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Recollection and Recycling of Automotive Lithium Ion Batteries in India

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***Abstract*—In this paper, we develop strategic network model for collecting and recycling of used Lithium ion batteries from Electric Vehicles. This framework explains logistics concept for collecting the used batteries and it is developed by considering complexity in both physical and economic scenario in returning the core for recycling in India. This paper covers efficient recollection and cost effective, environmentally suitable recycling of lithium ion batteries for emerging countries like India. We also introduced, second life application in addition to the recycling of LIB.**

Keywords—automotive lithium ion batteries, recollection, Network planning for recollection, battery recycling, remanufacturing, disposal, Reuse, Second life

I. INTRODUCTION

Indian automotive industry with clean or zero emission is a target for a sustainable environment; in this regard, Government of India is planning multiple ways to reduce the carbon footprint and one of the solutions is promoting electric vehicles(EV). Upcoming policies and legislations indicate gradual increase in EV share in automotive sector (e.g. complete 3W EV by 2023, 2W EV by 2025 for ⩽150cc, 4W EV fleets by 2026 and further growth in other segments by 2030) . Demand will increase in both personal and public mobility for EVs due to urbanization, growth of public EV infrastructure, ride-sharing fleets, and last mile connectivity. In future, residual energy source i.e. battery, will be the heart and fuel of vehicles (EVs and Hybrids). Currently, the most popular application is Lithium ion battery (LIB). As the EV population increases, battery-recollection, recycling, reuse, remanufacturing would be the key measure to reduce the raw material (precious metals) consumption and pollution from hazardous materials. The LIB battery market is expected to grow exponentially by 2030 and offers $1,000 million business opportunity for recycling in India [1]. Currently in India, we do not have structured model for collection and recycling of spent batteries. This paper has a concept proposal on recollection, and the reuse and recycling processes are based on global literature. Our efforts in this paper is relevant for and can be deployed in emerging economies like India.

II. PROBLEM STATEMENT

There are three issues associated with the disposal of lithium ion batteries in India:

A. Environmental

Lithium ion batteries contain flammable and toxic components, and the risks of disposing LIBs in landfills are possible explosions or contamination of soil and groundwater. There is risk of increase in carbon footprint due to inefficient recycling processes or irresponsible disposal methods.

B. Economic

LIB contains precious metals (e.g. Lithium, Cobalt, and Nickel etc.) and India does not have a source of lithium and currently imports batteries/cells. Any attempt to set up local LIB manufacturing will require the import of lithium/cells. Currently, there are no standard regulations defined on recollection, recycling processes, recovery percentage or reuse in second life. It effectively increases the total cost, which includes expenses on material cost, reverse logistics, labor cost, energy and environmental pollution control. Scarcity of precious metals can occur if spent batteries left without proper recycling methods and there will be additional load on mining industry.

C. Legislation and Infrastructure

Lack of government regulations, policies leads to slow development in infrastructure to support recollection, and recycling as a business is not lucrative to the investors, which possess greater problems. There are no subsidies for recycling of Li-Ion batteries as of now.

The efficient recollection model with cost effective and environmentally suitable recycling of lithium ion batteries in India can address all of these issues.

III. OBJECTIVE

The objective of this report is to develop an efficient recollection network model and recycling solutions for emerging economies like India.

IV. RECOLLECTION MODEL

Proposed concept works on reverse logistics or recollection network model (Core return method) to suffice the Indian requirement of recycling LIB. The entire process is divided into logistics and recycling (refer Fig.1). In logistics process, we collect the used or spent batteries (core) with the help of Hub and Spoke network model (refer Fig.2), from fleet vehicle owners and flying doctor model from end customers. In Recycling process, based on the health of the battery, further categorization will be done and it is explained clearly in this paper. Spokes are the touch points to end customers to drop a battery, if customer is located far from the spoke, flying doctor service can be used. Flying doctor or spoke collects the spent batteries from end customers by offering, either buy back for lump sum amount or exchange with new battery at discounted price. Each core return will fetch some value (buyback/exchange price) to the customer and all the supply chain partners will get certain price benefit. Spokes are the OECD (original equipment car dealer) who collect the core and send it to the centralized locations called Hubs.

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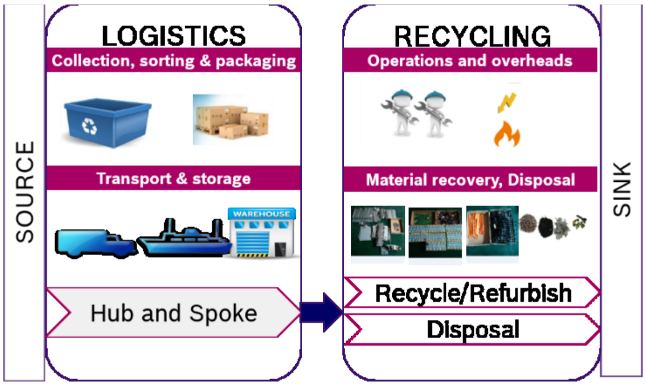

Fig. 1. Logistics and recycling model for spent LIB

The Hub to diagnose the health of the battery and based on the results, one of the below categorizations is applicable:

A. Recycle(end of uselful first life)

These batteries are defective, uncritical and can't be reused. Safe for dismantling at cell level and component recovery possible. Dismantling process carried over at Hub and only the battery cells sent to battery recycling plant e.g. Tata chemicals, Raasi Solar etc. Plastic and electronic components will be sent to respective recycling locations.

B. Reuse(Second life usage)

Batteries with reasonable state of health can be send to battery refurbishing/ remanufacturing companies for application in energy storage second-life applications e.g. solar, stationary power generation etc.

C. Disposal (Damaged)

This step is for packs which are damaged or in critical condition. These LIBs have a high safety risk during handling. Hence, these LIBs will be sent for disposal or for recycling directly without dismantling. It will have special packaging, to avoid explosion and other hazards.

LIBs are complex and classified under dangerous goods, Hub should have necessary permits for dismantling and also highly skilled man power required to diagnose and dismantle. Due to diversity in mass, size, construction and materials of batteries, it calls for highly flexible equipment and reskilling of labor, which may increase the investments or costs.

Spatial distribution of Hubs or spokes will depend on the recycling plants location (sink) and the volume prognosis from source geographies across India. For e.g. Metros and tier 1 cities will have higher penetration of 3W and 4W EV/PHEV. Whereas 2W EVs will be taking the rural market and some of the manufacturers capturing the market by partnering with Government bodies (e.g. Hero electric partnership with CSC e-Governance services India). Growth of EVs in India will call for network optimization of Hub and spoke model, capacity expansion and packaging decisions for logistics as market expands.

Extended Producer Responsibility (EPR) norms will accelerate recollection and the above model can be a reference to enable producers for faster implementation. Below are some of the benefits and challenges related to the network model

1) Benefits:

- Hassle free collection of spent batteries with greater spatial coverage
- Decentralized model improves the cycle time and saves the additional transportation cost
- Dismantling process to cell level at Hub reduces process steps at recycling plant
- Special packaging for varying battery pack size not required, as we transport battery cells alone to recycling plant from Hub

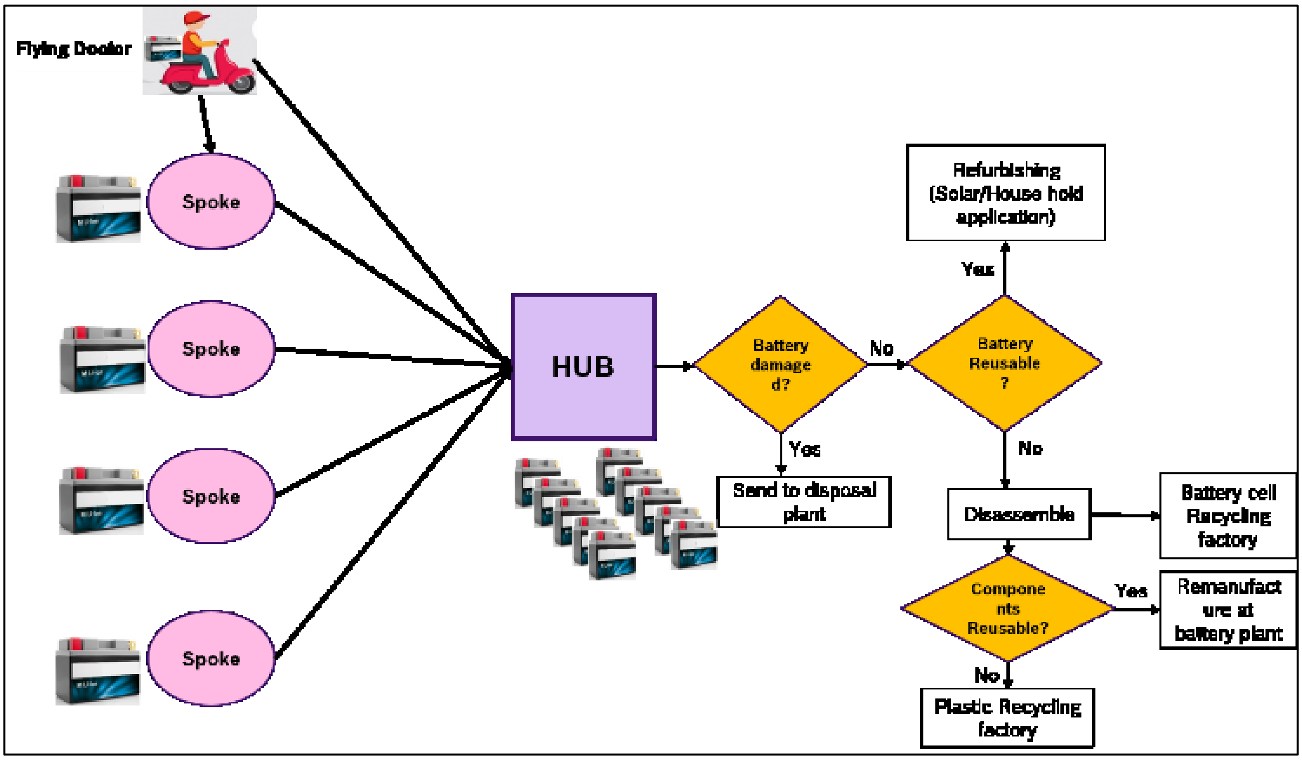

Fig. 2. Recollection flow chart with hub and spoke model

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- Standard packaging can be defined based on cell type(cylindrical, prismatic and pouch) with less efforts e.g. one box with capacity of 100 cells
- Well defined and efficient recollection model reduces impact on the environment due to pollution

2) Challenges:

- Lack of well-defined Government regulations and policies might have impact on level of standardization and efficiency level of network partners
- High initial capital expenditure, low interest for start-ups
- Return on investment will depend on the efficient management of cost levers and scalability of the model
- Low level of awareness among battery suppliers and consumers about recycling

V. LIB RECYCLING FOR SUSTAINABLE FUTURE

The growing rate of consumption of LIBs is an indication for environmental hazards at the end of life unless it is recycled properly (Hunt, 2015). Developed and emerging economies both find immense use for LIBs and consumed in 1000s of tons. High demand imminently will lead to scarcity. The scarcity will not be due to a lack of raw material but rather a lack of mines available to meet demand. Lithium can be found across the globe in North America, South America, Europe, Africa, and Asia, but nearly half of the global lithium supply comes from Argentina, Bolivia, and Chile. For a sustainable future, free of hazardous waste and availability of affordable raw materials, recollection and recycling is the solution.

State-of-the-art recycling processes globally focus on the recycling of cobalt and nickel, but not lithium. This is because of higher raw material costs of these transition metals compared with the costs of the less expensive lithium (Dunn et al., 2012; Hanisch et al., 2011b; Hoyer et al., 2013; Ziemann et al., 2012). Scientists find that no real lithium scarcity is foreseen until 2050 when easily extractable reserves in stable countries could decrease significantly (Weil and Ziemann, 2014). Lithium resources excluding the lithium in the oceans are calculated at 30 Mt by Kushnir et al. and will only be critical within this century if large scale use of EV batteries are needed “or if batteries are not recycled” (Kushnir and Sandén, 2012). Gruber et al (2011) estimate the resources of lithium at 38.68 Mt but agree that lithium has to be recycled with recycling rates of at least 90 % to prevent a future shortage (Gruber et al., 2011). Miedema et al. (2013) find the big potential of lithium recycling in Europe (Miedema and Moll, 2013), Zeng et al. (2013) in China (Zeng and Li, 2013) and Wang et al. (2014) in the United States (Wang et al., 2014).

With the current trend, the need for establishing recycling network and plants for emerging economies like India becomes necessary and potent. All aforementioned experts agree on the necessity of lithium recycling at least for long-term sustainability.

Approximately (95%) of a lithium ion battery is recyclable

Value	Material	% weight	% recoverable
	Copper	13	100
	Aluminum	17	100
	Lithium	1	100
	Fe	13	100
	Carbon	16	>90
	Other electrode mat'l	9	>90
	Polymer separator	6	>90
	Other polymer	5	<20
	Other non-recyclable (e.g. solvent, packaging)	21	0

High value
Medium value
Low value

Fig. 3. LIB content with recyclability percentage

VI. RECYCLING PROCESS STATE OF THE ART

LIBs have high scope of recyclability, as an approximate 95% of a LIB is recyclable (refer Fig.3). It is estimated that up to 10% of the world’s supply of Lithium and Cobalt could come from recycled materials by 2025. Knowing that billions of LIBs will be discarded every year and given the high cost of lithium cobalt oxide, salvaging precious metals should make economic sense and one wonders why so few companies recycle these batteries. A shortage of lithium may not have that great of an impact on actual costs of batteries—a 300% increase in lithium cost would only raise the price of batteries by 2%. However, as nearly 42% of global supplies of cobalt are used for batteries, a possibility of a shortage of cobalt will affect cost of batteries. If prices of cobalt rises 300%, the reflection in the cost of batteries would be around 13%, which would be felt a little more by consumers. The reason becomes clear when examining the complexity and low yield of recycling. If the purity of lithium is below 99.5 percent, then it is not suitable as raw material for battery manufacturing. It is often cheaper to mine raw material rather to retrieve it from recycling. Lithium from recycled batteries is commonly used for non battery applications, such as lubricating greases that are found in WD-40 and other products, rather than batteries[2]. The retrieved raw material barely pays for labor, which includes collection, transport, sorting into batteries chemistries, shredding and separation of metallic and nonmetallic materials, neutralizing hazardous substances, smelting, and purification of the recovered metals.

In the recycling process of LIBs, major components such as cathode material (lithium metal oxide), anode (graphite), polymer electrolyte, separator (Polyvinilidine fluoride), metal casing, plastics and battery management system(BMS-electronic control unit) are to be separated and converted into a reusable material (Gaines and Cuenca, 2000, Wakihara and Yamamoto, 1998, Contestabile et al., 2001). The LIBs have different cell chemistry to suit the varied applications as per their inherent energy density (refer Fig.4). This adds to the complexity for defining the processes for recollection and recycling. The safety aspect of the cell is relevant, for transportation, handling and pretreatment before recycling.

Because LIBs are complex products, a wide variety of methods for recovering the valuable metals from spent LIBs using pyro metallurgical (Smelting), hydrometallurgical (leaching), the combination of both processes, direct recycling(physical processes) have been reported (Kang et al.,

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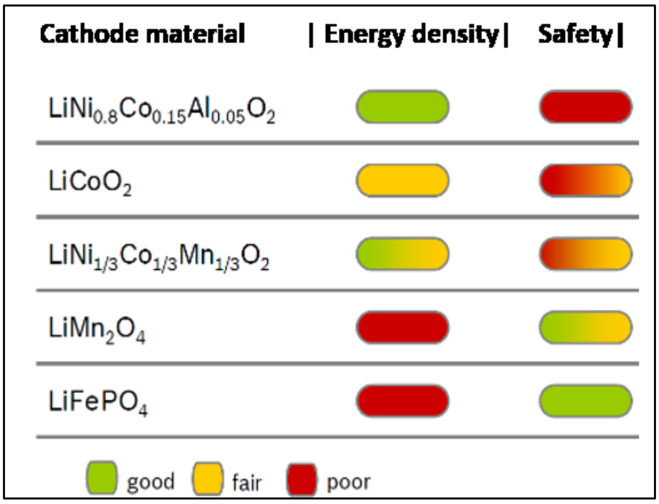

Fig. 4. LIB cell chemistry with energy density

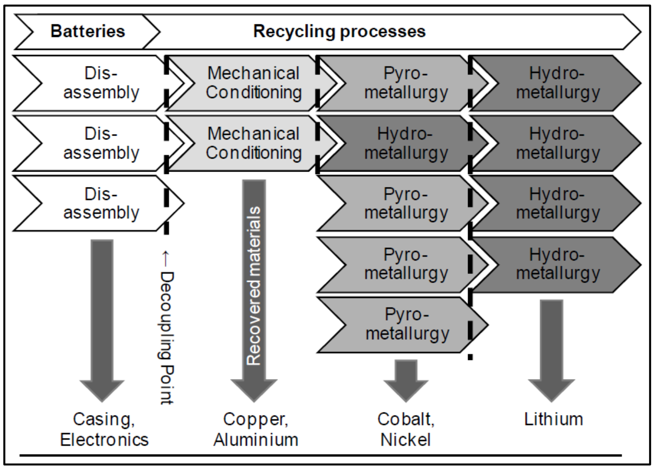

Fig. 5. Flow chart of typical processes for recycling spent LIB [3]

2010, Espinosa et al., 2004, Ferreira et al., 2009, Provazi et al., 2011, Wang et al., 2009, Li et al., 2012, Li et al., 2009). Some of these paths, starting after the pack has been dismantled are mapped out in Fig.5, which shows the interrelationships among process types. Leftward paths yield products of higher value. Process components can be combined in different ways, depending on factors like quantity, characteristics of the material, value of the materials that can be recovered.

VII. REUSE AND SECOND LIFE: THE NEWEST VALUE POOL IN ENERGY STORAGE

With continued global growth of electric vehicles (EV), a new opportunity for the power sector is emerging: stationary storage powered by used EV batteries, which could exceed 200 gigawatt-hours by 2030[4]. Automotive Lithium are discarded at 80% SoH (State of health) as they do not support EV traction. However, these batteries are efficient for stationery application in renewable energy storage E.g. It can be used in solar power storage and household application during scarcity, providing greater grid flexibility and firming to the grid. As indicated in the recollection model, careful and skilled evaluation of spent automotive EV battery, sorting, remanufacturing and defining applications for reuse is possible. Damaged and unsafe batteries should however be discarded for second life. With rapid increase in growth of EVs and hence the supply of second-life batteries volumes will be drastically increased. This volume will be higher than the demand for the li-ion utility-scale storage applications. For overcoming this large volume, and several other challenges the future-proofing of the concept is necessary.

The challenges can be broadly covered under four areas:

A. *Form-factor challenges:*

The automotive EV batteries pack designs greatly vary in size, composition (majorly electrode chemistry), cell format (prismatic, cylindrical, pouch type). This is due to the fact that, each OEM designs the battery pack to suit its vehicular energy demands, safety, cooling design and space availability. By the year 2025, there will be more than 250 models from established OEMs. So, this high complexity due to lack of standardization and fragmentation of volume will affect the estimation, scale and hence cost of refurbishing the spent batteries for second life reuse.

B. *Declining cost of new battery packs:*

With higher economies of scale in production, faster technological advancements and process improvements, the cost of new batteries will keep declining. As new batteries become cheaper, the cost differential between used and new diminishes, given that the rate of decline in refurbishing cost is expected to lag the rate of decline in new manufacturing cost. Unless the cost gap remains sufficiently large to warrant the performance limitations of second-life batteries relative to new alternatives, it will be difficult for the repurposing companies to sustain the second life battery business.

C. *Nascent second-life battery standards:*

There are minimal mention of standards with regard to second-life batteries. Few industry standards focus on battery-management systems or state-of-health disclosures, but this will not be sufficient unless standard battery specifications for the given applications are set.

D. *Lack of Regulatory policies for second-life or reuse:*

Except for few markets like China and parts of USA, major markets lack regulations for OEMs, second-life companies and potential customers. While there are regulations for recycling or remanufacturing of consumer electronics in most markets, but regulations with regard to EV battery specific requirements or delineations of responsibility between the producer and the consumer are lacking.

While these challenges are significant, there have been targeted actions with which we can overcome these in the coming years. For this, the suppliers, end users, and regulators need to draw a sustained course of action. One solution can be, where the OEMs or the EV makers can partner with the second-life application companies and design the batteries accordingly. For example, Nissan formalized a partnership with Sumitomo Corporation to reuse battery packs from the Nissan Leaf for stationary distributed and utility-scale storage systems. Similarly, Renault announced its Advanced Battery Storage Program in 2018 for collaboration with multiple energy sector partners for second-life application of used EV batteries.

Regarding the challenge of reducing costs, the similar scale has to be industrialized for remanufacturing to remain relevant and have the considerable value gap between new and used batteries. Regarding lack of standards, many industry bodies are jointly chalking out safety, performance potential

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and classification of storage applications. With respect to lack of regulations, the OEMs and other stakeholders can take a lead to be responsible for the sustenance of the EV revolution without affecting the environment and depletion of resources. Industry consortium can work on models like leasing batteries, buy-back of old batteries or exchange to keep the recollection and reuse as second life as a way forward.

VIII. CONCLUSION AND FUTURE SCOPE

In this paper, we proposed one of the efficient recollection network models for spent LIB, stated the need for recycling and its processes, reuse and second life for lithium-ion batteries is analyzed. Our future research paper will concentrate on an integrated planning approach for recollection and analysis of state of the art eligible recycling process for India, and emerging countries. This model helps EPR as an example to implement the recycle model in near future and recycling gains momentum only with well-defined Government regulations and policies.

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