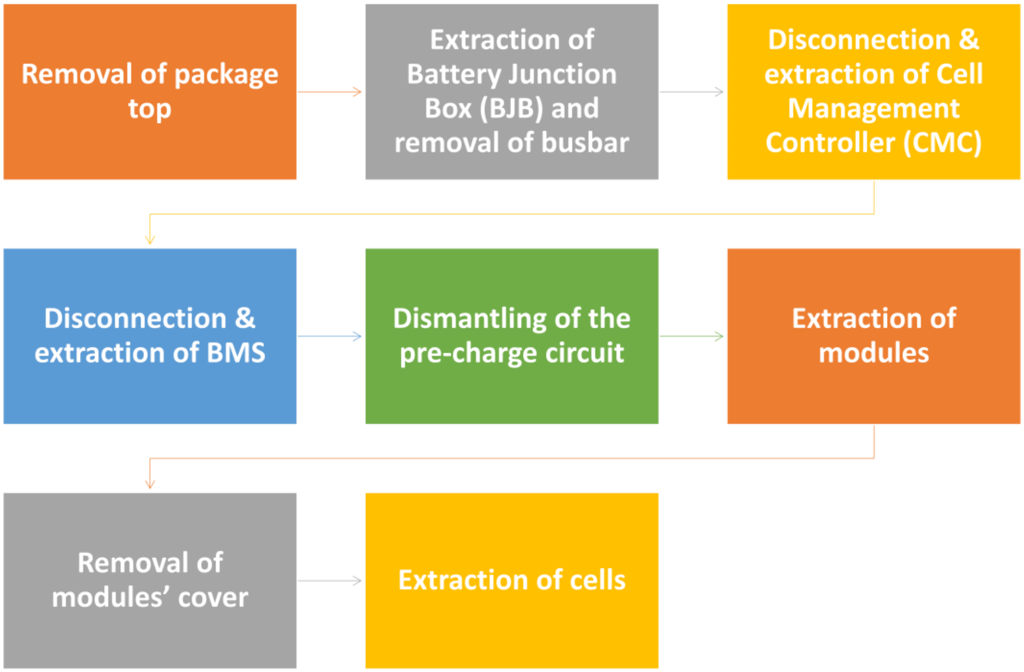


Fig.2. The dismantling process is shown in a flowchart [97].

The disassembly procedure is normally hazardous due to the high pack voltage, requiring trained technicians and specialized technology [98], while robotic battery disassembly may minimize the risk of human accident whilst also lowering manufacturing costs [99]. A task planner for robotic disassembly has been developed for the disassembly of electric vehicle Li-ion battery packs in [100], with the key goal of increasing the system's versatility and robustness. Centered on an Audi A3 Sportback e-tron hybrid Li-ion battery pack, lab tests were used to verify the designed task planner. The suggested procedure has measuring errors of less than 5 mm, according to the results. Furthermore, the machine is capable of performing all of the steps in the correct order and in a total time of 34 seconds. Virtual disassembly can simulate disassembly using data such as the device configuration, components, connections, weights, and materials. As a result, it is appropriate for detailing various disassembly options in order to simplify the disassembly steps [101]. Another innovative battery disassembly technology is built on a cloud network, which can gather field data from the internet and organize the disassembly process based on the cloud computing findings [102]. The net joint movement of the robot could be minimized by more than half using cloud simulation and cloud computing. Ref. [103] suggested a framework for automating electrochemical impedance spectroscopy (EIS) data collection utilizing a manipulator arm, which reduces the health and safety threats associated with LIBs by minimizing human interference throughout data collection. Visual servoing (VS) was used to monitor the robot when monitoring the target object in order to deal with uncertainties that could occur in the real world. The task was completed with an 83% progress rate after being replicated over 30 times with three different camera resolutions. The EIS findings from the robotic test were near identical to those obtained manually, and the Nyquist coefficient was calculated. The approximate time and cost for the dismantling process as shown in **Table 1.**

Table. 1

Times and cost required for the dismantling process [95].

Cost items	**Module**	**Cell**
Required times for disassembly to modules	5 hours	5 hours
Required times for disassembly to cells	N.A.	2.75 hours
Cost for disassembly to modules	€ 500	€ 500

Cost for disassembly to cells	N.A.	€ 275

The reassembly procedure during remanufacturing is somewhat close to the disassembly steps. The original test methods still are valid since the remanufactured packs are employed for the same reason. Furthermore, the initial battery management system (BMS), equalization management system (EMS), and thermal management system (TMS) are seldom modified. In terms of assessment techniques, screening procedures, and disassembly systems, repurpose is close to remanufacturing. Since the repurposed LIBs will begin their second life in various scenarios, the pack configuration may change, new software and/or hardware for BMS may be used [104], and different TMS and EMS may be used. The pack will be disassembled into modules (cells in EV applications are normally joined by welding) and regrouped based on the screening results, at which point any required refurbishment will be performed [105], [106].

3.3 Application of repurpose battery

The second-life battery can be used in a variety of industries. We will discuss about its implementations in this segment.

3.3.1 Grid Stationary Application

These vast quantities of SLBs can be mixed to create a wide range of MWh-capable packets, making them ideal to be used in stationary grid storage [7]. The usage of SLBs in power grids can help reduce the impact of peak load demand, known as 'peak shaving'. Customers, both small enterprises and consumers, will be able to optimize their energy consumption patterns depending on market requirements, maintaining effective energy use. Tong et al. [107] proposed a home energy solution based on repurposed batteries and photovoltaic arrays to reduce daily grid energy consumption. Experiments revealed that the approach effectively resolves the dispute between solar intermittency and fluctuating energy demand, reducing grid consumption by 64% to 100%. Matsuda et al. [108] investigated the feasibility of repurposing an electric vehicle (EV) battery for a clean energy power grid on a remote island to address concerns such as frequency fluctuation and power surplus, using real-world data collected over a seven-month span on Koshiki Island to determine the appropriate battery requirements.

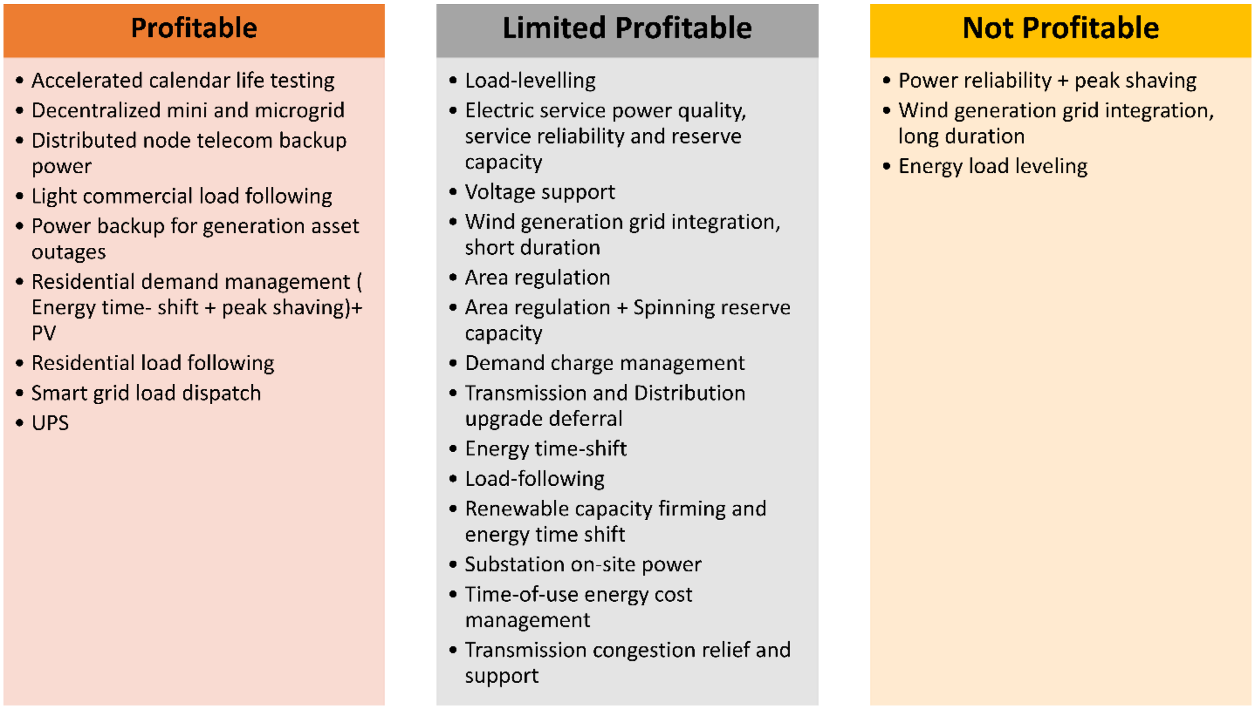
The battery can be used to mitigate the effects of renewable energy sources (RES) intermittent characteristics [7]. The intermittent presence of RESs, on the other hand, poses serious concerns about the grid's reliability and credibility. Ref. [7] proposes a procedure for deciding the optimum size and ranking of the SLB-ESS to facilitate RES grid integration. As the amount of renewable energy produced rises, the amount of energy provided by the storage facility falls. Similarly, as renewable energy production declines, the amount of energy provided by the storage facility rises. As a result, the ESS helps to reduce the intermittency induced by the RESs by charging or discharging the active control. The cost of electricity consumption is higher during peak hours than during off-peak hours. Energy arbitrage is considered a suitable solution in this situation. When energy costs are low, an energy storage device may be used to store energy. The stored energy is then used at peak periods. As a result, the cost of electricity consumption will be reduced. The usage of a storage unit will also help to mitigate the loss caused by inconsistency [109]. Using electricity arbitrage, satisfy peak demand while reducing the need for a high-capacity generator. The longevity of generation-side facilities, such as generating units and plant equipment, is dependent on timely maintenance. Owing to the strong demand for a steady supply of power, it can be difficult to find a timetable for the upkeep of such facilities. As a result, during the maintenance phase of generation properties, a replacement is available to provide the required backup. Renewable energy sources and traditional storage systems can be considered in this respect. However, their application in this case creates a number of issues. Since renewable energy sources are intermittent, they require external energy storage equipment, which raises the cost [4]. As a result, reconditioned batteries [110] are the most practical alternative in this market. When power generation assets are temporarily shut down for repairs, the SLB-ESS is triggered. A grid's frequency must be kept within a certain range of the nominal frequency. A disparity in supply and demand arises as a result of load fluctuations. As a consequence, there is frequency inconsistency. Frequency control is also needed to keep the grid frequency within the desired range. Auxiliary grid services such as frequency and area control can be provided by SLBs [111]. Furthermore, it is less expensive than a new battery.

3.3.2 Off-Grid Stationary Application

Another possible direction for SLB use is the isolated grid, which can operate in either an integrated or standalone fashion without the use of a conventional network. The incorporation of sustainable energies into this grid reaps the value of energy sustainability from an environmental and economic standpoint [112]. Since renewable energy sources are intermittent, energy storage systems are used to ensure reliability. The cost of energy storage will rise if new batteries are used. In this area, second-life batteries can be used to ensure commercial and environmental benefits.

3.3.3 Mobile Application

In more than 75 % of cases, a retired battery with a capacity of more than 60 % will meet the everyday needs of drivers [113]. Reconditioned batteries are suitable for use in short-range vehicles and recreational vehicles which have a shorter range of travel. As a result, in these types of vehicles, it is advantageous to use a second-life battery. As the number of EVs grow, so does the need for electricity to charge them. Furthermore, demand fluctuates from time to time, with peak demand lasting just a few hours. This dilemma could be overcome by using idle vehicles for vehicle to grid (V2G) facilities at charging stations [114]. For a short journey, SLB-ESS has more power than is required [113]. As a result, an electric vehicle with a reconditioned battery will provide electricity to the grid during its idle period. There has been a surge in electric vehicles (EVs) as a substitute for conventional internal combustion engine (ICE) vehicles due to environmental and economic benefits. However, a shortage of charging infrastructure is a major issue. Although the latest battery can be used in fast-charging stations, its high cost makes it unsuitable. As a result, SLB is the better option for use in a fast-charging station because reconditioned batteries are less expensive than new batteries. In [115], a DC fast charging system built on the topology of a hybrid photovoltaic-SLB tram network is proposed. MIPC (multiport interleaved power converter) is used to monitor the flow of power in this case. The system can also be used as a tram network holding system. There are several fields in which a second-life battery can be used, but not all of these fields can yield the same benefit. Profitable, minimal profitable, and non-profitable areas are shown in **Figure 3** based on current SLB costs.



Profitable

- Accelerated calendar life testing
- Decentralized mini and microgrid
- Distributed node telecom backup power
- Light commercial load following
- Power backup for generation asset outages
- Residential demand management (Energy time- shift + peak shaving)+ PV
- Residential load following
- Smart grid load dispatch
- UPS

Limited Profitable

- Load-levelling
- Electric service power quality, service reliability and reserve capacity
- Voltage support
- Wind generation grid integration, short duration
- Area regulation
- Area regulation + Spinning reserve capacity
- Demand charge management
- Transmission and Distribution upgrade deferral
- Energy time-shift
- Load-following
- Renewable capacity firming and energy time shift
- Substation on-site power
- Time-of-use energy cost management
- Transmission congestion relief and support

Not Profitable

- Power reliability + peak shaving
- Wind generation grid integration, long duration
- Energy load leveling

Fig .3. An economic overview of the profitability of second-life battery applications [9], [116].

3.4 Recycling and challenges:

3.4.1. Recycling

Batteries that are unsuitable for second use need to be recycled. For long-term development, battery recycling is crucial. The recycling method will break retired batteries into various components and remove valuable materials for use in the supply chain [98], [117]. It is considered the most commonly available approach for EOL LIBs [118] because of its high scalability and ease of handling. Physical and chemical processes [119] can be used to recycle valuable resources such as metals and cathode active materials. Recycling is a time-consuming procedure that normally requires many phases. Pre-treatment extracts cells from EV packs and then breaks them down into useful particles that can be utilized in the next step [6], [13], [120]. The products are then separated using pyrometallurgical, hydrometallurgical, bi-hydrometallurgical, and direct recycling techniques [121].

Based on variations in physical properties, the pre-treatment stage separates and enriches useful components and materials from EOL LIBs (such as shape, density and magnetic properties). Pretreatment will aid in improving recovery rates, lowering energy use, avoiding safety threats, and lowering environmental risks [120], [122]. Since spent LIBs also have residual energy that may trigger a short circuit or even an explosion during the pre-treatment period, the batteries must normally be stabilized first [123]. The brine process and ohmic discharge [124] are the most often used stabilization techniques. The brine process involves soaking the LIBs in a solvent such as NaCl or Na_2SO_4 for a long enough time to properly discharge them. Discharging the battery with an external load circuit is referred to as the ohmic discharge process. The ohmic approach will reduce the time it takes to completely discharge expended LIBs as compared to the brine method. The battery system will be broken into module or cell level during the disassembly procedure, with steps including opening the battery casing, cutting electrical links between modules, removing mechanical connections between components and the foundation, and extracting auxiliary electronic parts [13], [125]. The aim of the disassembly method is to reduce environmental costs thus maximizing economic gains [126], and for LIB disassembly, several advanced technology have been used. The LIBs need coarse shredding after disassembly to reduce the granularity of the products for further recycling [127]. To avoid thermal runaway and minimize emissions, the battery shredding or crushing process may be carried out in an inert gas atmosphere such as carbon dioxide [128]. Crushing and separating stages can help enrich precious materials, and multistage methods have the ability to be used on a wide scale.

The new recycling process is mostly based on high-value metals in cathode materials, such as Co, Li, and Ni [118], [129] since cathode materials account for around 40% of the overall value of LIBs. After pre-treatment, the useful portion of the products can be submitted to pyrometallurgical, hydrometallurgical, bio-hydrometallurgical, and direct recycling processes [130], [131]. Pure metals, alloys, compounds, solutions containing metal ions, and slag are some of the major components of the recycling process [120].

3.4.2 Recycling challenges:

Because of the difficulty of battery construction, battery material chemistries, and the existing scarcity of waste stock to supply the LIB recycling industry for the operation to be commercially feasible, recycling is regarded as less appealing [132]. Low volume sources of EoL LIBs are blamed for the shortage of lithium battery recycling in Europe. Just 5% of LIB battery waste, including car batteries, was collected for recycling in 2019 [133]–[135]. Several corporations contend that the 5% figure worth of LIB waste obtained is deceptive [9]. Lithium battery demand in North America is comparatively low, according to the Consortium for Battery Innovation, so the materials recovered from LIB manufacturing activities would most likely have to be exported to other countries, including such China [133]. Wang et al. [136] studied the economics of LIB recycling infrastructure and discovered that providing a well-functioning storage and recycle framework is critical for reducing associated environmental effects, and recycling is only commercially viable if sufficiently spent LIBs are available. It was recorded that waste batteries produced in Europe and North America were exported to China owing to higher buying rates for waste materials [137]. According to Technavio, an Australian market research firm, LIB recycling is on a limited scale globally, with total LIB recycling accounting for just 8.86% of the secondary battery recycling market share in 2018 [138]. Few recyclers in the United States, Europe, Canada, and Japan have effective LIB recycling process technology, but they lack the waste battery supplies to make it viable [139]. According to Circular Energy Storage's most recent figures, more than 1.2 million tons of waste LIBs will be recovered worldwide by 2030; the amount of recycled lithium available to the global battery supply chain will be about half that of today's lithium mining sector, and recycled cobalt will be around a quarter of today's equivalent [140]. The battery collection network and recycling scheme will need to be supported and improved by government policies.

As seen in **Figure 4 (a)**, a LIB is made up of different elements. Three of the most common metals in LIBs are cobalt, lithium, and nickel. The price of cobalt and lithium has decreased in recent years, as seen in **Figure 4 (b)**. Recovery of cobalt from spent LIBs will struggle to cope with mined cobalt if the price of cobalt fell. Furthermore, prices of lithium have been falling and volatile [141]. If battery producers choose mined over recycled, depending on purity and cost, many recyclers would be forced out of business [9]. Another threat to the viability of battery recycling is the recent resurgence in the use of $LiFePO_4$ as a cathode active material in automotive applications, facilitated through the introduction of cell-to-pack designs such as the BYD blade [142]. The lower value and high availability of iron and phosphorous compared to nickel, manganese and cobalt reduces the financial incentive for battery recycling and may require additional recycling incentives or legislation.

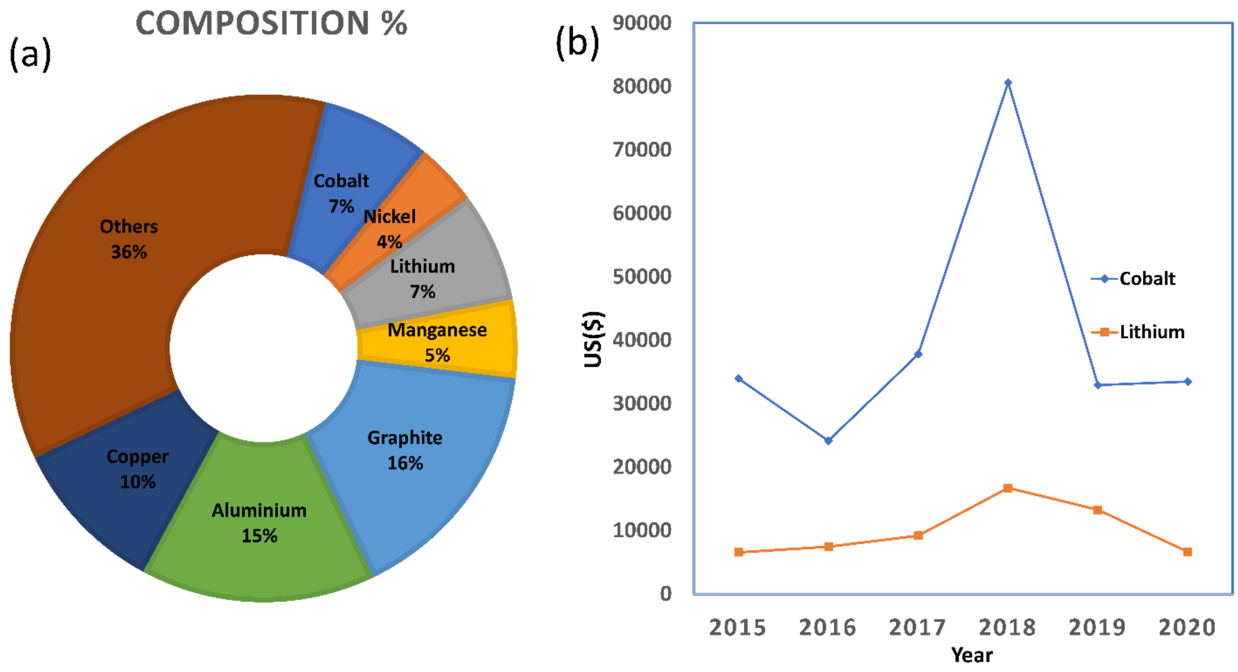


Fig.4. (a) Components of a typical NMC lithium ion battery by mass [9]. (b) Price of cobalt and lithium per metric tonne between 2015 and 2020 [143], [144].

Recyclers must sort and isolate batteries by chemical composition to meet the requirements of manufacturers purchasing recycled products [145]. One of the difficulties in sorting spent LIBs is recognizing the chemistry within the battery due to a lack of proper labeling, uniform design, or simple signs on the box, which makes the sorting process challenging to automate with robots [13]. Robotics and automation are carried out in highly organized facilities in the industrial industry, where robots execute preprogrammed routine behavior in relation to precisely known objects in set positions. Since there is no design standardization for LIB packs, modules, or cells in the automotive industry, and it is unlikely to happen anytime soon [13]. As a consequence of these current constraints, artificial intelligence (AI) research could provide a viable solution to this big problem [9].

4. OPTIMAL BUSINESS MODEL

4.1 Cost Issue

The main cost contributors for the use of SLBs are listed in a study released by the Sandia National Laboratory, with funds for producing SLBs, labor expenditures, general and administrative costs, and packaging materials identified as the major contributors [146]. The cost of purchasing retired batteries is the most costly of all prices, accounting for 56 % cost of second-life batteries [146] . **Figure 5** depicts all of the variables that influence SLB price that were discovered in this research. Here, labor costs and general administration come in second and third, both accounting for 13% of the total cost of battery refurbishment. However, labor and general administrative expenses differ from country to country. According to **Figure 6**, the cost of qualified skilled labor in various countries, the refurbishment labor cost in China, Chile, and Poland is lower than in the United States and Australia [147]. Since general administration is linked to labor costs, the expense of general administration is reduced as well [9]. McLoughlin et al. [148] showed costs for SLB-ESSs for various purposes, including residential, commercial, and industrial applications, with residential setups having the lowest costs and industrial applications having the highest, as predicted from their sizes. Transportation costs are the second most significant cost in this case. Neubauer et al. [149] looked at the impact of SLB-ESS module size on cost, taking into account various cell-level fault rates to figure out how much it would cost to buy used batteries and make SLB-ESSs for module sizes up to 24 kWh. At high cell fault levels of 1% the cell buying cost was not greatly affected, but the manufacturing cost of SLB-ESS increased as more work was taken in the testing process to identify faulty cells. For nearly all module sizes ranging from 8 to 24 kWh, the lowest fault rate of 0.01 percent resulted in the lowest cost of around $30/kWh. Thus, variations have been observed in various cost analyses, as seen in **Figure 7**.

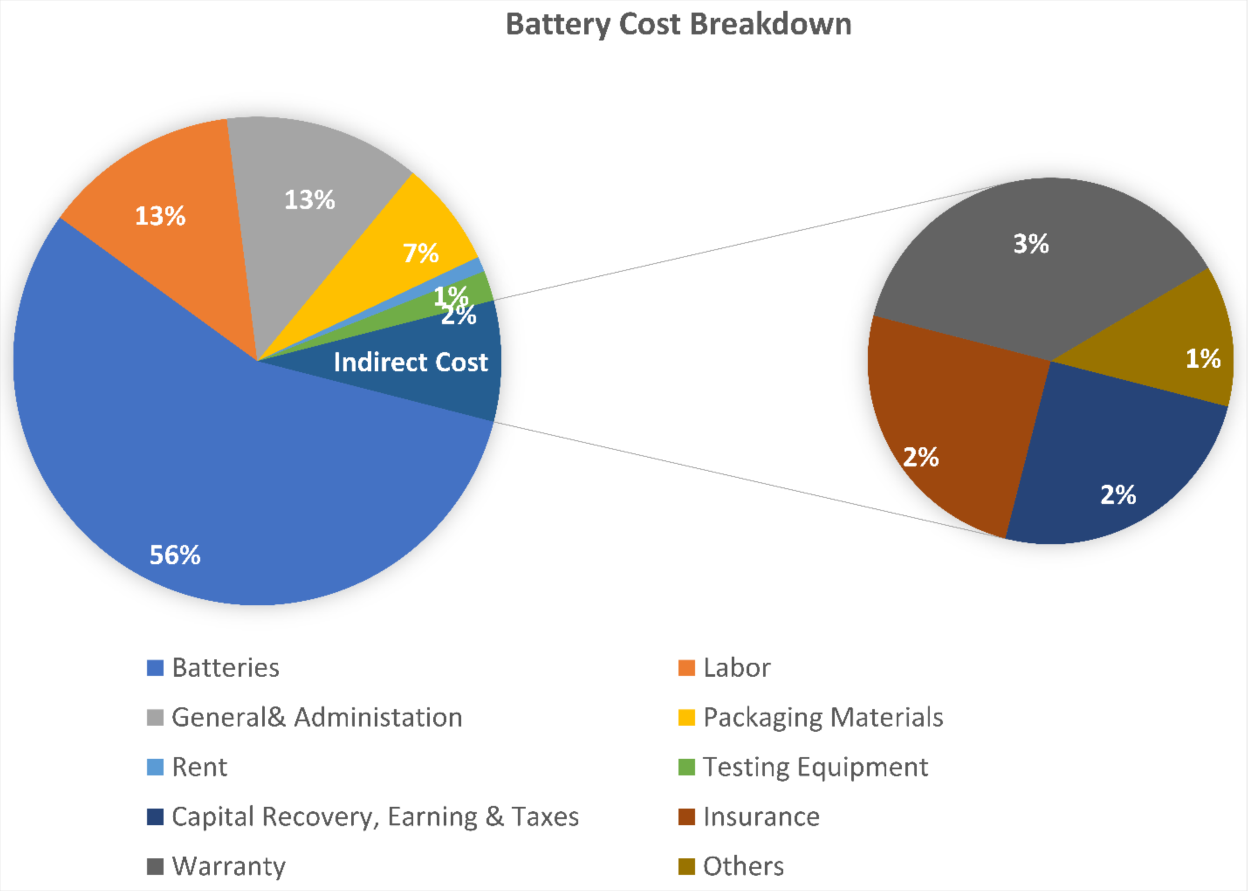


Fig.5. Cost breakdown of seconf life battery [146].

Fig.6. Differences in labor costs across countries [147]

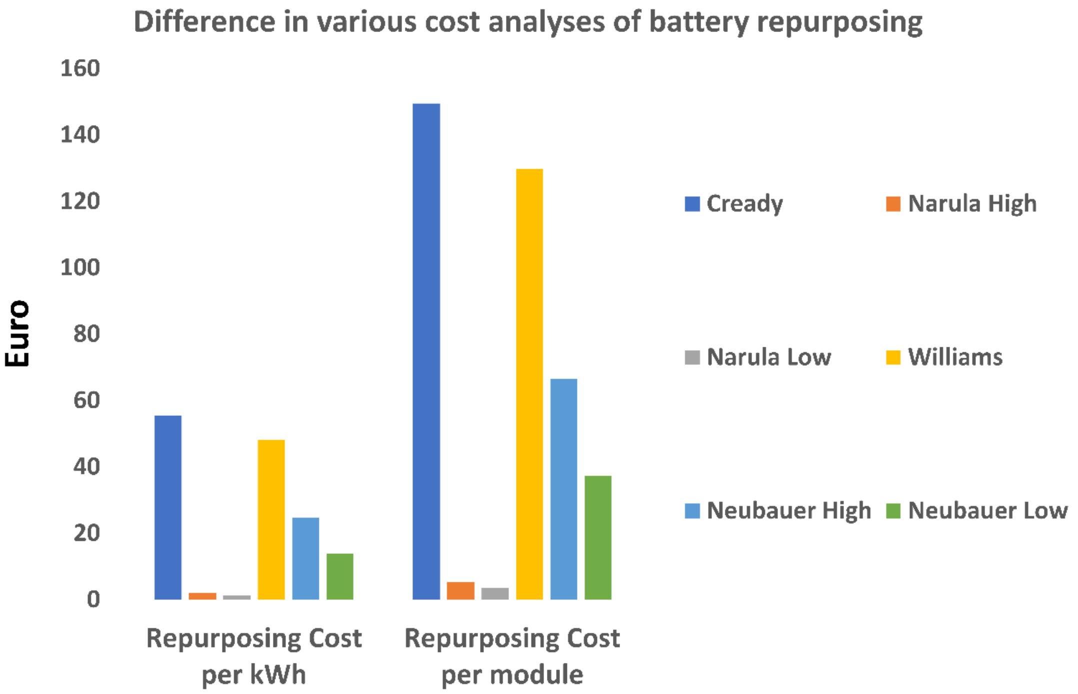


Fig.7. Disparity in various battery repurposing cost analyses [146], [149]–[152].

The sale price is made up of the purchase price, the cost of repurposing, and a profit margin. Ref.[153] introduced a new factor known as the "discount factor" to promote the utilization of SLB by manufacturers and EV users who may otherwise have no demand for recycled batteries. According to the available SLB literature, repurposing costs and sale prices range from optimistic to fair to reasonably high. According[154], the sale price of SLB will be about $44/kWh, with the cost of re-purposing estimated at $20/kWh. According to Casals et al. [155], if SLB is purchased at €38.3/kWh for a residential application, it becomes lucrative for customers. In [156], they calculated the Benefit-Cost Ratio (BCR) by considering the initial capital cost, annual sales, operation and maintenance, and discount rate, and concluded that new LIBs are more lucrative than SLB if the SLB costs 80% or more of the new LIB value.

4.2 Business Model

The business model viability of reusing electric vehicle batteries is based on a number of important factors. The cost of repurposing, which includes dismantling, assessing, applying a BMS, and repackaging, could make the SLB price unfavorable [95], [156]. Furthermore, since the cost of new LIBs is decreasing over time, SLB deployment may become a problem in the future. According to reference [157], the cost of newly assembled batteries will be halved by 2020 compared to 2015. This is due to significant technical advancements in battery production and economies of scale. Customers will choose new LIB to SLB if the environmental gain were forgotten and the price of LIBs decreases to the point that it might cost the same as SLBs. According to reference [150], original equipment manufacturers (OEM) will play a significant role in the SLB industry by launching SLB projects, since they have convenient access to the SLB supply chain and already have the experience and equipment needed to produce SLB-ESS. Nissan has already shown the viability of such a strategy through its 4R Energy Corp. joint venture with Sumitomo Corp. [158]. A sustainable business model should be built based on certain criteria such as current expense, internal rate of return, and return on investment to achieve sustainability. Several OEMs have played a key role in the development of business models, as seen in Table 2.

Table 2
Some notable business models for reusable batteries [159], [160]

Joint Ventures	Country	Description
Yinlong Energy	China	YLE (Yinlong Energy) sells electric vehicles to financial institutions, which then rent them to bus companies. YLE gave free repairs to these bus operators as part of a 10-year lease agreement. After the tenancy ended, the bus companies will refund the EVs to YLE.
Brunp	China	Brunp was a resource recovery company that collected discarded vehicles and retired batteries.
4R Energy	Japan	4R Energy was the first company to focus on the EV battery's intermediate operation. The corporation tried to identify the technological issues associated with battery reuse. They used retired batteries from taxis in a variety of projects to check technological challenges and business model checks.
FreeWire Technology	USA	Mobi Charger (a smartphone and compact charging station) was created by FreeWire Technology using Nissan Leaf batteries. The Mobi Charger will be charged and run all day long during the night, particularly when electricity is cheap. This invention has reduced construction costs and time, as well as providing one of the most effective methods for reusing retired batteries.
General Motors/ ABB	USA	A GM office building site will be powered by 5 Chevrolet Volt LIBs, a 74 kW solar array, and two 2 kW wind turbines.
Renault/Connected Energy Ltd	United Kingdom, Europe	"E-STOR" is an on-site energy storage system that avoids power grid overload and manages supply and demand.
Daimler GETEC/The Mobility House Remondis/EnBW	Germany	Degraded EV batteries from Daimler EV models are used in a battery storage unit with a total capacity of 13 MWh

Mitsubishi/PSA EDF/Forsee Power/ MMC	France	Optimization of bi-directional battery energy consumption from retired batteries
BMW/Vattenfall/ Bosch	Germany	2MW of output and 2.8MWh of energy are provided by 2,600 battery modules from 100 electric cars.
BMW/PG&E	USA	With the support of 100 BMW i3 owners, an 18-month pilot project will show EV smart charging and grid performance optimization.

The National Renewable Energy Laboratory (NREL) in the United States developed a business model for evaluating EV LIBs reuse costs based on a set of assumptions, including transportation distance, capital cost, and material cost, that revealed a total reuse cost of 44 \$/kWh, with battery cost of 20 \$/kWh and repurposing cost of 24 \$/kWh[161]. SLB's consumer paradigm of industry was highlighted by Klör et al. [162]. Ref.[155] investigated the economics of repurposing second-hand EV batteries in residential situations, finding that if the battery price is 38.3 €/kWh, which is the positive lower bound of the predicted price, repurposing EV LIBs is economically feasible. It could be difficult to make a profit if the battery price increases to 83 €/kWh. Table 3 lists several noteworthy business models suggested by various authors.

Table 3

Proposed business model of different authors

Authors	Proposed model	Description
Wen-Chen et al. [163]	Sell an EV exclusive of battery but lease it	Customers who lease newly produced batteries from manufacturers only pay a reasonable monthly rental. After the first application, the retired battery can be sent to the reuse stage. It will be ready for further lease to the energy storage industry once the upgrade is completed.
Jiao et al. [164]	1.Standard Business Model	SLBs are only sold by the OEM to battery second use (B2U) solution providers. The final solution for end-customers is prepared by the B2U solution provider.
	2.Collaborative Business Model	Instead of simply selling, the OEM collaborates with B2U solution providers and contributes to the creation of the final solution for end-users..
	3. Integrative Business Model	The OEM develops and delivers the final solutions to the final customers.
Klör et al. [162]	1. Closed Market Model	OEMs work with battery or automobile suppliers to span the entire life cycle of the electric vehicle batteries (EVBs).
	2. Intermediary-based Market Model	On the basis of second life consumers' requests, an intermediary can collect retired EVBs from automotive companies, car owners, and battery manufacturing companies and offer them for use in second life applications.
	3. Open market Model Market	On an online marketplace, a marketplace operator can run an open market to bring demand and supply of retired EVBs together.
Linda Olsson et al. [165]	1.Linear Business Model	OEMs use personalized modules in their vehicles. OEMs and dismantlers have formed alliances that enable them to collect all used batteries for recycling. Batteries can be removed and unpacked in approved workshops that have been certified by dismantlers or OEMs before being sent to recycling actors for recycling.
	2.Optimized Recycling Model	After the recycling company and the OEMs collaborate, the recycling actors will collect retired batters from dismantlers or workshops. The recycling company performs unpacking and recycling in an automated process.
	3.Circular Model 1	Dismantlers or workshops conduct diagnostics on retired batteries to see if they have enough power to be used again. Batteries are

	refurbished and repaired in approved workshops that are in close contact with the OEMs in order to prepare them for further use in vehicles.
4. Circular Model 2	Dismantlers or labs conduct diagnostics on withdrawn batteries to see whether they have enough power to be used in cars again, whether they can be recycled, or whether they should be refurbished, repackaged, and transported for reuse.

5. Future research direction

Batteries with a second life and their implementations are relatively new subjects. As a result, some problems, such as standardizations and regulations for SLB, should be developed. There are no governing principles in place for SLB. Manufacturers use a variety of cell chemistries and sizes, making second-life applications difficult. While some well-known firms, such as Nissan, have played an important role in resolving this, it is insufficient [4]. There are several industry obstacles that are limiting the growth of the second life market [166]. When using a large number of retired batteries, technological obstacles such as scanning, protection, evolution procedures, and regroup strategies can be difficult to resolve. This problem can be solved by doing thorough analysis to identify second-life applications, historical datasets, and managing the potential cost of repurposing. To prevent incidents and needless non-required regulations, it is important to ensure the safety and working environment. More study is needed on safety in the handling and transportation of retired batteries, as there has been less work in this area and there is a risk of accidents due to a lack of awareness, inadequate commercial and legislative solutions.

The cost of battery manufacturing is steadily declining as advanced manufacturing technologies and instrumentation become available [157]. As a result, lowering the cost of SLB is important. If the cost of SLB cannot be regulated, the new life battery will one day be less costly than the SLB. Both the atmosphere and the economy will suffer as a result of this situation.

Through our study, we have determined the following requirements that will bring progress in this sector:

- Standardization and regulation for SLB should be established. Non-exposed latent phenomena of electrode loss should be exposed.
- Accurate resolutions should be developed to eliminate market barriers.
- A realistic scenario should be created to determine the effect of SLB on the ecosystem.
- Advanced technologies should be created to reduce SLB wastage through better manufacturing and diagnostics.

Other aspects of the reconditioned battery serve as important steppingstones for future testing. High-quality batteries, such as solid-state batteries, would enter the industry as a result of technical advancement [4]. As a result, it could be useful if significant studies can be conducted on the possibility of a second life for these types of batteries during the development stage. In terms of stability, interruption, and data protection, further research should be done to improve the efficiency of wireless power transformation to charge a battery.

6. Conclusion

Decarbonized power and transportation electrification are seen as the most potential alternatives to the environmental crisis, which is one of humanity's most intractable issues. The electric vehicle movement is steadily altering the transportation market. Due to advantages such as high energy/power density, high efficiency, and long life, LIBs have been commonly used for EV energy supply. As a result, LIB demand is growing last year in tandem with the popularity of electric vehicles. As a consequence of these developments there will be a substantial number of retired LIBs and a lack of Li assets. However, owing to possible economic and environmental threats, the EOL problem of LIBs must be closely considered with the significant rise in EVs. SLB may be used in second life applications with significant economic and environmental advantages, according to the literature discussed in this paper. The economic effect of reusing EV batteries could lower the cost of EVs and provide a more affordable option for SLB users. SLB may be used in a variety of applications, each with its own suitability and lifetime. Furthermore, as compared to the current LIBs, the environmental effect of using SLB results in fewer air pollution and CO2 emissions. The manufacturing mechanism of batteries is removed when SLB is used as an ESS. The usage of SLB instead of new batteries has a beneficial effect on raw resources such as water, and electricity, all of which are conserved. However, technical issues such as safety, assessment processes, testing, and rigid management during the repurposing period continue to exist. Based on research, abuse verification techniques and measurement instruments are used to verify the protection reports of former EV LIBs. SOH estimation and other evaluation methods can be useful in determining EOL LIB performance characteristics and measuring the significance of the second life phases. On the other hand, fast and reliable measurement methods with good generalization ability are still a problem. Screening and regrouping technologies are critical for EV LIB reuse, since they ensure homogeneity in the second life kit, prolong service life, and improve protection. Although there is still room for improvement in terms of automation. The economic feasibility of SLB is in question. Overall, researchers accepted their advantages, but they disagreed on the breakeven point at which those modern batteries could be marketed in order to be more economically viable. To overcome such uncertainties, further research in different countries is recommended. Nonetheless, the widespread of SLB will inevitably face certain additional obstacles, such as the lack of identical SLB characteristics on a broad scale and the difficulties of correctly measuring SLB. However, with the exponential development of the electric vehicle sector, SLB requirements, appraisal automation, and further economic studies, such obstacles may be solved. Although there have been a few demonstration projects and commercial ventures, the majority of them have been in the sense of ESS production. Based on the thorough literature analysis, it can be inferred that in order to build and improve a modern and reliable approach for estimating the SoH of lithium-ion batteries, special attention should be paid to all of the following issues: precision, ease of assembling and disassembling battery packs, end life prediction, suitability for practical circumstances, and successful implementation on BMS. As a result, further research into the performance, protection, economy, and environmental aspects of rechargeable battery production, secondary battery usage, and recycling is needed.

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