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Electric Vehicles Second Life Batteries

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1. Introduction

The second-life of batteries after their utilization in electric vehicles (EV) is in line with both the Waste System Mandate 2008/98/EC (EU, 2008) and the 2015 Round Economy activity plan of the European Commission (EC, 2015c). Regardless of the expanding interest in the theme, "second use" is not as of now utilized properly in any of the different waste orders.

In this unique circumstance, the objective of the project is to investigate the arising need of second life use of EV batteries and to create and apply an adjusted strategy to dissect the supportability of such frameworks. The specialized achievability and the natural, monetary and social exhibitions of EV battery second-use would be surveyed, particularly thinking about the extraction of assets utilized in batteries, assembling, end-of-life energy and life cycles.

At the point when EV batteries no longer meet the necessities for being utilized in a vehicle, they actually hold energy stockpiling limits which can be conceivably utilized and repurposed for example inside the electrical circulation framework. At the point when an EV battery arrives at the finish of its valuable first life (for example keeping 80% of all out usable limit and accomplishing a resting self- release pace of just around 5% over a 4-hour time frame), producers have three choices:

1. Basic removal, that most much of the time happens if packs are harmed or on the off chance that they are in areas that need vital market structure. In many areas, guideline forestalls mass removal.
2. Recycling, to recuperate specifically exceptionally esteemed metals like cobalt and nickel, particularly because of most inventive cycles, as hydrometallurgy.
3. Prior to recycling, reuse the batteries in fixed applications, where diminished exhibitions capacities are as yet important.

This report attempts to fill-in some information holes concerning the specialized, ecological, financial and social exhibitions of the second-use utilizations of EV batteries. The project specifically focuses on better designs and segmentation of second-use battery, testing exhibitions of a portion of its components (utilizing exploratory offices-case studies and actual displaying), creating significant execution markers for the predicted framework (embracing a day-to-day existence cycle thinking approach) lastly examining results. Obviously, we ought to likewise address the inquiries of strategy suggestions and exploration needs.

2. Methodology and Approach

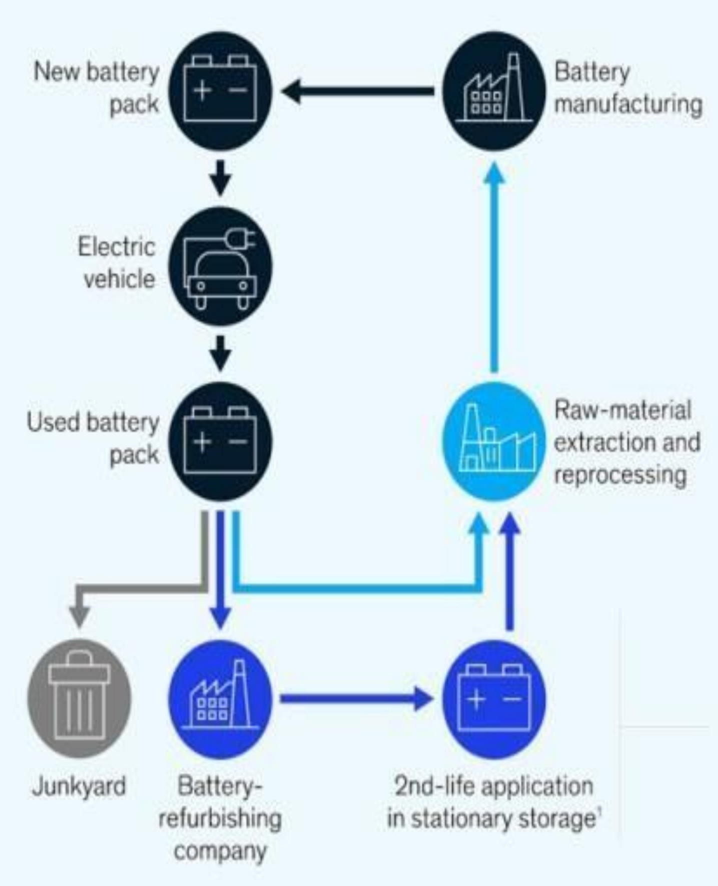
After the "1st Life", a few alternative options are conceivable prior to reusing the electric vehicle battery pack:

1. Repurposing of 2nd life EV battery packs, that signifies "utilizing the pack as it is", after a selection of choice and combination of suitable packs

(according to criteria like residual state of health, capacity, and so on…)

2. Refurbishing of second life EV battery packs- that implies that the packs are first dismantled and single cells are reconditioned and repacked in new modules previously being utilized in fixed applications.

Figure 1: Source: McKinsey [1].



EV packs, whenever designed with this extension, can be utilized directly in fixed applications. On the opposite side, after their first EV use.

Remanufacturing- EV packs could likewise be refurbished to be utilized again in EV applications (rather than on fixed ones). This we will not be going into anyway.

We will be discussing the processes involved in each of the two methods we intend using- repurposing and refurbishing. However, the battery remanufacturing process will just be explained.

2.1. Things to consider when repurposing EV battery packs: Prior to being reused in second-use applications, EV batteries ought to be tried to check their state of health (SoH) and remaining ability to distinguish the best fitting second-use application [3]. Some significant data emerge from their operational history of the battery pack, for example working temperature, normal driving distances, and the propensities for singular drivers [4,5]. From both a monetary and specialized perspective, the chance of reusing the entire battery pack without destroying it is the best alternative [3].

If impractical, the battery pack can be destroyed and the modules/cells could be tried and re-used in another battery load with new materials/parts, for example BMS [3,5]. In the event that there is a possibility for the reuse of the EV battery after its utilization in EV, a more adaptable BMS could facilitate its utilization of second life; in this sense, "plan for dismantling" turns into an applicable challenge. As the battery ought to be planned to boost its worth during its entire life cycle, included additionally are plans for expected second-use. For instance, to lessen the repurposing expenses of second-life and facilitate the reception of repurposed EV batteries, the foundation of a BMS in EVs with the capacity to store all information at the singular battery cell level (particularly temperature, voltage, depth of discharge (DOD), state of health (SOH), state of charge (SOC) and, whenever happened, short circuits) is of most extreme importance.

1. It's a 'ready to use' approach: Reduced time and price of batteries repurposing (less labor-intensive activity, less investment in rebuilding process).
2. Reuse of existing native pack BMS.
3. Integration activities can be provided by several systems integrators.
4. A specific Master BMS (for the whole system) has to be developed.
5. It is not possible to connect packs in series but only in parallel.
6. What this means is that, it would need a DC to DC converter to raise the DC voltage to the PCS working level, or to oversize PCS due to high currents, increasing system cost.
7. Requires more installation space with respect to standard stationary BESS based on battery modules.
8. System Integrator doesn't guarantee the battery performances (life extension, efficiency, rate, …). Just expected residual capacity can be guaranteed by battery manufacturer.

2.2. Steps to consider in refurbishing of EV batteries: The initial step of the potential reuse of EV batteries is the collection after their removal from EV and their sorting. As pronounced by (EC,2014), the assembling pace of both auto and modern batteries in Europe are almost 100%. Subsequently, a high accessibility of EV batteries after their utilization in EV is on the rise.

It is necessary to dismantle packs, collect modules, measure/test, sort, repack and certify the used EV batteries:

1. An "adhoc" supply chain has to be setup
2. There is an increase of cost of batteries re-use
3. A new module (tray) BMS has to be realized
4. Currently, only few system integrators have required know-how to implement this option
5. More time required to realize and certify repackaged modules
6. Once realized in the repackaged modules, the assembly and system integration of the stationary BESS system requires the same needs of common BESS
7. Warranties on battery performances can be guaranteed by system integrator

To see better the arising need of electric vehicles batteries repurposing, it is important to break down the EV battery supply chain all in all. It is underlined that the normal increment of the EV market brings about expanding batteries stream. Table 1 below distinguished vehicle makers as vital participants in this interaction due to their admittance to specialized data and their advantage in the point as they may be proprietors of the battery pack and acquire monetary benefits from the batteries reuse.

Figure 2: Source: Enel [2].

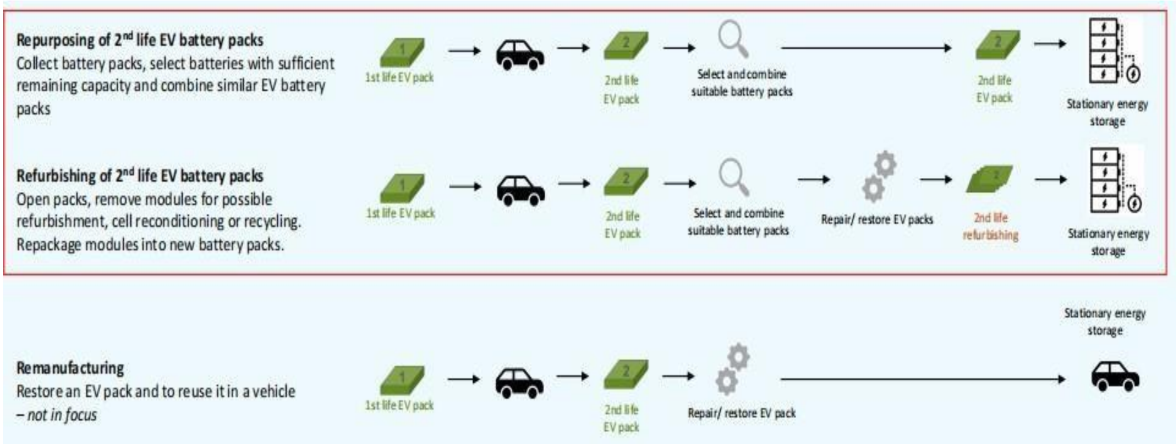


Table 1: Vehicle makers and their batteries reuse.

	Actors		Website
1	Battery manufacturer	**EUROBAT** - Association of European Automotive and Industrial Battery Manufacturers	
2	Car company	**RENAULT**	www.eurobat.org
3	Car company	**FCA**	
4	Car company	**PEUGEOT/CITROEN**	
5	Car company	**HYUNDAI MOTOR**	
6	Car company	**MITSUBISHI**	
7	2nd use project	**Bosch/BMW/Vattenvall** (pilot project: Second life for electric-vehicle batteries)	http://www.bosch-presse.de/presseforum/details.htm?txtID=7067
8	Waste batteries collectors	**Battery Foundation** (Stichting Batterijen) in NL (Advised by Wecycle instead because they work in cooperation with ARN)	https://www.stibat.nl
9	Waste batteries collectors	**ARN** - centre of expertise for sustainability and recycling in the mobility sector.	http://www.arn.nl/en/
10	Expert	**EGVIA** - European Green Vehicles Initiative Association	http://www.egvi.eu/about-egvia/organisation
11	Expert	**IKERLAN** - Spanish knowledge transfer centre - Project Battery 2020	http://www.ikerlan.es/en/
12	Expert	**VUB** - The Vrije Universiteit Brussel	http://www.vub.ac.be/en/
13	Expert	**ENEA** - National Agency for New Technologies, Energy and Sustainable Economic Development	http://www.enea.it/it

2.3. Battery remanufacturing process: To display the assembling step, the battery segments have been bunched in four fundamental groups: battery cells, battery bundling, battery management systems (BMS), and cooling system. This manufacturing process already takes place by major stakeholders e.g. TESLA, SVOLT, CATL and is beyond the focus of our project. It is expected that the manufacturing of the battery happens in Europe, and subsequently the European power blend, at medium voltage is utilized.

Of the 22 gigafactories arranged in Europe, ten will be situated in Germany, with organizations including Tesla, CATL and SVOLT.

The boom will be filled by mechanical advances significantly lessening the measures of metals like lithium, cobalt and nickel expected to make batteries, just as billions in state appropriations that have seen the quantities of EVs bought ascend all through the EU, for instance by 260% in Germany in 2020 [7].

2030 it will quit offering vehicles with regular ignition motors available to be purchased in Europe, while Porsche expects that before the decade's over in excess of 80% of its models will be electric. The entirety of this is a motivating force for organizations to settle in Germany, clarifies Germany trade and invest senior auto director Stefan Di Bitonto [7].

"Germany is the core of the European vehicle industry so here is the place where the most elevated volume of batteries

will be purchased and sold", Di Bitonto says. "The foundation of battery production lines here will be a multiplier for organizations providing the enormous suppliers. That implies openings for different firms to benefit from the pattern, as we have effectively seen related to Tesla and CATL" [7]. This is where we fit in.

3. Discussion of Applications

By 2025, 3.4 million used electric vehicle (EV) batteries are expected to hit the market, and it means just as much hazardous waste. Although used EV batteries are no longer adapted to supplying energy to demanding engines like cars, most of them retain 50 to 90% of their capacity after their first life in a vehicle. Less requesting applications than versatility, like fixed uses, may comprise promising alternatives to reap the saved worth of utilized EV batteries.

3.1. Applications of second life batteries

3.1.1. Residential application: Most of the electricity demand in residential applications corresponds to space and water warming. This demand for power shifts for various pieces of the day. With RES combination with the matrix like PV, the power need can be met during the daytime. During the evening, notwithstanding, when there is no PV age, the pinnacle request happens and along these lines requires utilizing energy stockpiling frameworks like batteries. Thinking about the cost, SLB (Second-life batteries) a reasonable answer for this issue [1]. Using SLB as capacity empowers the PV-created energy to be put away with the goal that it tends to be used later.

3.1.2. Commercial application: The commercial demand for electricity on average is much higher than the residential demand. Be that as it may, the PV age is subject to environment conditions, for example, rainfall and cloud commonness requires the need for storage systems. Peak shaving applications require 3000 to 4000 kWh, which requires higher storage capacity [8]. Therefore, this application requires a large package of SLB.

There will be one profound release and a few shallow releases each day, along these lines to stay away from over the top Depth of discharge, this application might be appropriate in areas with high sun powered irradiance [9]. The battery back-up application in far off zones requiring little force hardware is likewise an appropriate application for the reconditioned batteries.

3.1.3. Industrial applications:

Generation-side asset management: The life of power generation assets such as power plants depends on regular and carefully planned maintenance. However, the demand for continuous power supply makes it difficult to schedule maintenance cycles. In addition, forced inspections and temporary maintenance are also frequent in power plants. Therefore, other sources are required to provide the necessary power reserves during the suspension period. The use of renewable energy is a potential solution to this situation. However, the intermittent nature of these sources requires the consolidation of other storage devices. More and more traditional storage devices such as batteries are used [10]. This method is feasible but at the same time expensive. Therefore, considering overall stability, reliability and economy, secondary batteries are the most feasible solution [8].

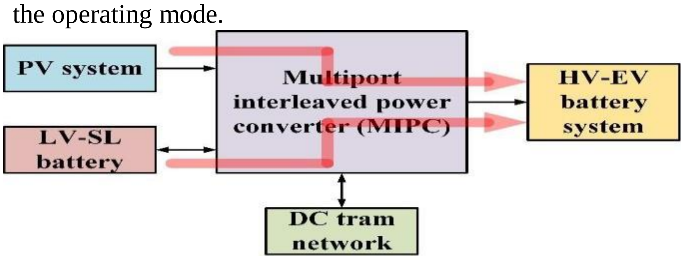
Storage of renewable energies and integration in the grid: The International Energy Agency has identified a sustainable development scenario where renewables reach have a share of two-thirds of electricity generation output and 37% of final energy consumption by 2040 [11]. Smart BESS also allows levelling peaks in renewable energy generation (“over-generation”), a peak that takes place around noon for solar and generally during the night for wind power generation. 2nd life EV batteries certainly will lower the cost of Batteries Energy Storage Systems BESS.

Applied to telecom tower: As one of the world’s largest telecom tower operators, China Telecom Tower is listed as the only company in the pilot program to develop key technologies, explore business models, and help establish standards related to secondary life batteries. Since 2015, China Telecom Tower has been testing second-generation electric vehicle batteries to replace its lead-acid batteries in telecom base stations across China. Despite some degradation, second- generation batteries are still better than lead batteries in terms of service life and energy density. Last year in Jiangsu province the Tower stopped purchasing lead-acid batteries, and all the backup power sources will be replaced with lithium batteries coming from electric vehicles [12].

3.1.4. Mobile applications

EV charging station: In recent years, from both economic and environmental considerations, the number of electric vehicles as alternatives to traditional internal combustion engine (ICE) vehicles has increased significantly. However, the scarcity of charging infrastructure is the main problem for electric vehicles in the market. Electric vehicles need to be charged through a battery charging system, and lithium-ion batteries can be used in fast charging stations, but they are not economically feasible due to high prices. On the other hand, the price of SLB is much lower, so it can be used to provide temporary storage and power buffering for fast charging stations. Reference [13] proposed a DC fast charging system for electric vehicles based on a hybrid photovoltaics (PV) SLB-tram network topology, as shown in the figure below [14].

Figure 3: Different operating modes of the DC fast charging system [13]. The battery can be charged from different sources, and can deliver power when required, depending on the operating mode.



3.2. Cost and Impacts of SLBs

3.2.1. Reduces the costs of ESS: In this time of always expanding utilization of environmentally friendly power sources energy storage system ESSs are turning into a fundamental part to supplement renewable energy sources (RES)- discontinuities, and furthermore to give various subordinate administrations to the lattice. In such cases, the significant expense of ESS becomes a genuine concern. SLBESSs are required to cost not exactly as new ESSs, and still be fit to serve the network obligations consummately.

In a project piloted by the American electric utility company American Electric Power, together with Nissan North America and the Australian battery management system (BMS) company. Relectrify, ESS costs were reduced from $289 per kWh (new batteries) to $150 per kWh [15]. More generally, ESS (new or retired EV batteries) entail economic advantages at an individual level (household, company) by enabling cost savings in buildings, through the storage of PV power or the replacement of diesel backup generators. Such replacement may be financially interesting from the start if provided on a leasing or rental basis. ESS can also enable profits if the battery is charged at a time of lower tariffs and discharge data time of higher prices (“energy arbitrage”). In addition, ESS are key to allow access to electricity in regions with low or no access to the grid.

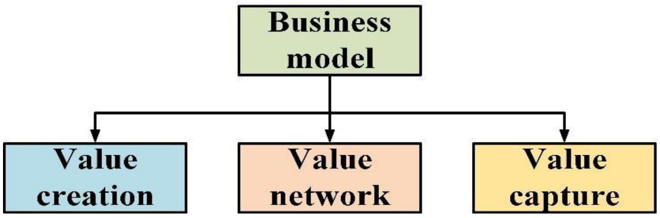
3.2.2. Enable discounts on the EV battery cost: The price of batteries makes the price of electric vehicles relatively high. If the SLBESS industry creates added value for second-hand electric car batteries, these vehicles will retain more resale value; if car manufacturers have battery recycling or leasing systems, then the price of electric cars themselves will drop. Nissan's Leaf EV [16] uses such a system. This approach is expected to increase the penetration rate of electric vehicles and help build a greener transportation sector.

By expanding the worth of the battery and making new income streams, repurposing can decrease its life cycle costs. Organizations may factor in the resale EV battery esteem by passing it on the EV battery price tag. Such a markdown could have a critical effect on the EV market as the high capital expense of the EV battery is one of the principal hindrances to the take-up of electric portability. The World Economic Forum (2019) [4] states that reuse/second life could diminish the expense of a normal battery pack for a traveler vehicle by 5.3 US$/kWh in 2030.

3.2.3. Energy and environmental impacts: The most significant impact of SLBESS is the benefits it promotes in terms of energy and environmental benefits. If the traction battery is not reused, 80% of the energy and the large amount of energy produced by the second-hand battery from other sources will be wasted. Reference [17] shows that from 2015 to 2040, 63% of electric vehicle batteries may fall into the waste stream. This will be a huge waste of energy, time and energy spent on collecting raw materials and manufacturing batteries. If these batteries cannot be reused, they will eventually be polluted by landfills. Therefore, the use of the second lifespan significantly reduces these wastes and provides an opportunity to fully utilize the energy used to produce batteries in an environmentally friendly way. Reference [4] pointed out that extending battery life through SLB applications can reduce total energy demand and the possibility of 15~70% of global warming. Repurposing has been identified as a low-carbon strategy contributing to GHG abatement: [18] calculate a 56% reduction in CO2 emissions enabled by an EV li-ion battery used for peak flattening, compared with natural gas fuelled-electric power generation.

3.2.4. Business strategy: In order for the idea of a second-life battery to survive as a business, the cost of SLBESS must be lower than that of the new ESS at that time, and the price of SLBESS must match the service it will provide. Recycling after the reuse stage is a key component to obtain the greatest economic and environmental benefits from the SLB concept, and recycled materials should also have a lower price than new materials [19]. Reference [20] shows that by 2020, the price of new batteries can be halved compared to 2015, and these things must be kept in mind in the design of SLB business. For companies in the ESS or electric vehicle business, if they start SLB companies, it will be easier to avoid this situation because they have easy access to SLB supply lines and already have the expertise and equipment to produce SLBESS. Nissan has passed its joint venture with other companies: 4R Energy Corporation [21]. Prove the feasibility of this method. This method is also applicable to entities that have both electric vehicles and ESS businesses, such as Tesla. Reference [22] predicts that these original equipment manufacturers (OEMs) can play an important role in the SLB market. The feasibility of an enterprise depends on aspects such as net present value, internal rate of return, and return on investment. The development of SLB companies must be able to obtain satisfactory scores in these areas to show their strong capabilities. With this in mind, the business model of the industry must be developed. Reference [23] lists four such cases, they create SLB use and create value in various ways: ESS, electric vehicle charging, recycling and financial leasing; they use Chevrolet Volt and Nissan Leaf as research cases. Reference [24] shows that electric vehicle batteries can increase the value by 35%.

Figure 4: Essential parts of business model (adapted from [23]), SLB businesses must satisfy these in order to thrive.



3.2.5. Barriers and possible solution to SLB usage: However beneficial and sensible the SLB usage is, there exist several obstacles that have to be considered and overcome for this practice to become mainstream. To keep supply of batteries with the existing demand, the cost of the Batteries must be monitored [4]. Proper policies and necessary incentives as well as business models must also be developed. The used battery supply is expected only to grow, and the technology to produce SLBESS does not require much improvement. The SLB cost is not expected to rise above the new batteries currently, but it can become prominent in the future if major breakthroughs take place in battery technology. There is the need of market and policy development, though these are not supposed to be much of a challenge considering the opportunities SLB usage provides. Table 2 shows different barriers of SLB use and their potential solutions opportunities and increases the cost. Therefore, to ensure development of a market for these batteries, specific policies and strategies are required [21]. To encourage the use of second-life batteries federal and state tax credits, rebates, and other financial support should be provided. The reuse and collection of used EV batteries should be specified and the policy makers should ensure that the recycling of a battery only occurs once in the entire useful life of the battery has been utilized. Furthermore, the amount of hazardous material such as cadmium and mercury should be regulated and a proper waste management plan for the battery disposal should be adopted in order to protect the environment. The current policy and mechanisms adopted by NA (North America) and EU (European Union) regions regarding the EV batteries are presented in Table 2.

Table 2: Barriers and potential solutions of SLB usage.

Barrier	**Degree of impact**	**Potential solution**
Shortage of raw materials	Low	Proper waste management/collection of used batteries
Shortage of supply	High	Implementing proper production methodologies
Shortage of demand	Low	Investing in market development
Shortage of public interest	Medium	Organizing education, training, seminar,

		symposium, pilot projects.
Shortage of technology	Low	Investing in research and development (R&D)
Creating market structure	Medium	Investing in market development
Creating business policy and framework	Medium	Developing organizational, state, and federal policies. Ensuring availability of bettery data.
Securing supply and distributing chain	Medium	Market and supply analysis.
Maintaining reasonable price and performance	Low (possibility of increase in future)	Market analysis and technology development

3.2.6. Policy implications: With the world moving towards a more environment-friendly direction to meet with the energy demand there has been a prolific increase in the generation of electricity using RESs. However, these RESs introduces intermittency, which affects the stability and reliability of power. Large scale energy storage devices i.e. batteries can be used to mitigate this intermittency. Furthermore, batteries have a wide range of applications such as peak shaving, area regulations, etc… [8]. However, large scale applications of batteries is very much expensive due to their high price. The used EV batteries, having reached 'end-of-life cycle', can be a critical and inexpensive solution for this purpose. These batteries can be recycled, repurposed, and reused for different applications. However, there are economic uncertainty and liability concerns about second life batteries, which limits the market opportunities and increases the cost. Therefore, to ensure development of a market for these batteries, specific policies and strategies are required [21].To encourage the use of second-life batteries federal and state tax credits, rebates, and other financial support should be provided. The reuse and collection of used EV batteries should be specified and the policymakers should ensure that the recycling of a battery only occurs once in the entire useful life of the battery has been utilized. Furthermore, the amount of hazardous material such as cadmium and mercury should be regulated and a proper waste management plan for the battery disposal should be adopted in order to protect the environment.

4. Summary and Conclusion

In this case study of second life batteries (SLB) we infer that:

1. Extension of battery life time is necessary through a second-use phase.
2. Second-life battery energy storage systems (SLBESS) can be produced through a standard production procedure, which involves modeling, testing, and manufacturing.
3. Modeling of SLBESS can be done through processes similar to standard battery modeling.
4. Used batteries need to be inspected and categorized for determining their eligibility and fitness to be used in SLBESSs.
5. Standard safety practices must be upheld in every stage of SLBESS production.
6. Cost of SLBESS must be kept competitive.
7. SLBESS can be used in an array of applications, especially in stationary uses such as in the utility grid, creating significant values.
8. There are significant environmental and economic impacts of SLB usage.
9. SLB businesses require proper business models to operate sustainably, and some of such practices already exist while more can be developed.
10. SLB usage face several barriers currently, but there exist viable solutions to overcome those.
11. In addition to existing state and federal policies, more are required for nurturing SLB technology and market in national and private levels.

The used batteries hold significant potential to be used in a second life, which has been discussed in detail in this study. The current SLB scenario has been discussed in detail first to point out the necessity and opportunity of such a practice.

The processes of producing SLBESSs to create a deliverable product to establish this practice has been demonstrated afterwards along with related cost and safety analysis. The applications and impacts of SLB have been discussed as well. Business strategies and policies required to make SLB businesses sustainable have been discussed in addition to the barriers and related solutions of SLB usage. The future work related to this paper can be on the second-life potentials of upcoming battery technologies such as solid-state batteries.

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