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Recycling and Repurposing of EV Batteries

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Abstract: *It is a fact that electric vehicles (EVs) are beneficial for climate protection. However, the current challenge is to decide on whether to reuse an EV battery or to recycle it after its first use. This paper theoretically investigates these areas i.e., recycle and reuse. It was found that there are several commercially used recycling processes and also some are under research to regain maximum possible materials and quantity. The concept of reusing (second life) of the battery is promising because, at the end of the first life, batteries from EVs can be used in several applications such as storing energy generated from renewable sources to support the government grid.We built a system dynamics model to capture the decision factors for repurposing or recycling end of-life EV batteries. Our findings reveal that the EV battery regulation is effective when it comes to building the required recycling capacities. Our simulations highlight that the current recycling capacities are insufficient to meet the growing demand, thereby highlighting the need for investors to expand the current facilities. On the other hand, the EV battery regulation, which promotes recycling with mandatory recycling shares, leads to a considerable dropping of shares in the emerging repurposing market. Our study concludes that, to achieve a circular economy for EV batteries, balanced support for recycling and repurposing is needed. We call for a complementary policy framework that ensures that repurposing is an integral part of the closed-loop system.*

Keywords: battery recycling; battery reuse; battery second life; circular economy; lithium-ion cells; electric vehicles; battery components recycling; sustainability in mobility; battery safety; battery cost analysis

I. INTRODUCTION

Electric vehicles (EVs) could play a major role in mitigating the effect of climate change. It is expected that EVs can help in decarbonising and building a sustainable world. The deployment of EVs is being boosted by public administrations in several regions of the world. The global deployment of EVs increased from 17,000 in the year 2010 to 8.5 million by the year 2020 . Such rising trends correspond to increasing demand for high-performance batteries for EVs such as Li-ion batteries (LIB), which is regarded as the most promising chemistry for EVs due to their intrinsic characteristics and significant cost reduction in the past decade (from USD 1100/kWh in 2010 to USD 156/kWh in the year 2019)

The dual objectives of extending battery lifespans and recovering materials underscore the circular strategies of repurposing and recy cling. These two strategies, though they can be competing at times, could be combined to a two-loop system. Parallel developments in the energy market have bolstered the viability of the repurposing approach. Notably, stationary storage applications have emerged as a promising repurpose strategy, as EOL batteries carry sufficient capacities to sustain industry standards and prolong the average battery lifetime by ten years. Consequently, there is an increasing demand for home and community storage battery systems driven by consumers' growing desire for self-sustaining energy solutions.Despite having two alternatives, once the second life use is finished the battery is sent to the second option to be recycled as part of a circular economy strategy to minimize the amount of waste produced. A visual representation of the batteries life in a circular economy perspective is shown in fig. 1

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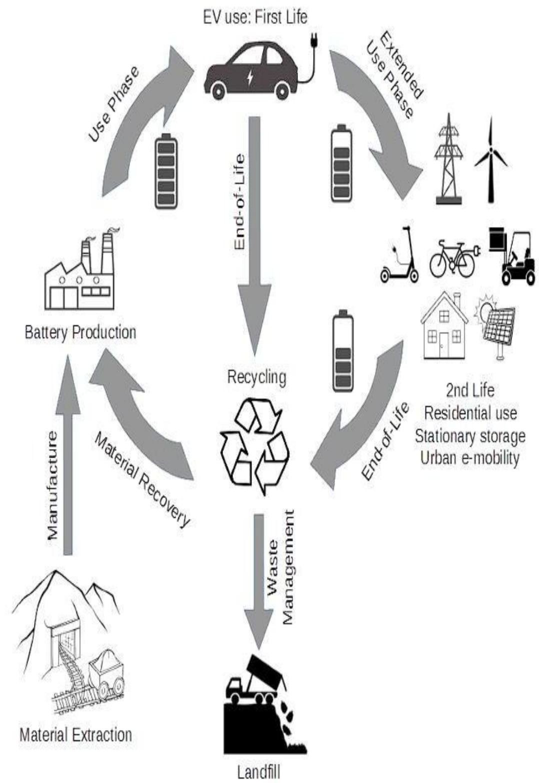

Figure 1: Battery life in a circular economy perspective

In order to fulfil the range-anxiety standards, EV battery capacity has continuously increased since then, giving the EV battery cost decrease a similar final cost for EVs over time. Nowadays, the battery energy of EVs ranges from 30 to 90 kWh with an average selling close to 44 kWh.After 10 years of development, batteries have improved in all possible directions (performance, cost and environmental burdens). Nonetheless, the GWP of the product tion phase of EVs with 64 kWh of battery energy storage capacity is still 25% higher in comparison to diesel vehicles. Although the GWP was triggering the entrance of EVs into the mobility sector, there are other categories in which the environmental impact of EV manufacturing substantially worsens in comparison to ICEV, which are abiotic depletion, photochemical oxidation, acidification and eutrophication, all of them having impacts higher than 50% . Knowing that many of the materials used in battery manufacturing are considered critical materials, abiotic depletion is now the principal reason for developing new battery chemistries with lower environmental impact.

The article aims to answer some of the questions such as, is a second life of a battery worth the effort e.g. is it economically and environmentally necessary? How can we include this, and recycling approaches LCA's, to avoid misleading information?

II REUSE

As indicated in Section 1, there are multiple stationary applications where electric energy storage systems could be installed that can be gathered in two groups [20]. The first group is oriented to electricity generation and grid distribution with larger-scale installations such as time-shifting, seasonal energy storage, large-scale renewable integration, transmission and distribution investment deferral or grid regulation. The second group is more oriented to a user-level perspective, in this case, there are both relatively high, medium and small-scale installations depending on the final user (industry, tertiary or residential building) like energy management, power quality, power reliability, distributed renewable integration and transportation applications. In both groups, power requirements range from a few KW to several hundred MW and some of them require fast response times while others do not. Similarly, their storage capacity range from kWh to MWh and the services might ask for several hours of energy delivery or only for some minutes of support. Thus, it is expected that, for the first generation of EV batteries sold, many batteries will reach their EoL as soon as they are removed from the vehicle and should proceed to recycle. However, for newer EV models, batteries will present much better conditions for their use in the second life, which can be either in stationary storage applications or in EVs as spare parts for those with manufacturing defects or crashes that need low-cost replacements. For all that, battery reuse might follow three possible directions depending on the goal of the remanufacture pursues. Direct reuse and battery dismantling to the module or cell level [26]. Direct reuse offers lower costs but it provides less adaptability options due to stacking problems. The option of module dismantling allows for a more versatile solution, capable of going from small to large systems. However, a new battery management system (BMS) and control systems should be implemented. This option is called to be the one mostly used by remanufacturing companies. Finally, the dismantling into cells maximizes the versatility and reduces the inhomogeneity of the resulting battery, as an individual selection of cells according to their SOH and other characteristics can be undertaken. Nonetheless, the cost rises due to an increase in the manipulation, testing and need to implement completely newcontrol systems at the cell, module and battery level [27]. Overall, going for battery reuse strategies give the chance to Europe to become a potential battery manufacturer. At the moment, Europe is dependent on raw materials and also on new batteries built elsewhere. Once battery recovery begins, Europe will be capable Energies 2021, 14, x FOR PEER REVIEW 6 of 16 of positioning itself as a potential world provider, as most EVs are being sold mainly in Europe (39.8%), China (39.6%) and North America (10.7%) [28,29] as shown in Fig. 2

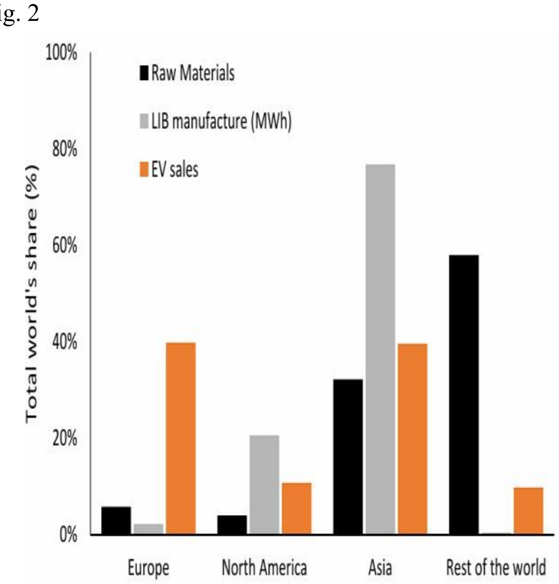

Figure 2: Percentage of electric vehicles (EV) world sales

III RECYCLING

Some EOL EV batteries are send directly to recycling, where the EV batteries is dismantled and hydrometallurgical, pyrometallurgical and other technologies are use to recover valuable chemicals and metals such as cobalt, nickel and aluminium. Recycling is discussed in more detail in this report.

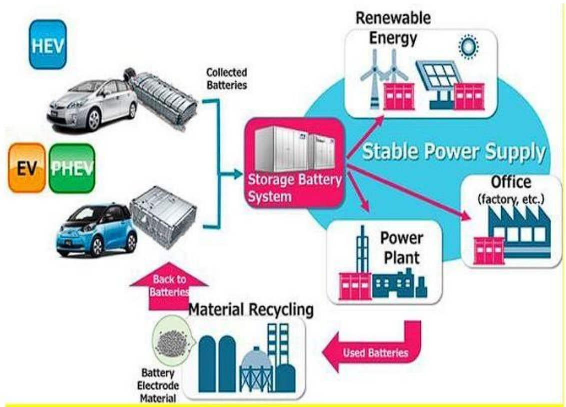

Figure 3: End of life of EV Batteries

IV FUTURE RECOMMONDATION

As explained within the present work, the increase of EV battery units and their capacity in coming years will pose an environmental challenge that will have to be dealt with by approaching reuse and recycling strategies. To do so, the first step is to identify whether the battery is in a reusable or recycling state. This can be done by following two logical steps (maybe in combination in some cases), (a) identifying battery source i.e., regular used or damaged vehicle, and (b) battery testing like visually, electrically, mechanically etc. The need for such steps is, for example, if the EV had a major accident and the battery is leaking, then there would be no sense in carrying out any further testing as it will be obvious that such battery would be non-reliable and possibly unsafe to reuse i.e., it should be taken directly for recycling safely. To ease the transport of such batteries, if possible, it is beneficial to not only remove the battery from the EV but also the battery components should be dismantled onsite or at some possible quarantine area [22], so that this would be safe and not require a specific type of transport i.e., a vehicle having features for transporting batteries within a specific battery container, as per the Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR) rules. Such onsite dismantled batteries can be only recycled at the recycling facility.

V CONCLUSION

The global EV market is significantly increasing and hence battery consumption as well. The challenge in the market is to find an optimal solution from two options, whether to recycle the battery after its first use in the EV or to re-use (second life). Looking at the battery reuse strategies, it was found that the benefits of battery re-use are not only expected to be in the second life applications but the remanufacturing process as well. Another aspect that was reviewed in this article is recycling. From this point of view, it is always logical to regain good precious materials after the end of life of a battery system. The idea of recycling is supported by both ecological as well as economic perspective.

While recycling of small sized li-ion consumer batteries is well established in the US, the recycling of li-ion EV batteries is much more complex as the units are heavy (up to 400-500kg for many models), dangerous until fully discharged, and require a lot of dismantling. Costs to recycle EV batteries are not well identified or understood, but it appears that recycling EV batteries using today's technologies incurs a cost rather than generates revenue based on metal values. Traditional recyclers charge EV battery owners a fee based on the time it takes to recycle the battery, and pay a credit back based on metal values recovered.

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