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Opportunities in Circular Economy for End-of-Life (EOL) of Electric Vehicle Batteries: A Review

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Abstract- Due to the low carbon emissions, electric vehicles are regarded as sustainable transportation. The purpose of the current study is to explore the possible options for retired electric vehicle batteries (EVBs). This study is based on a narrative review and explores the options from various articles, websites, theses, magazines, and books that have been downloaded. The literature revealed that retired batteries can be recycled, remanufactured, and reused. Energy storage systems for grid balance and home-based energy storage were mentioned as potential repurposing uses (wind power plants, power plants based on solar panels). After recycling the batteries, the raw material can be utilized to create new batteries for electric vehicles, telephones, computers, and other electronic devices.

Keywords- *Electric Vehicle Batteries, Refurbishment, Remanufacturing, Recycling*

I. INTRODUCTION

The concept of circular economy (CE) has been viewed as a way to address many global issues, including resource scarcity, waste reduction, and sustaining financial advantages [1].These days, the circular economy is widely used at the corporate level since businesses need to concentrate on product design and business model innovation to maintain their place in the market [2].It has been regarded as an effective technique for the reduction of sustainability pressures all over the world [3]. The circular economy is an example of a lake, that is used for product reprocessing and conserves energy while using resources economically and producing the minimum waste [4]. Pearce and Turner developed the term “Circular economy” and initiated it in 1990 as specified by [5]. In the broadest sense, the circular economy is a strategy that integrates economic growth and environmental protection [6]. Reduce, recycle and reuse (3R) circular economy defines a long-term economic development setting to detach economic development from the multiple uses of resources (such as land, forests, water, power, products, etc.) and insight the eco-friendly and environmental damages [7]. Finding innovative business models that supports the circular economy and putting them into practice and spreading them are the hardest aspects of this approach. Existing business enterprise models are effected by closing product loops. In order to handle these changes, businesses should participants in theprocess of improving their business models. The increased focus on circular economy highlights the (growing) need for new BMs [8].

Electric vehicles (EVs) are regarded as sustainable vehicles because they produce less carbon dioxide during their entire life cycle, from birth to recycling. Because of this, electric vehicle production has been more closely monitored, and according to available data from sources, there will be an estimated 125 million EVs on the road by 2030[9]. These electric vehicles (EVs) were developed earlier than gasoline-powered automobiles, and the early 20^{th} century has been referred to as the “period” of the electric vehicle. (see figure 1).

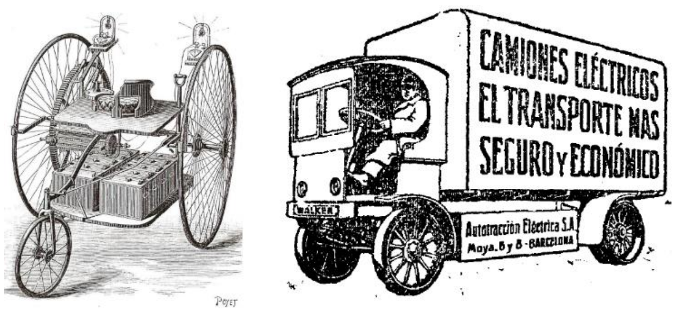

Figure 1. The first electric vehicle from Ayrton and Perry in 1882 as given in [10](p. 20)

However, for several reasons including sustainable oilfield exploration and the beginning of Ford Model T assembly-line production which was created in 1920 [11]. The history may also be traced back to the 19th century, to the launch of the first electric vehicle in 1828 [9]. Formerly, electric vehicles were considered gasoline-powered cars because they made less noise and were easy to start. At that time gasoline-powered vehicles were much noisier than EVs and needed a special person to start them and wait for the engine to warm up [12]. According to the world economic online forum (2018), car companies want to produce more electric vehicles than conventional vehicles.

By 2020, BMW plans to begin mass production of EVs additionally, Renault intends to begin producing 20 attractive electric vehicles by 2022. By 2030, Volkswagen plans to invest over $84 billion in battery and electric vehicle production. Moreover, it creates Volvo's commitment to integrating electrical or hybrid engines in every vehicle [13]. Even though electric vehicles are more environmentally friendly than other types of vehicles, there is still space for a circular business model in the EV sector. EVBs are approaching the end of their useful span as a result of the exponential rise in EV manufacturing, which has led to significant concerns for long-term growth and environmental security [14].The extension of their useful lives is the key component of CE's strategy of using materials to research by Gaustad,G.et al. (2018). In this sense, EVBs that are retired can still be put to service if they are recycled or reused [15]. The greatest hazard to environmental security arises when EVBs reach 80% of their initial capacity and are handled ad processed at this point. There would be a waste of resources used in the production process such as energy and R&D expenditure if EVBs are recycled rather than reused. However, these batteries still have the potential to be used after initial life in secondary applications including the storage of renewable resources and backup power. Compared to reuse, repurposing provides obvious economic and environmental advantages for EVs [16].

Several major automotive companies like General Motors,Nissan,Renault, and Toyota, have started to conduct pilot programs to investigate the address technical issues relating to the second use of EVBs [17]. Conversely, circular economy systems suggest an approach and it is a chance to find the best techniques and tactics so that the ideal atmosphere may be created for the second usage of retired EVBs [18]. Lithium-ion batteries are one of the essential components of electric vehicles that are utilized for energy storage due to their long life span and efficient electrochemical characteristics [19]. Additionally, Li-ion batteries are now also used to build electrical energy grid systems [20]. Commercially, LIBs are typically utilized in EVs they reach their end of life (EoL) when their capacity is reduced by 20% [21]. It was suggested that EV batteries should be reused in this situation when they still have 80% of their original capacity [22]. South Korea, China, the united states, and other countries have started research projects to improve the rate of reuse and remanufacturing to apply a circular economy effectively in the past decades [4]. The techno-economic potential of retired EV batteries in secondary energy storage applications is being investigated by researchers. EVBs can be used in ESS at both low and high levels [23] (p. 7). After being removed from electric vehicles, EVBs can be used in a variety of ways. To extract the most possible value from EV batteries before recycling, the business model for the use of repurposed batteries will be established in the current research using the circular economy and system dynamics methodologies. If they are repurposed as compared to recycled, they can be used for a variety of purposes. By adapting the business model, the second use of EVBs can be extended to ten years (one more lifetime) and substantial profits can be generated [24] (p. 23). This study is based on a narrative review and explores the options from various articles, websites, theses, magazines, and books that have been downloaded.

II. LITERATURE REVIEW

A. *Circular Economy (CE)*

During the past few years, the circular economy (CE) principle has surprisedand gained the focus of industry professionals, academics, and policymakers. To maintain global ecological, social equity, and business transfers circular economy promotes circular products and business transfers to create a world that will last for future generations [1]. It would change economic thinking and it alters manufacturing with competence: reuse what cannot be recovered, remanufacture what cannot be repaired, and reuse what you can [4]. Remanufacturing of parts,refurbishing, finding solutions, material reuse, and reconditioning of equipment are all examples of circularity techniques [25]. In a circular economy, reuse is recommended if an item cannot be remanufactured or reused. Reusing involves dividing exclusive raw materials from a united EoL point to provide a second supply. Recycling is a frequent process for a large number of heavy steel like lightweight aluminum, and steel combined with copper [5]. Manufacturers must adopt new product design paradigms so that the circular economy ideas can be valued as desired to the situation of completion of life [26]. Figure 2 illustrates the 3R concept (recycle,reuse and reduce) as it related to applications of circular economy [5]. Remanufacturing is used in its entirety to raise the value of retired products and make them look like new ones, but the remanufactured products consume less energy than the new ones [27].

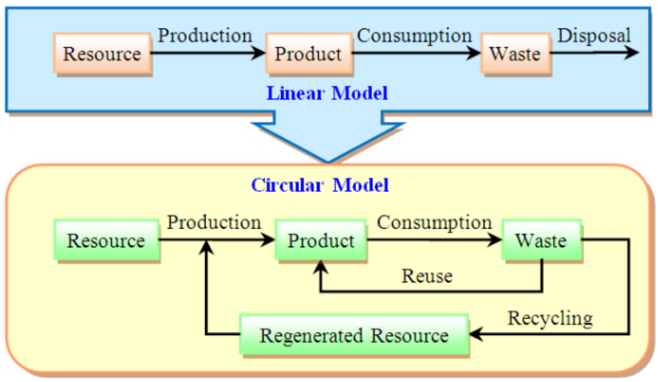

Figure 2. Feature of linear and circular models(Source: [7])

The circular (closed) system is the base of the circular economy concerning the 3R idea. It is used for the circulation of products as well as the usage of energy and raw materials at various levels [6], [28]. According to Stehal (2016), there are different types of commercial economies; circular,linear, and performance.A linear economy (LE) runslike a flowing stream, converting natural deposits into base materials and points that are readily available to engage in several actions that increase the value of the finished products. Old tires are either recycled, used to make ropes,shoes, or bumpers, or disposed of at the owner's choice.

Conversely, the circular economy is like a lake where products are recycled and energy is conserved but fewer resources are used and more waste is produced. Supplying items (or molecules) as solutions with lease, rental cost, and share company models reinforce the reach of an efficient economy. The distributor retains possession of the product and its personified beneficial resources, waste in the process, and bringing the work for the expenses [4]. According to Elisha (2020), a circular economy is a closed-technical economic system in which valuable resources, components, and other items lose value as soon as realistic, long-lasting resources are used to gather with systems assuming flow to the core. Manufacturers' layout in a circular economy indicates that it should be reusable [29]. A much more thorough analysis of a market economy that is corrective or regenerative in purpose and design is generated by the Ellen MacArthur institution [5]. There is an alternative; a "CE" would reduce problems in industrial towns, turn items, and reduce waste that is most likely approaching the end of their useful lives into resources for others [4]. A circular economy analyses a financial system that is based on business models that replace the "EoL" idea with minimizing, reusing, additionally reusing, and also recovering products in production/distribution and consumption procedures, thus operating at the micro-level (clients, business, products), meso-level (eco-industrial parks) as well as the macro-level (nations, locations and also previous), to complete enduring development, which recommends pro-environmental practices. [1].

B. Linear Economy Vs Circular Economy

The circular economy principle became prominent in the construction of china's economic growth in the 1990s as well as the limited natural resources available to produce goods and services [30]. The empathizes in the opinion of Kaimal and Sajoy (2020), was focused on reducing the price of the finished product. Uncontrolled natural resources extraction was done to accomplish this goal. The removal of raw materials and the reasonably priced automation of processes using them was primarily the focus. The reasonable use of resources received no attention. As business/production paradigm, known as the "linear economy model" resulted in significant energy and raw material waste [31]. Figure 3 shows the flowchart for the linear economy.

Figure 3. Linear economy model flow chart (Source: [31]

With its economic and sustainability advantages, the circular economy principle is being applied more frequently to address issues like waste creation and resource scarcity [6]. Circularity, however, is not a new idea However, the concept of circularity is not unique as such. Since the goal of the business shifts from creating produce income from providing relics to developing earn money from the circulation of materials as well as additional products over time, the circular strategy differs from the typical linear business model of production of take-make-use dispose of as well as a commercial system that is heavily dependent on non-renewable fuel sources [3]. The current monetary system, often known as the linear economy, is based on the ideas of taking, discarding, and consuming. The same goes for the wasteful use of resources. Due to this, issues with resource scarcity and environmental degradation are becoming increasingly serious daily[32]. Therefore, using circular solution models can make it possible to routinely reuse products and materials while using renewable resources whenever possible [3]. In figure 4, a clear and equally expansive depiction of the circular economy is shown.

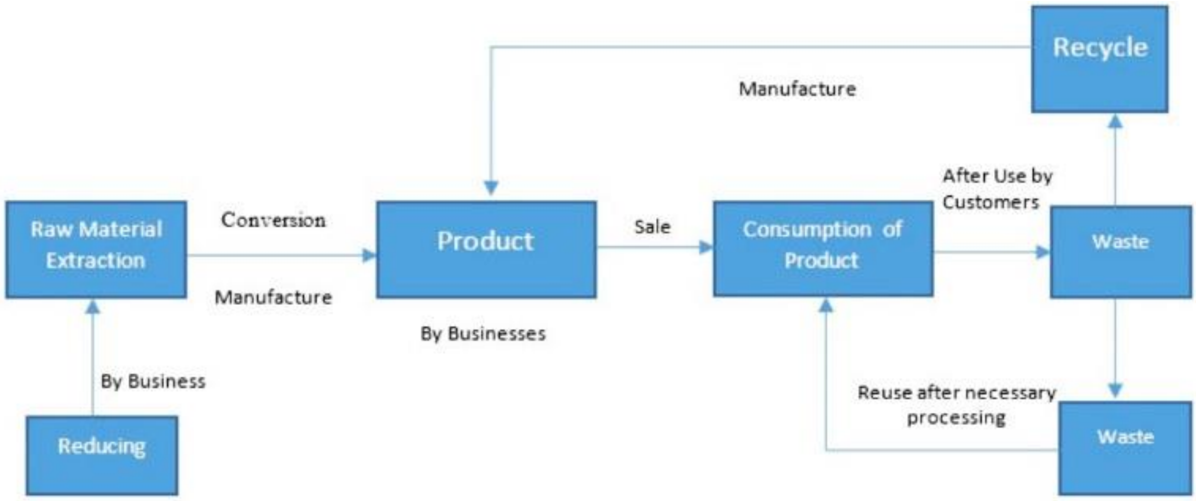

Figure 4. CE flow chart [31]

Consume non-renewable resources; giving new product sales priority; fail to communicate, and also fail to introduce or update are factors that influence linear business tasks [32]. Consumer behaviors specific to the linear economy's solution model may prevent the circular economy from being modified. Demand or used or cares well is challenging to grow in a consumption-based economy [26]. A circular economy aims to create a virtuous circle so that products at their EoL are exchanged for the feasibly future development of a product, in contrast to a standard linear economy strategy in which raw materials are occasionally transferred as trash [33]. Murray et al. (2017), as stated in [34] suggested replacing linear economy for CE.

C. Importance of CE in EV Batteries Business Model

According to [1], "a circular economy is a financial system based on business models that change the concept of "end-of-life" with minimizing, alternatively recycling, recovering and reusing products in production/distribution and usage processes, therefore operating at the micro-level (consumers,items,business) Meso level)parks,eco-industrial) and macro-level (area, nation,city), to complete sustainable advancement".

The reduction of waste generation, the decrease in raw material imports, and the acceleration of economic growth are just a few benefits of adopting a circular economy [15]. According to [29], the premise of the circular economy is rapidly tape-recording passion as a way to decouple progress from resource limits, which is based on the WE online Forum (2017). It offers solutions for adjusting the growth and financial communication premise while maintaining equity, awareness, and ecological and financial integrity. Engineers, business owners, designers, politicians, and the future generation of leaders are all being inspired by it. In nature, cycles involving water and nutrients are abundant, and waste products can serve as supplies for the other things described by Stahel (2016) [4]. According to Yun et al. (2018), the issue of a shortage of the raw materials needed in electric vehicle production is likely to rise soon as the number of EVs rises. The main difficulties encountered throughout the recycling process of EVBs include higher costs and a lack of dependable and incisive innovation [35]. According to Stahel (2016), circular-economy projects models can be divided into two categories: those that encourage reuse and extend product lifespan through maintenance repair, upgrades, retrofits, and remanufacture; and those that utilize the materials from old products to create new resources [4]. The circular economy is a regenerative strategy designed to reduce waste while also focusing on the creation of items that are sustainable and easily recyclable [36]. The Japanese Sony-Sumitimo methodology is a fascinating closed-loop CE method [36].

In particular, Sony IBs for computers, cellphones, and cameras are utilized to recover carbon monoxide (CO)2 [36]. The process uses cogeneration, which was created through the combustion of electrolytes and involves the calcination of the generated cells [37]. Nowadays, commercial recycling efforts are considering that EoL batteries are a bit of a challenge. However, as soon as a significant number of used auto battery packs are gathered and transferred right away to the appropriate recycling facilities, it will undoubtedly lead to issues with safety, dimensions, and chemistry [36]. Given EV dimensions, LIBs packs will undoubtedly needto undergo a safe decoupling process before treatment is separated for recycling [35].

The framework for a circular economy must include CE models for the recapturing of value to be feasible and profitable [38]. According to Stahel (2016), using resources for the maximum amount of time possible can reduce some countries' exhausts by up to 70%, enhance their workforce ny4 and also significantly reduce waste [4]. By implementing innovative business models, the circular economy seeks to reduce waste, improve production, and improve resource performance while having one of the least detrimental effects on the environment [26]. All the businesses examined, according to Gautad et al (2018), showed that recycling technology, data details, strategy, and replacement development were essential for any kind of reaction to the absence of minerals and steel.

These methods can be linked to a variety of circular economy techniques that may help organizations to recognize important product danger reduction. For instance, resource performance can be improved by the adoption of dematerialization and lean manufacturing principles [5]. The CE's adjustment calls for a change in the management structure as well as cooperation from all parties including customers, businesses, the academic community, lawmakers, and financial institutions of various levels [32]. While these barriers must be removed, it is likely more important to understand how adopting CE may conflict with established and determined methods of working in information practical areas as well as what firm-level intangible skills (i.e., capabilities and knowledge), as well as strategies, are required to handle those concerns as shown in figure 5[33]. The circular economy theory holds that EV batteries can be recycled to reduce waste and the extraction of virgin materials before being used again in secondary applications to extend their useful lives [14] illustrated in figure 5.

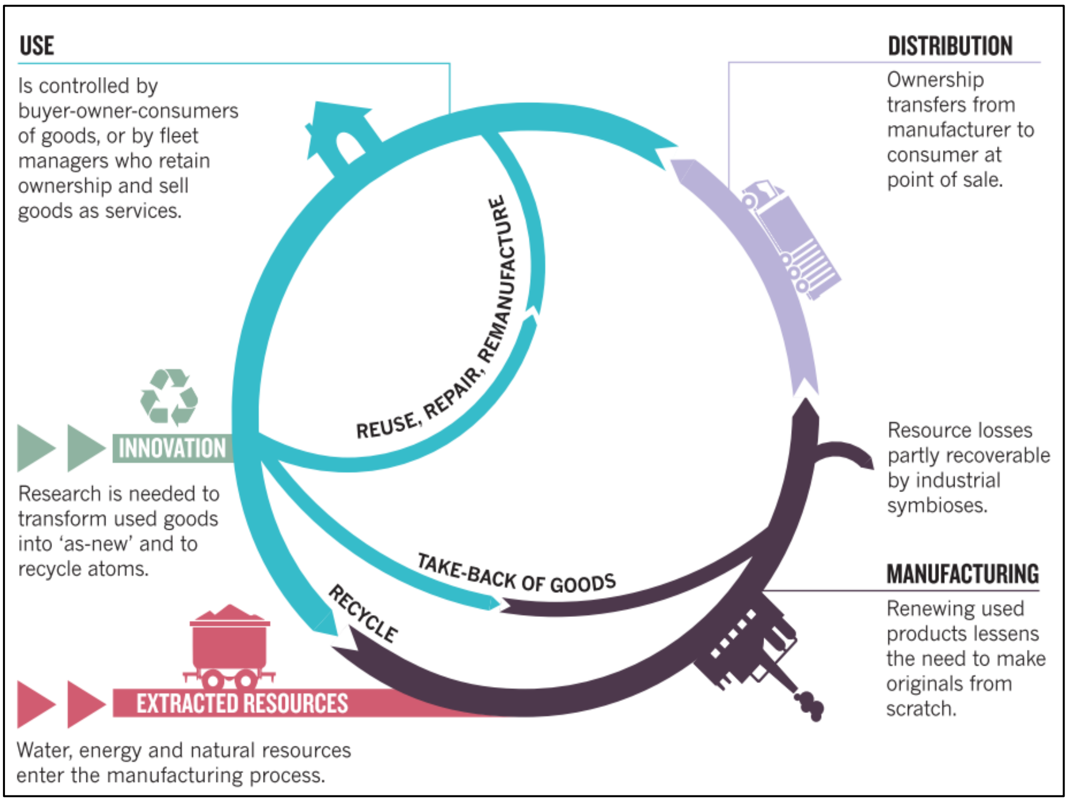

Figure 5. Closed-loop supply chain representation for the CE (Source: [4])

D. Reverse Supply Chain

Reverse supply chain (RSC) recovers products from end consumers or anyother point in the supply chain and returns them to the supplier network for remanufacturing, repurposing, or proper disposal. By doing his RSC contributes to manufacturing becoming generally much more sustainable in terms of the environment,society, and economy[39]. After their first and second lives, retired batteries must be collected for use in subsequent operations and integrated into the supply chain network. This is where reverse supply chain management (RSCM) comes into play. Thus, it is crucial to understand what RSCM is. And how does it operate? A dependable RSC assists in gathering EoL products with the most cost-effective and environmentally beneficial impact for recovery using methods [15]. The financial viewpoint of the network or how to build and reverse supply chain networks to reduce overall cost has been emphasized in the literature on RSC [40]. Alkahtani and Ziout (2019), suggest that a successful RSC network design would place a strong emphasis on sustainability. Many companies that produce or sell a consumer good have an RSC of some description to promote the return of products for a variety of reasons. However, they might not be aware of this, which could lead to missed opportunities to improve the service and ecological efficiency of their supply chain processes [39].

E. Electric Vehicles

The past two years have been a spectacular time for businesses that manufacture vehicles. Undoubtedly, 2017 was the year of electric vehicles (EVs) as international sales of BEVs and PHEVs exceeded one million for the first time [41](p. 03). Figure 6 suggests that as a result, the EV market share increased to above 1% of all global auto sales.

Figure 6 demonstrates that BEVs accounted for two-thirds of global sales in 2015. The most current prediction made by Deloitte is that EV sales will increase to 2 to 4 million in 2018 to 2020 and 12 million in 2025 based on reports from 2017. The cost of producing EVBs decreased significantly before rising to 2 million in 2030. The sale of BEVs is already beginning to exceed those of PHEVs globally and it is anticipated that this trend will only grow over time. By 2030, BEVs will probably make up 70% of all. From 2024 and forward, the penetration of fuel-powered vehicles would begin to decline as EV sales rise [41] (p. 04). The introduction of EVs and likewise PHEVs into the transportation fields is seen as an environmental opportunity to move toward a cleaner planet [42]. Electric vehicles are gradually but steadily entering the automobile industry, revealing a green future for the transportation sector [22]. Although the construction of electric vehicles (EVs) has better environmental effects than that of internal combustion engine vehicles [42]. It must be clarified that EVs are not only the solution to the issue but rather their integration with renewable energies [20]. There are two categories of EVs' battery electrical trucks (BEV). Which only have battery-based energy storage and must be recharged by plugging them in and plug-in hybrid electric vehicles (PHEV), which include both batteries and liquid fuel storage aswell as refueling systems [43]. According to Nordelof et al. (2014), "the hybrid electrical automobile" (HEV) is a car with both an electric motor and an internal combustion engine (ICE). When the battery is fully charged,both electric and internal combustion engines (ICE) power PHEV motors work[44].

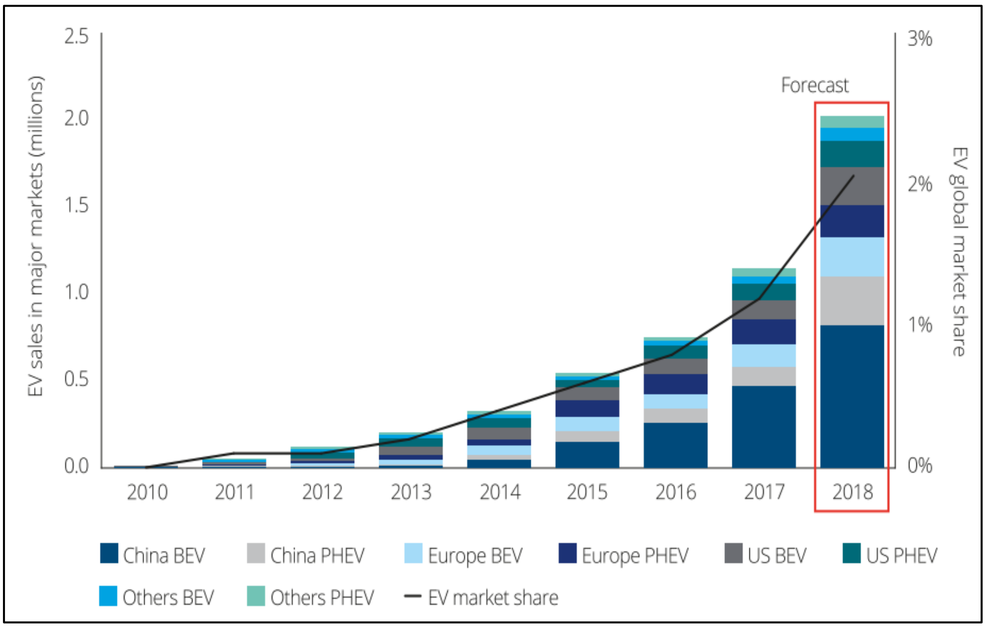

Figure 6. EV annual sales in major regions across the globe (Source: International Energy Agency (IEA), IHS Market Europe as cited by [41])

F. *Electric Vehicles Batteries*

Electric vehicles (fully electric,hybrid, or plug-in hybrid) are still in the process of being introduced to the market between 20000 and 2010, 1.5 million electric cars were sold which is a moderate number when compared to the 60 million cars of all kinds produced in just 2011 [45]. The global demand for electric cars (EVs) is increasing rather quickly. By 2050, EV/HEV sales share will account for at least 50% of all light-duty vehicle sales globally. EVs/HVs promise to bring significant benefits in terms of increased oil security, noise reduction, and decreased urban area pollution. They also aspireto contribute to greenhouse gas emission reduction. Because electric vehicles require larger batteries and the actual adoption of EVs has been viewed as a crucial element in material demand [46]. According to IRNEA (2017), all modern EVs rely on a type of lithium-ion-battery. High energy density,high specific energy (see figure 7), and long life cycle are all characteristics of lithium-ion batteries. Li-ion batteries are thought to be combined effectively with certain power as suggested in figure 7. due to their higher energy density, LIBs are being employed for energy storage in EVs [38], [47]. Beginning in the early 1990s, Sony employed LIB for the first time [47]. After all these years of study and development, LIBS is now lighter,smaller, and more durable [48]. However, the capacity of LIBs decreases over time and within use because of the indoor domino effect that occurred in the electrolyte, cathode, and LIBs lose capacity over time and with the use [48]. For instance, When they are used for grasp function, they are not considered to be at their best when they are between 70 and 80 percent of their initial storage space capacity [49]. Batteries for vehicles are thought to last for 150,000 miles, which is in line with industry standards[42] although lifetimes reported in the literature can range from 150,000 t 300,00 miles [50].

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There are many different battery types and as new systems are developed for company growth, they are being focused on the issue of incredulous transportation [9]. Much more common battery innovations may be found in figure 8 listed below, which appears in a Ragone plot of several of the full bunch. Early electric vehicles were built by Gaston Plantvé in 1859 and utilized rechargeable lead-acid batteries [11]. Waldermar Junger introduced the -nickel-cadmium battery in 1899; he made significant improvements to its ability to store energy but there was a difficulty with battery voltage as its life went on and the problem was referred to as a memory problem. The first LIB was released in 1985 [51]. After more than six years of development, the first LIB was introduced [52], [53]. Electric vehicles were created during this time by utilizing ZEBRA batteries and Nickel-metal Hydride batteries [54]. The very first LIB materialized in 1991 [9], [55]. Since lithium cobalt oxide batteries have a high energy density along the life cycle and are easier to manufacture, they have been the preferred battery for many personal digital devices (computers, laptops, video cameras, tablets, and more) [56]. Today, LIB is the preferred battery energy storage technology [9].

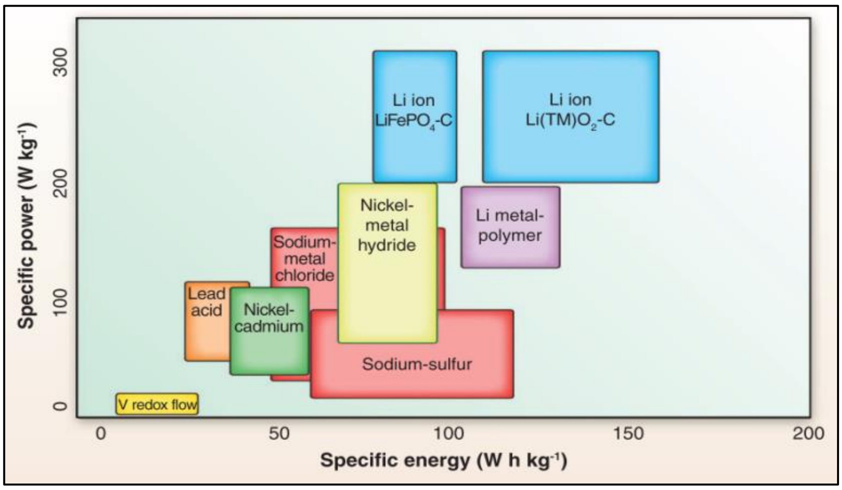

Figure 7. EV annual passenger car and light-duty vehicle sales in major regions Source: International Energy Agency (IEA), IHS Markit Europe as cited by [41]

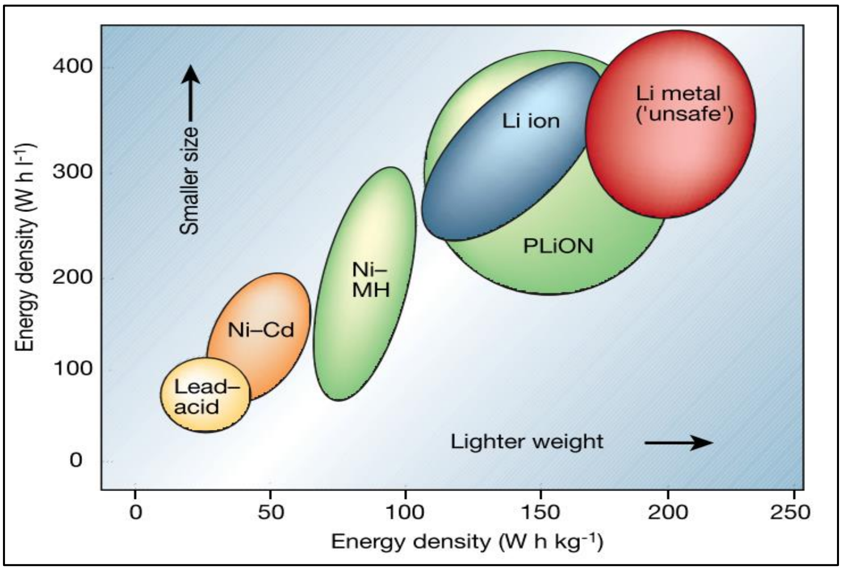

Figure 8. Various battery technologies as presented in Ragone Plot [55]

1) The lifespan of EV Batteries

Electric vehicle (EVs) reaches the end of its life when their health declined to 80% [57]. EVBs currently have a life expectancy of 10,000-200,000 km. additionally, it depends on the manufacturers, who generally offer warranties lasting between 5 and 10 years [58] (p. 64). An EV has an estimated range of 100 to 250 miles (160 to 400 kilometers) with a charged battery, according to Hirst et al. (2021). PHEVs were claimed to have a range of 25 to 55 miles (40 to 90 kilometers), while crossbreeds were also demonstrated to have an electric range of several miles [58]. Although a relatively limited number of EVs models are now showing signs of reaching the end of their useful lives, the EV market is growing which will eventually lead to larger EoL batteries. By 2030, 14 GWh of EVBs are predicted to their reach their EoL [59]. Nevertheless, 200 GWh of EVBs would achieve their EoL in these years due to the present rise in electric vehicle sales and market expansion [60].

2) Circularity for EoL of Batteries

A large number of EVBs reach their end of life (EoL) as a result of rising EV production and sales, which creates challenges with sustainability or environment protection [14]. The extension of resources useable loves was explored by Gaustad, et al. (2018) as a key component of the CE paradigm. EVBs can be handled following EoL using the circular economy methods of remanufacturing, reuse, repurposing, and recycling [15]. According to the circular approach, retired EV batteries should be used for grid storage or scattered renewable energy storage because they still have 70 to 80 percent of their original capacity [5]. According to Casals et al. (2019), this may appear negative from the perspective of electric vehicles as it calls for an expensive battery replacement that may be difficult for people to manage and shortens the useful life of EVs batteries, which raises some concerns In the power sector due to the act that to increase EV competition, vehicle manufactures plan for the second life of these EV batteries and offer reasonably priced energy systems [61].The EoL problem with electric vehicle batteries has received a lot of attention. Firstly, if EoL electric vehicle batteries are not properly managed they include hazardous electrolytes and a variety of other polymers that create serious risks to both the environment and human health [62].

Secondly, it was advised to reduce the consumption of raw materials and to reuse the EVBs to maximize their usefulness. This is because the increasing use of EVBs is also quacking the consumption of lithium and cobalt [63]. Thirdly, therepeating capability makes retired EVBs a potentially competitive choice in applications involving energy storage, which not only improves life efficiency but also produces extraordinary value for a wide range of stakeholders in the transportation and power industries [64].

G. Strategies of EV Manufacturers for Batteries

Electric vehicle manufacturers use a variety of tactics, including refurbishing, intensifying use, repairing,recycling, and repurposing to maximize the value of separated EV batteries [65]. This study carefully examines the repurposing of retired EVBs which has several advantages on all fronts; social,environmental, and economic. In the automobile sector, the concept of battery repurposing is not new and has been covered in research papers and industry reports. However, further research is needed to assess the viability of this business strategy. Profit-making to reduce the price of electric vehicles can inspire the viability of the business model to use retired EV batteries in secondary use [66]. Extended battery lifetime through repurposing may assist in reducing the battery cost for electric vehicle OEM or the total cost of ownership for EV customers [66]. It has been mentioned that efforts are being made to increase the use of EVs, as well as their maintenance, recycling, and repair. There is lacking data or unclear related to the EVB repairing,remanufacturing, refurbishing, and repurposing plans of various corporations are either unclear or lacking in [65]. The 9R framework described in the introduction would direct the number of circularity possibilities for batteries at their end of life with the direct reusing of the battery (R3) being the most circular and recycling (R8) being the least preferred end-of-life option. Any company should be looking to employ circular strategies, and consider various strategy combinations as a part of a strategy [67]. Batteries are currently only made for use in automobiles by auto manufacturers. This implies that the initial design of the batteries has a substantial impact on the cost of battery repurposing [67].

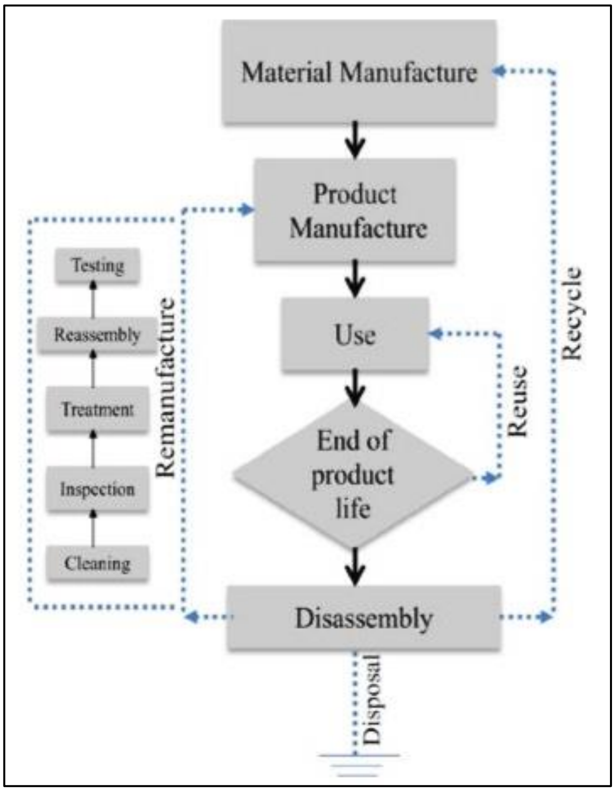

Figure 9. Different end-of-life strategies [67]

Figure 9 illustrates the looping strategies and ranks them inorder of circularity. Three strategies (refuse,reduce and rethink) in PBL's framework are rated even more circularly and require evaluation. The type of product and its quality will often affect the approach to recovery. The circular economy strategies share values with other methodologies and schools of thinking, hence they are not new. As a result, many businesses that adopt lean manufacturing ideas may also unknowingly be using circular economy practices and principles [68]. The strategies of batteries depend on the 9R framework shown in figure 10.

1) Repurposing of Li-Ion EV Batteries

Repurposing entails modifying a battery used for a post vehicle purpose so that it can be used in a road application like an energy storage system. The two main technological problems are reconfiguring the battery's cell configuration and creating a battery management system that is suitable for each energy system [69]. However, EVBs must cover a long way of second life before recycling begins. The useful life of an EVB that has been separated from the EV can be extended while still utilized at regular ESS[64]. Batteries may be able to go additionally third life since not all circumstances have the same EoL, yet low costs cannot support new changes; additionally, second life may offer benefits beyond purely financial improvement, such as the advancement of a circular economy or the promotion of social and environmental consciousness [61].By combining the upstream and downstream cycles of constructing framework components, CE-used batteries reduces the environmental impact caused by the creation of new batteries while maintaining a comparable storage capacity [70].Reusing LIBs for ESS in repaired steps is a driving innovation to assist superior demand regulation in addition to the supply of electricity [64].For ESS applications, such as automation and data management, computer-based remote control, stability, for the improvement of the efficiency, and business economics of power generation along with the flow, retired batteries recovered from electric vehicles and PHEVs offer the most cost-effective solution [64]. The sustainability of EVs may be improved with the repurposing concept of EVBs and at the same time, income for partners can be obtained together with the sustainable advantage [16] (p. 19). Another way to reuse EoL electric vehicle batteries is through repurposing, where the batteries are put to use in ESS, peak shaving and load shifting, and electric ground vehicles among other valuable applications [71].According to et al. (2014), there are only two ways to categorize the repurposing of EVBs. The first course of action is to create a selection for more demanding applications, like renewable energy systems like wind and solar power plants. Another option is to use them to change the power during peak hours in smaller applications like household appliances, office buildings, and grocery stores that require significant energy but require slow reaction times [64]. However, this chance may only be successful if electric power is produced by utilizing advantageous ecologically friendly modern technology, such as RE generators [44]. ESS comes in a variety of forms including capacitors, flywheels, industrial structures, and batteries. In contrast to lead-acid or nickel-based batteries which have far shorter life expectancies, LIBs have a much wider range of applications[47].LIBs are the kind of entities that has a bigger applying range holding a lot longer life expectancy in contrast to nickel-based batteries or lead-acid.

Figure 10. The 9R framework (adapted from PBL, 2017) [68].

The term "battery repurposing" which is frequently mistaken with the term "reuse" refers to the full or partial use of a battery in a different application than its intended usage [61].Existing second-life applications have concentrated on reusing the battery when its capacity no longer satisfies the operating cycles and performance standards of automotive use (80%) but is still completely adequate for other applications like stationary storage systems.second-life batteries can be expected to live an additional 12 years in energy storage although the life span of a second-life battery can increase to 30 years depending on the application [68].Repurposing of post-vehicles application lithium-ion batteries offers a second option to increase the useful life and hence reduce the battery's overall cost.repurposing entails breaking down batteries into individual cells reassembling those cells differently than for the vehicle application and designing the hardware and software forthe control; system specific to the new purpose. Thus, repurposing applications seem to necessitate their design, development, and manufacturing operations [69]. Gianes and Cuenca predict that effective storage systems made from reused lithium-ion batteries may be sold for \$50/kWh to \$150/kWh and that research and development costs could be in the range of \$50/kWh to \$150/kWh [69]. Remanufacturing avoids costs on both production of new batteries and the storage of batteries after they have been used in vehicles. Both new and refurbished batteries require material, labor, and overhead. For a new battery, these expenses come to almost \$10,000 whereas for a remanufactured battery they come to around \$2500. Thus, remanufacturing results in savings of \$7500 in expenditures [69].

a) Applications of Repurpose Batteries

Several automobile companies are now funding B2U initiatives. Similar to this, a project for the creation of 2nd life development was carried out with a joint venture between BMW, Vattenfall, and Bosch in Hamburg Germany. The goal of this experiment was to comprehend how old EV batteries age and how much energy they can store. To increase battery life, it was identified how to apply EV Li-ion batteries in stationary applications as shown in figure 11[72].

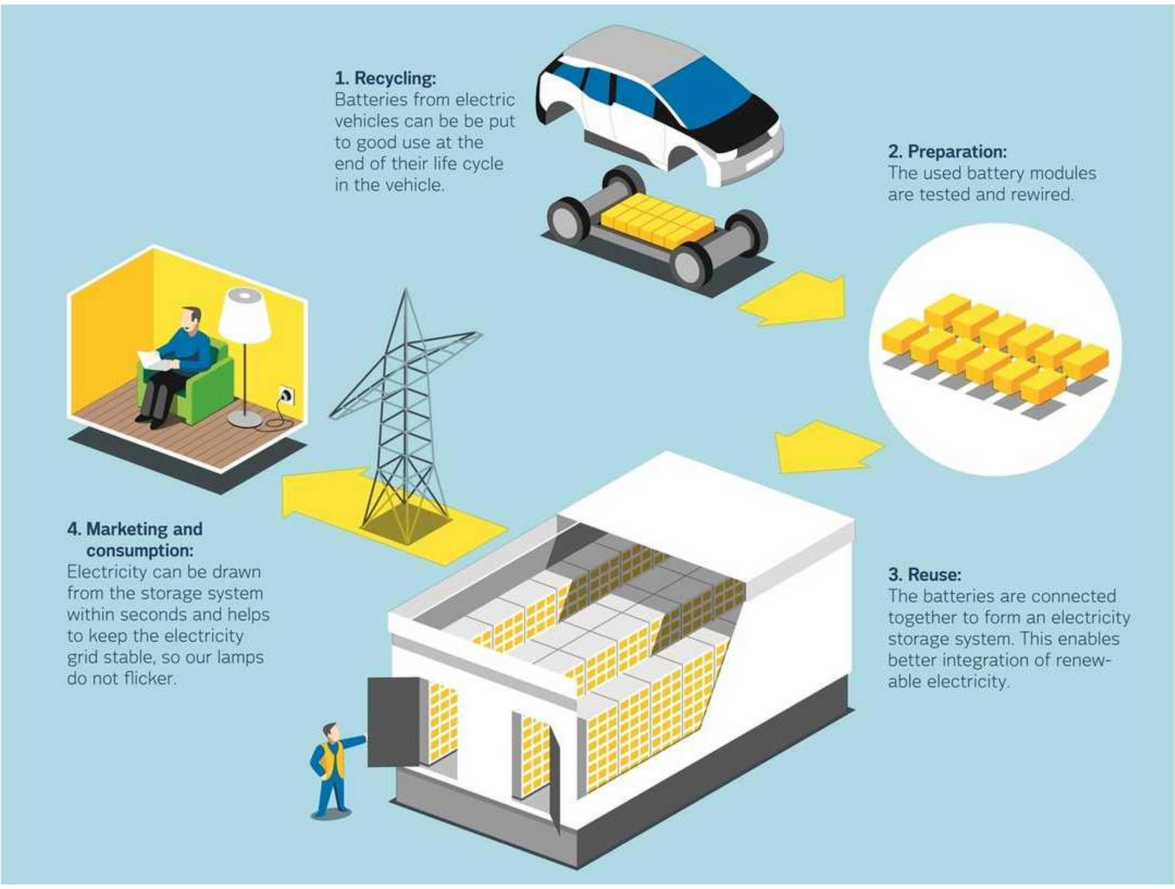

Figure 11. Second life for retired batteries in electric storage system project in Hamburg (Germany) [72]

Several studies are currently being done on the technical and financial viability of using electric car batteries as energy storage devices during their second life. Lithium-ion batteries that have been used before or "secondarily" still have plenty of life left in the, but idea of using these batteries in stationary applications hasn't yet really taken off on the market. Recent studies on increasing inter in the automobile business and developing startup ecosystem indicate that this may finally be changing today [73]. Electric vehicles normally need to be replaced after losing about 20% of their capacity so there is still 80% of capacity available for stationary storage applications. not only GM but other EV manufacturers are paying close attention to the market for used batteries. One of the first significant automakers to test used EV batteries in a grid-scale storage facility was Nissan in 2015. BMW evaluated old batteries in demand response situations during an 18-month pilot study in collaboration with pacific gas and electric in the same year [73]. With 80% of the original capacity, the batteries removed from the car can now be used again before being recycled. After being utilized in an automobile, this battery is now referred to as a "second life"battery when it is employed in other applications [74].

The following are some applications for repurposed batteries:

- **Telecom and datacenter backup services**: Currently the largest second-life application in the world is backup services for telecom and data centers which depend on a stable power supply.
- **Behind-the-meter storage services (BTM):**Commercial or domestic applications used to provide power backup during the power cut.
- **Front-of-the-meter storage Services (FTM):** Utility-scale services that focus on applications for frequency regulation, voltage support, and surplus renewable energy storage are known as front-of-the-meter-storage devices.
- **Low power electric vehicle:** The batteries can be used to power slow-moving vehicles like golf carts,forklifts, etc. even though they cannot power passenger vehicles.

b) Batteries used in Renewable Energy Systems

One of the most effective ways to successfully integrate a significant amount of solar and wind renewable energy in power systems throughout the world is through the use of battery storage devices. A recent study by the international renewable Agency (IRENA) shows how electricity storage technologies can be applied in the power industry for a range of purposes including utility-scale cases, e-mobility, and behind-the-meter applications [75]. Concentrated solar power plants and batteries can both be used to store renewable energy for a limited amount of time. Renewable fuels like hydrogen and ammonia can play a part in this. When wind turbines and solar panels are producing more electricity than their customers need, utilities would produce these files using the excess energy to store them[76].

The largest of the current renewable energy storage projects utilizing hydrogen that are currently in operation are facilities located in Germany at Grapzow.Lead-acid, Ni-CD, n=Ni-MH, Li-ion, and other types of batteries are readily accessible on the market for use in the production of renewable energy systems as shown in figure 2.7. The sodium/Sulphur (Na/s) battery technology is widely used for grid application (200 setups worldwide) with a discharge capacity of 315 MW. In addition, there are emerging battery opportunities for many other battery systems due to practical low-cost (redox-flow) as well as increased efficiency [47]. However, LIBs are expensive to implement at ESS, there are other options available such s salt Sulphur batteries for large installations [77], even though these batteries must run at high temperatures (above 250 °C), making them less practical for trucks or home applications. Battery costs for managing applications that would start to generate meaningful earnings should uncourtly be lower than 200 EUR/kWh. As a result, its integration into the electric power grid is difficult, similar to how electro-mobility works. Since Li-ion batteries are so expensive, research is being done to find more affordable alternatives including lithium-sulfur batteries, which have a high specific power of 2600 Wh/kg, which is more (5times) the Li-ion batteries. However, they are still in their beginning state, with a significantly lower life cycle (of about 50 cycles compared to the higher than 1000 cycles of Li-ion), a significantly higher seld-discharge (10 times faster), and a power thickness that is practically half than of Li-ion [48]. As a result, Li-ion is still often the best alternative [61]. The UK's installed power storage capacity in 2017 was only 3.1 GW, according to table 1. this capacity can be increased by using EVBs in the centers such as solar,wind, and hydroelectric stations. Batteries have emerged as a crucial method of storing renewable energy since their cost has sufficiently decreased to enable industrial adoption. The growth of renewable energy is mirrored in the demand for batteries. The world bank predicts a sustainable growth in global renewable energy capacity from 165 gigawatts in 2016 to 929 GW by 2022. The IRENA has calculated that in 2030, the world will need 325 GW of pumped storage and 150 GW of battery storage respectively [78].

TABLE I. INSTALLED CAPACITY AND ELECTRICITY PRODUCED BY EACH TECHNOLOGY (SOURCE: [79] (P. 9))

	Installed Capacity (GW) 2017 Q2	Annual Change	Energy Output (TWh) 2017 Q2	Annual Change	Utilization/Capacity Factor 2017 Q2	Annual Change[9]
Nuclear	9.5	~	16.6	+1.0 (+7%)	81%	+5
Biomass	2.2	~	3.5	–0.3 (–9%)	75%	-7
Hydro	1.1	~	0.4	–0.1(–16%)	19%	-4
Wind	15.5	+1.0 (+7%)	9.3	+3.3 (+56%)	28%[9]	+9
Solar	12.4	+1.9 (+18%)	4.0	+0.6 (+17%)	16%	~
Gas	28.4	+0.6 (+2%)	27.7	–2.9 (–10%)	45%	-6
Coal	14.0	~	1.3	–2.7 (–68%)	4%	-8
Imports	4.0	~	5.3	–0.6 (–11%)	61%	-7
Exports			0.0	–0.3 (–88%)	0%	-3
Storage	3.1		0.6	+0.0 (+1%)	10%	~

2) Recycling of EV Batteries

Various techniques for recycling traction batteries have been developed over the past ten years [80]. Recycling is useful to alleviate material scarcity, reproduce cheaper materials with old components, reduce energy recycling helps to reduce material scarcity, generate less expensive materials using recycled parts, which save energy, develop sustainable processes and reduce emissions [81]. Reverse supply chain management has been the subject of numerous studies and evaluations from various angles.

Three stages were mentioned; the beginning of life (BoL), which involves production and design; the middle of life (MoL), which includes fixes and logistics (flow); and the final usage.

Reverse logistics (event), remanufacturing, disposal, reuse, and recycling are all included in the third phase, which is referred to as EoL [40]. The compulsory costs of disposing of, reusing, or recycling batteries at the end of their useful lives must be taken into account by anyone wishing to enter the EV market [41]. Modern recycling practices are typically "loose" or drawn-out cycles that reduce product energy to its cheapest "nutrient" level [82]. Battery specialists can determine whether a battery is appropriate for second-use applications or if it should be submitted for recycling. In second–use applications or fixed energy storage applications, second batteries can be used as cells, modules, or batteries as a whole [83]. Before being sent for recycling, EoL electric vehicle batteries can be used for up to 60 percent of their original capacity [84]. At the moment, batteries in cars can be disposed of and repurposed to reduce their impact on the environment [61]. Figure 12 illustrates the process involves in a circular economy; product input, style, production, recycling, and usage which is tied directly to material input and is thought of as the end-of-life phase, this closes the loop for material use [85].

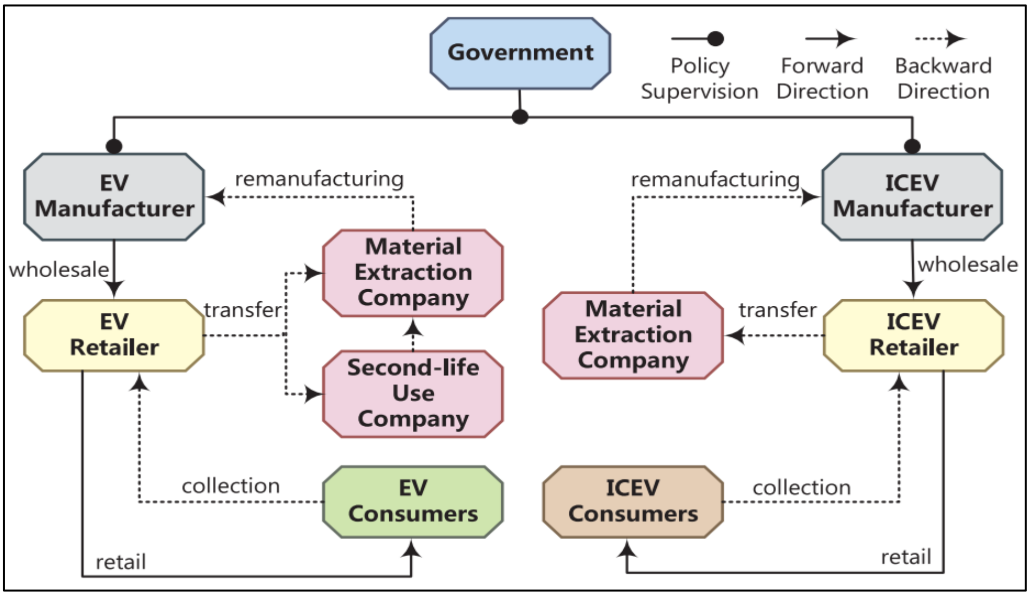

Figure 12. Framework for recycling EV batteries (Source: [14])

According to the requirements of the relevant laws, EV manufacturers must fulfill their obligations in the recycling of batteries and should provide a facility where used EVs can be gathered, stored, and transferred to other expert businesses. This recycling process is shown in figure 12 by Flavor et al., (2019). Electric vehicle sellers are typically in charge of collecting batteries from consumers due to the marketing benefits of providing after-sale service. The effective ones will undoubtedly be used in a variety of applications after being evaluated for recurring battery capacity, charging/discharging performance, and condition of health [86]. Batteries that are effective for different use should be recycled to recover important materials, such as lithium, magnesium, cobalt, etc., which will undoubtedly be taken out and used to make EV batteries once more [14]. Recycling EV batteries causes the remaining 80% of their capacity to completely disappear in addition to reducing the active bulks in the batteries to component material [67]. By 2020, the worldwide EV batteries will account for more than 75 of the market for light-duty vehicles, and 70% OF EVs are powered by Li-ion batteries. To guarantee the supply of lithium required for battery production, the green revolution has become a major concern in the automobile industry through the reuse and recycling of batteries [46]. The recycling of some materials doesn't always provide an ecological benefit compared to the primary manufacturing of these raw materials because of the high process complexity and lengthy process in chains [80]. Recycling allows for the recovery of material used at many stages of production from fundamental building blocks to battery-grade components. To make the product acceptable for any use, the valuable metals (Co and Ni) are recovered and transported for refinement. This slag which is currently utilized as an ingredient in concrete contains additional elements including lithium. If pricing or restrictions made it appropriate, the Li could be recovered by using a hydrometallurgical process [87].

Figure 13 illustrates the diagram which shows the overall graphical representation of the techniques, methods, and procedures of the recycling of electric vehicle batteries. The price of recycled lithium can be up to t times higher than the process of lithium made using the least expensive brine-based technology [89]. Recycling is anticipated to be a key aspect of the effective material supply for a battery manufacturer.

However, given the rising number of EVs expected to hit the market in the future and the service supply shortage [46]. An affordable and simple recycling procedure has been identified after reviewing the research [90]. According to Jody et al., increased technological advancements could enable recycling to recoup up to 20% of the cost of batteries. Several techniques could be used to recycle used Li-ion batteries to recover the metal, the two most common are hydro metallurgical procedures and pyro metallurgical procedures. The majority of literature favors the hydrometallurgical procedure for metal recovery because the pyro-metallurgical method is costly and energy-intensive [91]. Recycling has two advantages; removing recoverable materials from the battery during the recycling process and saving money. There are types of extracted materials; lithium salts, aluminum, and others (plastics,steel,paper, and, miscellaneous metals) [69]. In addition, each county has its strategies for dealing with used batteries therefore it is crucial for the long-term objective to look at their efforts [81].

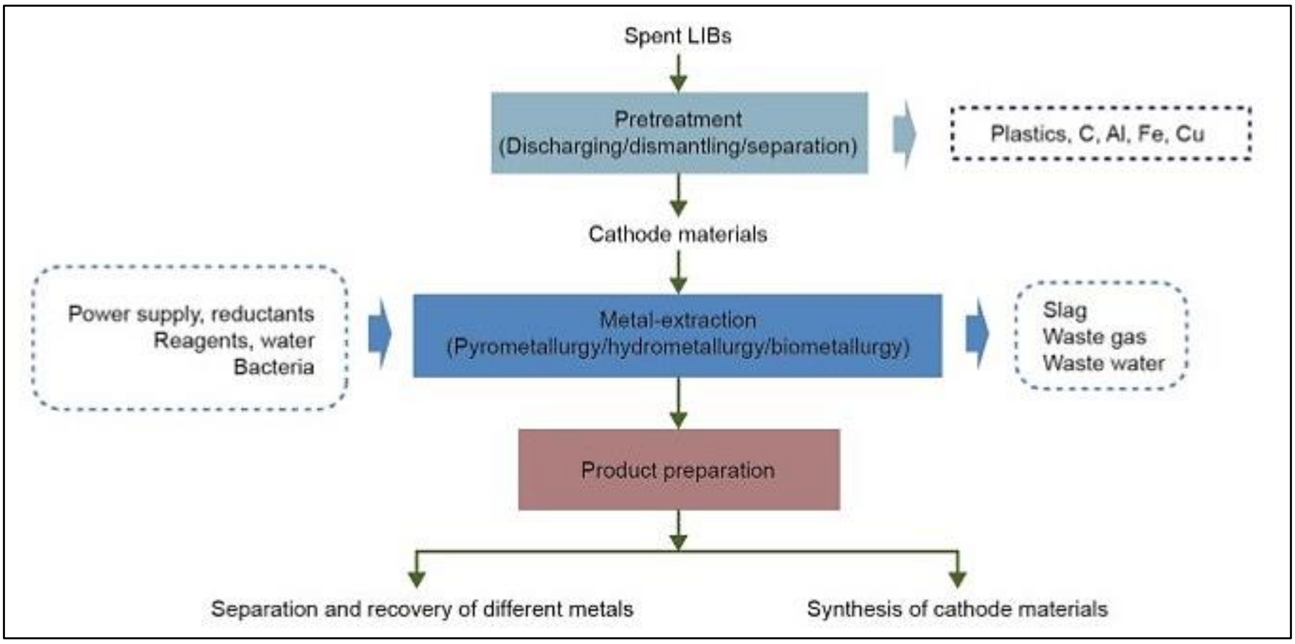

Figure 13. General schematic of the methods and processes for recycling spent LIBs [88].

III. CONCLUSION

Recycling electric vehicle batteries is a key area for expansion. Vehicle manufacturers are moving towards electrification as a result of rigid greenhouse gas emission regulations and higher fuel economy criteria. Electric vehicle (EVs) batteries suggest that transportation becomes more electrified and their use in vehicles will grow nowadays. Due to their small size and high energy density, EV batteries required special handling precautions due to their chemical temperament. The processing of post-vehicle application batteries must be done in a way that is not determined to the environment, and that does not utilize natural resources according to the principles of environmentalism and sustainability. Thus, recycling of the materials comprising the batteries must be considered even if not currently economically viable. Energy storage systems and renewable energy technology are constantly evolving. The amount of energy that can be produced mostly depends on the system used and this can be affected by several factors like environment, location, and availability. Recycling batteries is a practical response for everyone involved in the value chain of electric vehicles. This study shows the possible options for retired electric vehicle batteries. This study also suggests that after recycling the batteries, the raw material can be used to create new batteries for electric vehicles and other electronic items (computers, mobiles, telephones).

CONFLICT OF INTEREST

There was no conflict of interest among the authors of the present research.

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