EV Batteries Remanufacturing

BORG Automotive Challenge – Team 33

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Abstract

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European aspiration is to achieve a 100 percent Electric Vehicle (EV) sales target by 2030, which brings new business opportunities for the automotive remanufacturers to get involved in EV batteries remanufacturing. This involves overcoming the current weakness in the EU automotive market position for the Hybrid and Electric Vehicle batteries remanufacturing as well as after sales support and manufacturing.

Almost all major automotive manufacturers have already produced a Hybrid or fully Electric car model. However, the price of the car is still expensive due to the Lithium-ion Battery cost. This paper reviews the evolution of the Lithium-ion Batteries design changes in the production and remanufacturing opportunities as well as anticipated changes in cost due to manufacturing. Europe has the biggest market share of the EV, which is set to grow further substantially. The following aspects which are relevant to the EV battery components are covered in this review;

- **Technical Analysis** of EVs end-of-life Lithium-ion (Li) Batteries for the reuse, recycling, remanufacturing options provide growth opportunities for Independent Remanufacturers (**BORG Automotive)** in Europe.
- **Battery efficiency** – 90% efficiency is seen in the EV Battery Cells after 10 years old Electric cars; because EV batteries come with a15-year life cycle, so that the Li Batteries can be reused and remanufactured for the 2nd life cycle, as required.
- A high-level **review of environmental Impact and benefits** of remanufacturing EV Batteries and contribution to energy and carbon reduction.
- **Innovative E-Mobility** Infrastructure in Europe, review of EV's chargers' points, EV Charging Timeline, and Remanufacturing Li Batteries Challenges.

EV battery remanufacturing provides tremendous untapped benefit and opportunities in the European markets. The automotive sector is the most beneficial area from remanufacturing and which accounts for 70% of all remanufacturing companies across the globe. To be able to access this new market BORG Automotive must build up new reverse engineering knowledge for Electric Vehicles and Li Battery Packs to find a suitable methodology which helps them to develop new test stations and jigs based on new technologies for auto fault diagnostic testing and resetting of Electronic Unit boxes according to the Original Equipment Manufacturer (OEM) test specifications.

The increasing market demand for the Lithium-ion traction batteries implies the need to recover active materials from spent Li Batteries, as well as from the electrodes from the OEM production batch rejects to prevent future shortages. This would minimise the dependence on imported key raw materials for Li Batteries, because 75% of the cost of an electric vehicle is the Li battery system, which is determined by the battery cell investment and the proportion of an active materials is in high volumes compared to consumer electronic products which use Li batteries such as Laptops or Phones. **Two different** end applications and products are recommended in this report, first one is the reuse of **Li Batteries in the EVs** and second is recycle of Li Batteries to make a **Power Bank** and third application is the recovery of raw materials from battery Cells.

Keywords: Lithium-ion Batteries, EV Battery Remanufacturing, and Environmental.

1 Introduction of the Lithium-ion Batteries

Lithium-ion Batteries (Li B) usage and application has grown rapidly since the 2010 mainly due to the improvement in design which has increased the capacity over 500 per cent [1]. The biggest increase in the application is seen in the automotive industry, where the advancement in the battery technology has propelled the rapid adoption of electric cars and buses across the globe.

In 2018 the cumulative number of electronic cars has exceeded over 4 million [2] cars with over 100 different car models sold by all key car manufacturers and Electric Vehicles (EVs) are expected to reach 20% of the global automotive market share in 2025. Apart from electric vehicles, Li Batteries application and usage have increased in other applications such as; telecom control rooms, tele-communication base station, data centres, forklifts, bikes and marine industries.

Li Batteries reach the end of their useful life in the EV mainly because reduced capacity directly translates into range reduction, a characteristic unacceptable to most drivers. As the transportation sector continues to rapidly electrify, end-of-life Li Batteries are growing into considerable volumes. There are several options at an end-of-life for the Li Batteries including landfill disposal and multiple resource recovery routes, including reuse, remanufacture of active materials and recycling as shown below in the **Fig 1: EV Batteries End-of-Life Recycle Options.**

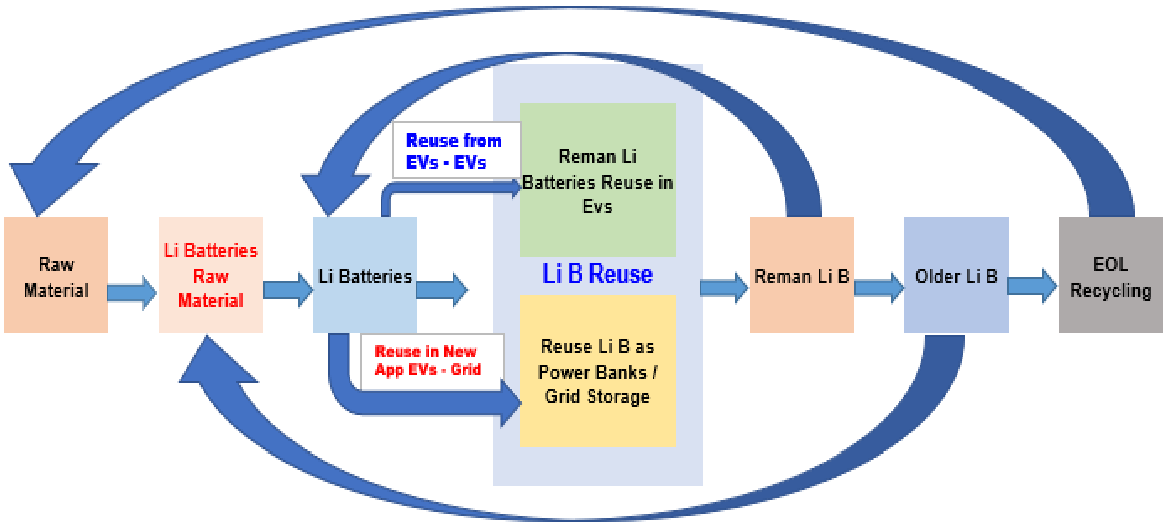

Figure 1: EV Batteries End-of-Life Recycle Options

Preventing the loss of the materials contained in the Li Batteries, while using a circular economy; which requires removing barriers from the linear methodology for the Li Batteries second life routes for the reuse or remanufacturing for the EVs for the repair or use as a power pack and grid storage both options depends on remaining Life of the Li Battery at the end of life of 1st life cycle in the EVs.

With more and more Li B in use and placed in the market, it requires after sales support for the customer throughout the usage of the cars, which require provide solutions for dealing with Li B issues, when they reach their end of life is rising. As shown in the Fig1, the **first recommendation is reuse of Li Batteries in the EVs** during the initial

10 years of the battery life, **and second recommendation is that reuse of the EVs batteries in the Power Banks** for the industrial and home applications of the batteries which are 10-15 years old in the field and **third application recycling of the Li Battery Cells** for Raw Material to get high value material out for the re-manufacturing of the Li Battery Cells according to the latest EV battery models and requirements.

Compared to primary batteries such as alkaline and zinc carbon, which were designed to be consumed just like any other consumable item, but these Li Batteries are designed to last for a long time. However, even a rechargeable Li battery is going to be degraded over time and at the end will cease to work. Depending on the chemistry, size, configuration and purpose a Lithium-ion can perform between 500 to over 10,000 cycles of charging and discharging which determines the life cycle of the Li Battery.

This means that a battery that is used every day in a power tool by a professional craft worker might reach end-of-life in a few years, while a battery used in energy storage applications could last for over 20 years. Although Li Batteries are not toxic in the same way as the lead-acid or the nickel cadmium batteries, but nevertheless do contain elements which should be prevented from bringing an exposed to the environment of Li Battery application usage, as shown in the **Fig 1.1: Li Batteries Global Market.**

It is important to recover the raw materials inside the Li Batteries at the End-of-Life (EOL), which can reduce waste and can be reused in the Remanufacturing of Lithium-ion Batteries.

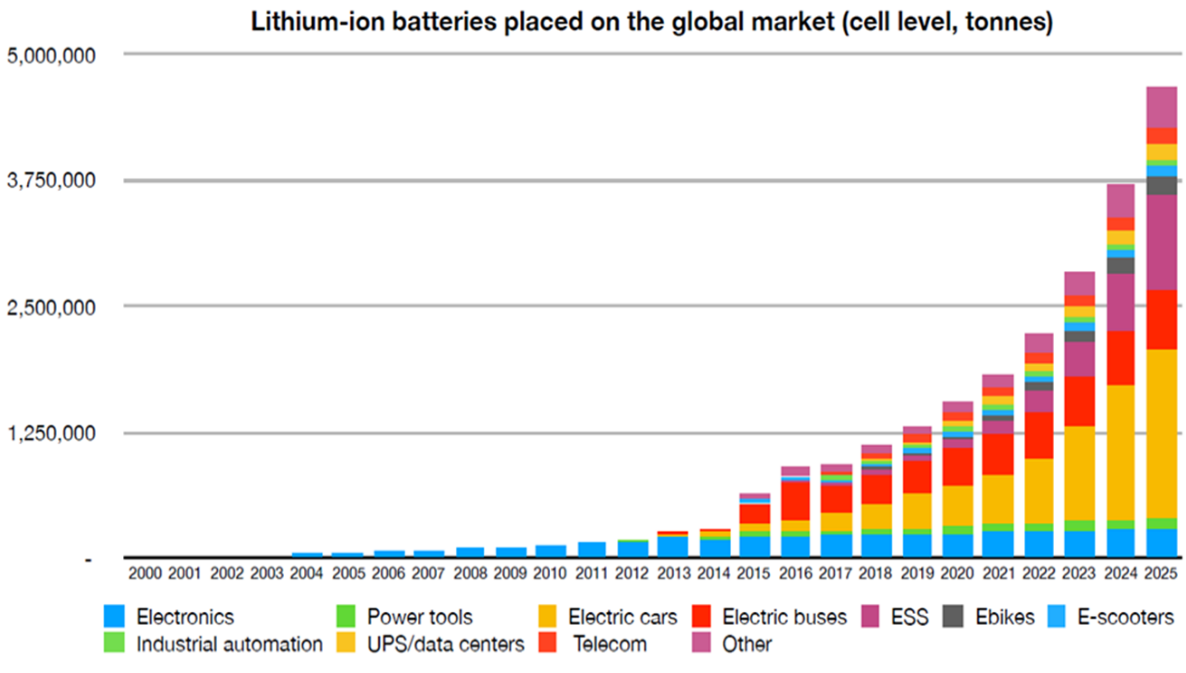

Fig 1.1: Li Batteries Global Market Application **Source: (Circular Energy Storage, 2018**)

As shown from the market trends with such unprecedented growth in EV application of the Li Batteries has increased the demand for the raw materials. Therefore, re-manufacturing of Li Batteries as the requirement has increased significantly due to the high demand and reuse of materials can only be a positive contribution both for an environmentally and economically.

Latest research activities aim at developing new technologies like lithium-air, lithium sulphur, lithium-polymer and sold-state lithium batteries, which are expected to come in automotive EVs in 2030. The global market for Li Batteries in the EVs is expected to grow from $7.8 billion in 2015 to $30.6 billion in 2024. This development in Europe has pushed policies like, the Paris Declaration on Electro-Mobility and Climate Change and Call to Action for 2030. Key issues which were identified when introducing the Batteries **Directive 2006/66/EC** were the hazards represented by the heavy metals Lead (Pb), Mercury (Hg), and Cadmium (Cd) in case of lack of end-of-life process controls for following both targets were set up for this;

1. Collection target for portable batteries, to avoid incineration or landfill with household waste.
2. **Regulation 493/1012** on **Recycling Efficiency (RE)** provides a required target for a minimum recovery of the heavy metals.

2.0 Technical Analysis of the Li Batteries

Literature Review clearly states that, Li-ion technologies have the most competitive position in Electric Vehicles and that is not expected to change before 2025. Li Batteries in the EV consist of the following elements; battery cells are combined in the battery module, which are then assembled into battery packs, as shown in the **Fig. 2: From Li Battery Cell to a Li Battery Pack.**

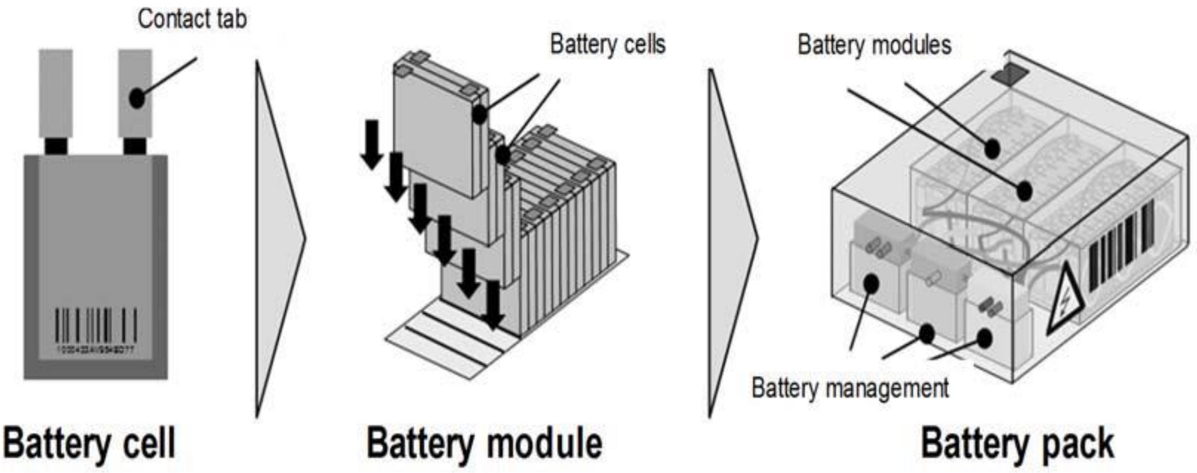

Fig. 2: From Li battery cell to a Li Battery Pack **Source: (A. Kampker et al., 2016)**

These Li Battery packs are integrated into the electric vehicle power train. Such Li Battery solutions are highly costly due to the high cost of the materials required to produce Li batteries and product safety features which are required to be fulfilled to meet the automotive industry standards and to guarantee the safe production process required for high voltage products.

Raw material scarcity puts an additional pressure on the market, which increase the price of raw materials which are required by the manufacturers for the Li B packs of the EVs. The Li battery material cost can account up to 40% of the Electric Vehicle price, which is set to increase due to the depletion of the resources and high demand. In order to offset the increasing costs of the required raw materials by maintaining the raw material in circulation, simply by reuse and re-manufacturing to enable the Li Batteries 2nd life cycle.

2.1 Li Batteries Recycling Technologies Development of EVs

According to the (European Battery Recycling Association, 2011) 1289 tonnes of Li batteries were recycled by the EBRA members in 2010. The key processes which are used for the Li Battery recycling can be divided into three separate operations; mining treatments, Pyro-metallurgy and the Hydrometallurgy processes, as shown in the **Fig 2.1: Li Batteries Recycling Processes.**

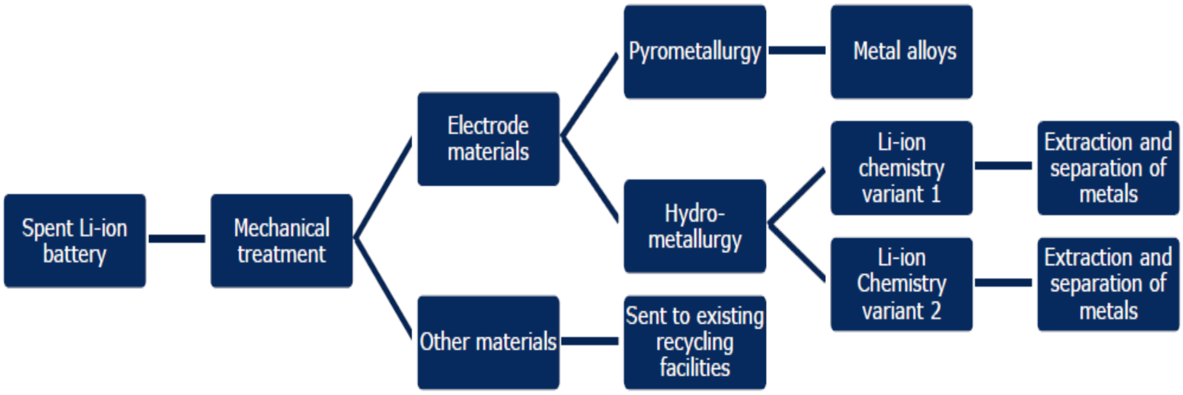

Table 2.1: Li Batteries Recycling Processes **Source: (Ekermo, 2009)**

Key different between both processes is explained below;

- Mining type treatment uses mechanical processes such as crushing for separation of materials (Espinosa, 2004), for which EV batteries get disassembled before any such mechanical treatment.
- *Pyro-metallurgy* requires high temperature processes to recover materials, and *Hydrometallurgy* involves bringing the material into solution followed by chemical treatment.

Li Batteries recycling processes which are used for recovery of the raw materials from batteries by the recycler and remanufacturer organization are shown in the **Table 2.1: Li Batteries Recycling Processes** [13] and notes taken from the "Recycling of Tracked Li-ion EV Batteries Report" which was study was conducted by the JRC.

Organization	Location	Process	Materials Recovered
Accurec	Germany	Pyrometallurgical and hydrometallurgical	Lithium Chloride, Cobalt, Copper, Aluminium, Steel & Plastics
AEA Technology UK	Scotland	Hydrometallurgical	Lithium hydroxide, Cobalt oxide, Aluminium, Steel, Copper, Electrolyte
Batrec	Switzerland	Unknown	Chrome-nickel, steel, cobalt oxide, manganese oxide

Euro Dieuze Industrie	France	Pyrometallurgical	Cobalt compounds and Copper
Recupyl	France, Singapore	Hydrometallurgical	Lithium carbonate, Cobalt, steel, copper, bimetallic alloys

Table 2.1: Li Batteries Recycling Processes Source: (Ekermo, 2009)

Both above processes are critical, for the recovery of raw materials from the Li Battery Cells for the third solution as shown in the Fig1 for the manufacturing of the Battery Cells for according to the latest design and software requirement based on the EV car models and specification required by the OEM.

2.2 Li Batteries Dis-Assay Cost Drivers

The Li Batteries pack is most valuable component of the EVs. Because the required raw material residual value is up to 75% of the used Li battery, which is still significantly much higher after the capacity dropped to just 85% and can be reuse which is the reason that makes a reasonable demand to reuse them, 2nd time in EVs to make it more profitable option for the re-manufacturers. As shown below in the **Fig 2.2: End-of-Life EVs Dismantling Procedure**, which provide various options to recycle, reuse and recovery of different parts and components of the Vehicles.

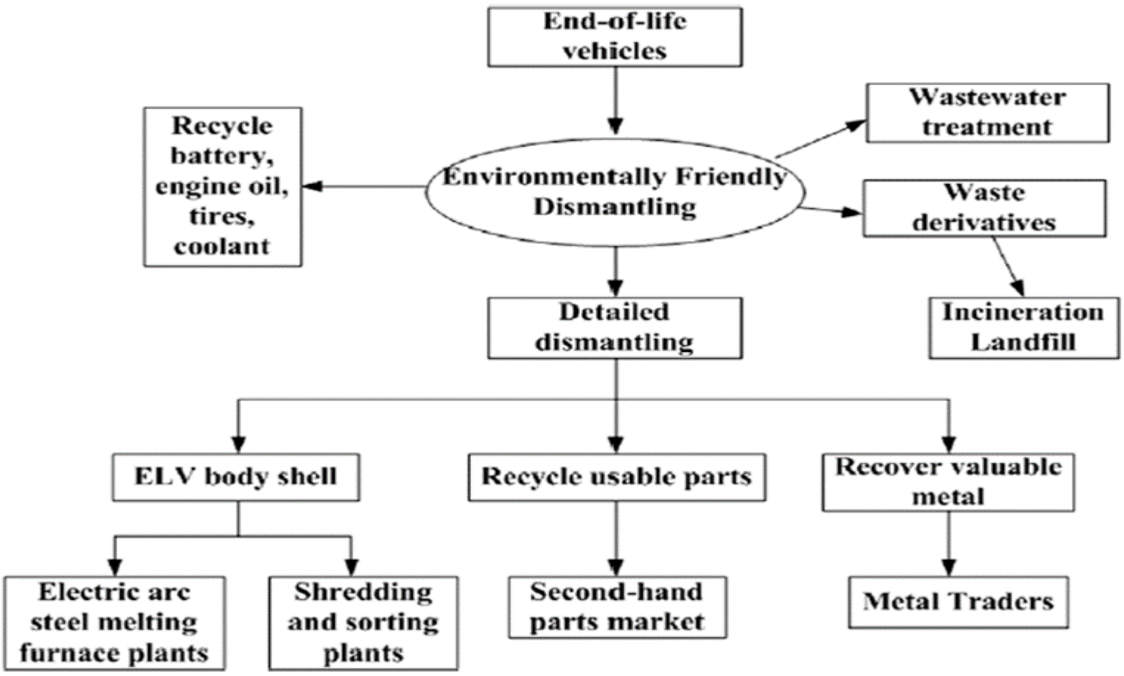

Fig 2.2: End-of-Life EVs Dismantling Procedure Source: (Kuan-Chung Chen, 2009)

Following **three re-manufacturing solutions are recommended** from the End-of-Life EVs which mainly depends on the age and condition of the Cars;

1. EVs Li Batteries get reused in the EVs for the 0-10 years car models.
2. EVs Li Batteries get recycled in the Power Girds for 10-15 years old EVs
3. Li battery cells get used for the recovery of the Raw Material to produce Li Batteries

Especially when the Li B cell and Li B packs are fitted in the housing covers power cut issue and together with the cooling management system and temporary sensors and battery management system are a key component in the remanufacturing process of the Li batteries. EVs after sales support, Li B reusability and ever-increasing number of car models which require a Li B remanufacturing solution. Durability and reliability of single Li cell in the battery pack vary, which affects the performance and capacity of the complete Li battery pack. Changeable cells or modules in a remanufacturing design can help to improve the lifetime and reduce the charging range loss over time.

Considerable improvements and design changes are already implemented and seen in the Li battery cells and packs design has changed during the last three years. And going forward up to the module base battery management range can be updated, as required and its possible to stop one cell out of the one battery pack if it started to fail, so that a cell failure is not going to affect the battery pack performance, such Firmware can be done to the field units by the re-manufacturer to make design improvements, while working with the OEM of the battery manufacturer's design engineering teams.

The potential **reselling price of 180 €/kWh** [9] of the Reman battery is assumed based on the stationary energy storage platforms. This price also marks the upper limit for the re-manufacturing cost drivers of the Li Batteries for the Remanufacturers.

Therefore, for an economic success of Li Batteries Remanufacturing requires a setup of an automatic disassembly line to make profitable, as shown in **Table 2.2: Reman Li Batteries Automatic Disassembly Cost Drivers.**

Category	Unit	Quantity
Invest for Automation	€	6 million
Residual value at End-of-Life of Li Batteries	€	3 million
Economic Life	Years	30
Interest Rate	%	3
Variable Costs	€ / Piece	96
Fixed Costs	€ / Piece	150.000
Sales Volume (* *based on Renault ZOE data*)	Pieces	30.000
Costs	**€ / kWh**	**19.44**

Table 2.2: Li Batteries Disassembly Cost Drivers Source: (A. Kampker et al., 2016)

2.2.1 Li Batteries Risk and Safety Factors

High investment cost combined with low numbers of end-of-life field return Li Batteries cause long amortization period. High voltage explosion risks and electrolyte fumes are few hazards in the disassembling of the Li battery packs plus, the complexity of the task and ever-changing design versions of the Li Battery cells, packs and electronics modules demand highly flexible technology approach to this whole process to get the high-quality control of the Remanufactured Li Batteries for an automotive sector.

Panasonic is one of the leading Lithium-ion battery manufacturers in the world, which meet requirements of the future Li Batteries, which emphasizes high energy density, safety and long life. Company focus on safety through using technologies such as, “Panasonic Solid Solution” (PSS) and “Heat Resistance Layer” (HRL) in Li Batteries.

2.2.2 Li Batteries UN Numbers

Each battery model, part number is identified with a UN number which classified them as a **“***Dangerous Good for Transport***”.**

- UN 3480: Lithium -ion Batteries including Lithium polymer batteries.
- UN 3481: Lithium-ion Batteries contained in equipment or packed with equipment.
- UN 3171: *Battery powered equipment and Vehicle*

According to the Batteries Directive, the term industrial batteries is used to classify Li Battery for the EVs and energy storage markets.

2.3 Advanced Li Batteries Manufacturing

A battery manufacturing production plant is completely changed for the Lithium-ion Battery manufacturing. The key processes which requires for the Lithium-ion electrode production are much closer to high precision ink printing on ultra-thin substrate, requires high precision automated mechanical handling of fragile electrodes, mm thickness paper sheets, as shown in the **Fig 2.3: Li Batteries Manufacturing Process**.

The assembly of high-density electrode coils is realized by a high precision robotics and CNC Prologic machines, which is installed in automatic assembly lines. Human intervention is not required and would not be even possible due to the nature of the nanocomponents. For reliability and quality control, such sensitive processes are performed in dry or white Cleanrooms, which are very similar to the semiconductor industry to produce the ICs or TFT LCD Displays.

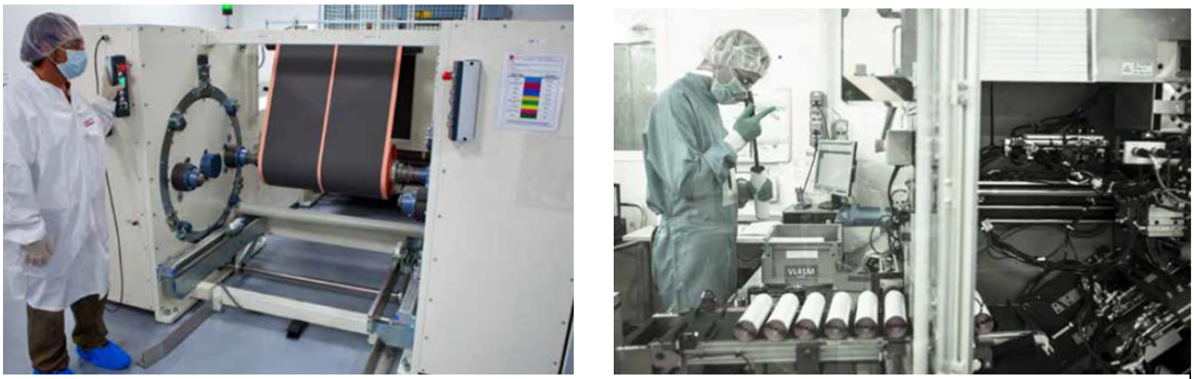

Fig 2.3: Li Batteries Manufacturing Process **Source: (RECHARGE Report, 2018)**

Following model can be used to show different production process capacity and labour allocation required, as shown below in the **Fig 2.3 A: Remanufacturing Processes Capacity** for reuse, recycling and remanufacturing for second life. Although there might be a problem with long lead times, when deciding on external factors to implement in the manufacturing processes, it may be positive that several of these factors can be regarded as fixed over long periods of time when designing processes.

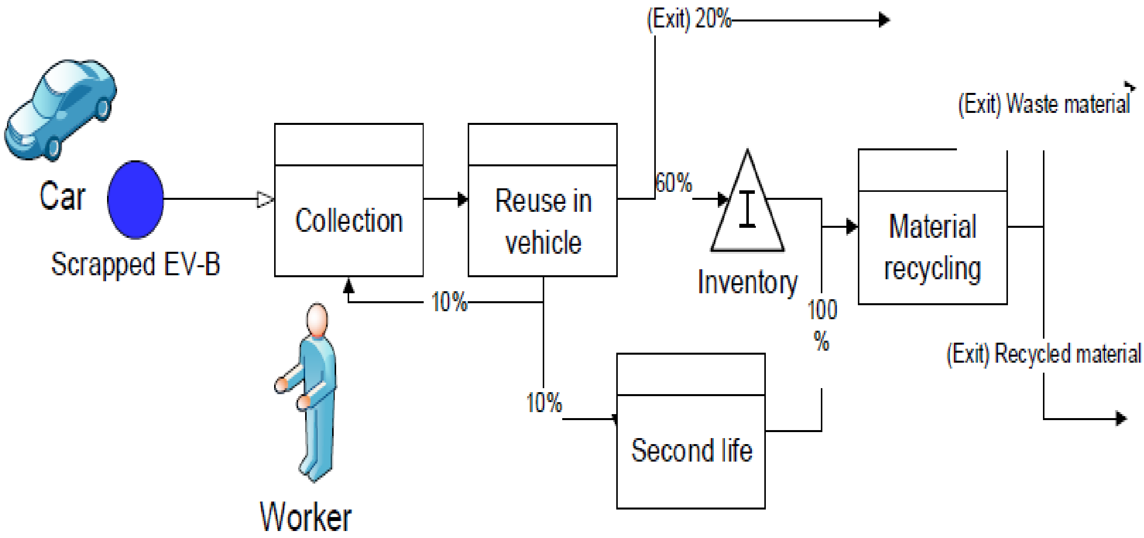

Fig 2.3A: Remanufacturing Processes Capacity **Source: (Batteries, 2019)**

Staff needs to fully train to Cleanroom handling conditions to achieve reliability and quality Li Batteries production for the satellite applications and other advance battery unit which required for the very long shelf-life up to 20 years. Which is the core reason Li battery life cycle being 15 years in the EVs.

Power of the Li Batteries depends on the solutions with many different electro chemistries such as; NMC, NCA and SLFP. They can discharge in less than 10 minutes and can provide power for the Fighter Aircraft F-35, for example, at - 40 degree centigrade, when most Wet Acid Based Batteries would be frozen. At the same time, these batteries are fully functional at extremely high temperature conditions like in e-Formula One Cars.

2.3.1 End-of-Life Vehicles Directive 2000/53/EC (ELV)

Batteries in vehicles covered by the ELV Directive which fall within the scope of the Batteries Directive, there are specific provisions in the ELV Directive that apply to batteries used in the EVs.

There is a distinction between the **Recycling Efficiency (RE)** targets of the Batteries Directive (a RE target based on the recycling process) and the ELV Directive targets (reuse, recycling based on total average vehicle weight). The batteries in the ELV account for 100% in weight into the calibration of the reuse and recycling (target of 85%), and reuse and recovery (target is 95%).

3.0 Market Analysis of Li Batteries

Rechargeable Li Batteries are designed to last for a long time, with the 10K- 15K recharging life cycles, so that they can be used for 15 years, but at the end, even a rechargeable Li Battery gets degraded over time and heat can effect and reduce the life cycle of the Li Battery and ultimately all Li Batteries will cease to work.

Which dependents on the chemistry of the cells, the size of the battery pack, configuration of heat flow and purpose cycle of charging and discharging of the Li Batteries. Rapid growth in the Li batteries application is seen in many applications which will change over the next 10 years, due to Li Battery Cell material characteristic differences and the end-of-life cycles volumes is going to be very different as compared to what has been placed on the market.

Li Batteries that reaches end-of-lives does not mean, that they will all automatically become available for Remanufacturing by the Independent Remanufacturers or OEM manufacturers. As shown in the **Fig 3: EV Batteries EOL Recycling.** About 50 per cent of the EOL Li batteries find their way to reuse or re-manufacturing around the world. The reasons for this are many; batteries are stored or lost by the end users or reverse logistic is not possible or get reused in other applications like Power Banks.

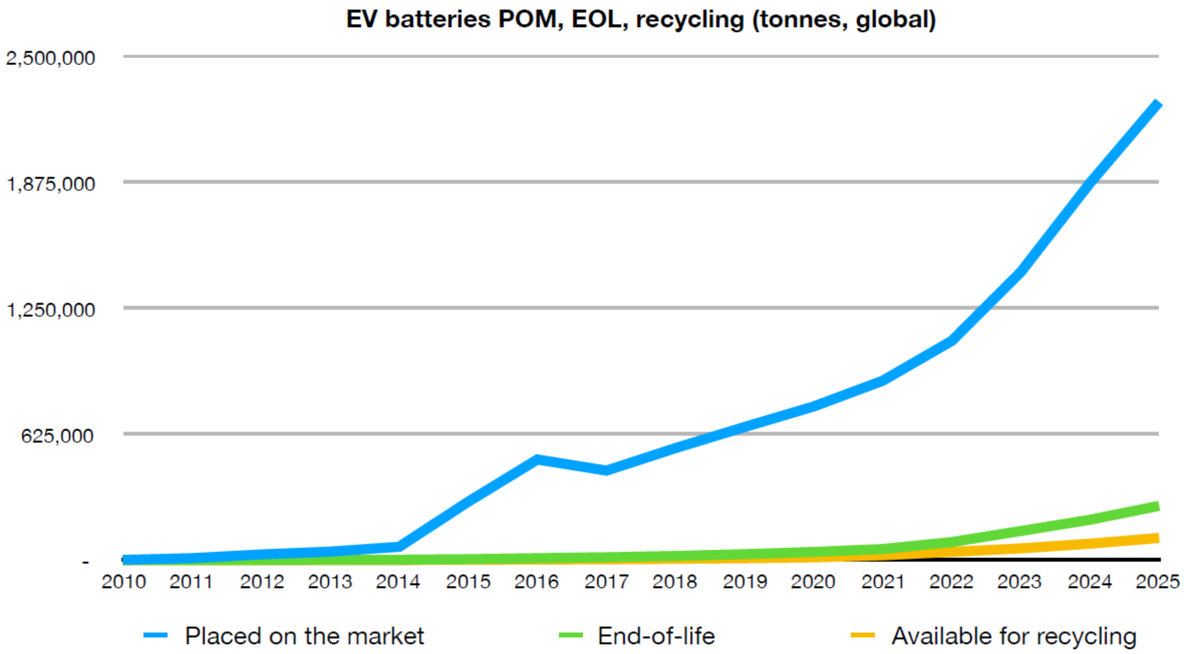

Fig 3: EV Batteries EOL Recycling **Source: (Hans Eric Melin, 2018)**

Lithium-ion batteries in EVs are expected to last much longer than those which used in the busses or trucks; because public transport batteries need to get changed and discharged daily due to the usage of 24 -7 hours, which requires charging done much more regularly. In EVs the Li Batteries are expected to get maximum life time out of batteries as compared to the bus usage in which Li Batteries reaches EOL (End of Life) much faster and generate high volumes of the rejects, which is equivalent to half of what will come out from electric cars in 2025.

EV batteries which get reused in the EVs or start a second life in different application at the end-of-life depends on the values of the Li batteries and the condition of the battery cells, this diversion at the end-of-life to reuse is causing a delay for the number of batteries which are available for recycling, which is the reason it will also take a long time for materials to recycle, it will have a larger impact on the raw material market.

It's quite clear that large amounts of Li Batteries reach battery collectors, electronic waste banks, e-waste processors and remanufacturing companies that will access for the remanufacturing for reuse in the Electric Vehicles. For EV batteries reuse for the 2nd life cycle, for different application depend on if the battery is no longer can be used in the EVs only then other applications will be considers, such as power back or energy storage systems.

3.1 Review of Li Battery Cell Global Manufacturers

China, Japan and Korea together hold 88% of total global Li Battery cell production and manufacturing capacity for all end-users and Asian countries are also home to the majority share of the raw materials which requires to produce the Li Batteries.

The global dominance of Asian Li B cell manufacturers is also reflected in the trade of Li B materials and cells [10], as shown in the **Fig 3.1: Flow of Li B Cells MFG Trading Trends**, which shows the positive trade balance of Asian producers and the negative trade balance to other world regions in 2014 for the Li Battery cell for all applications.

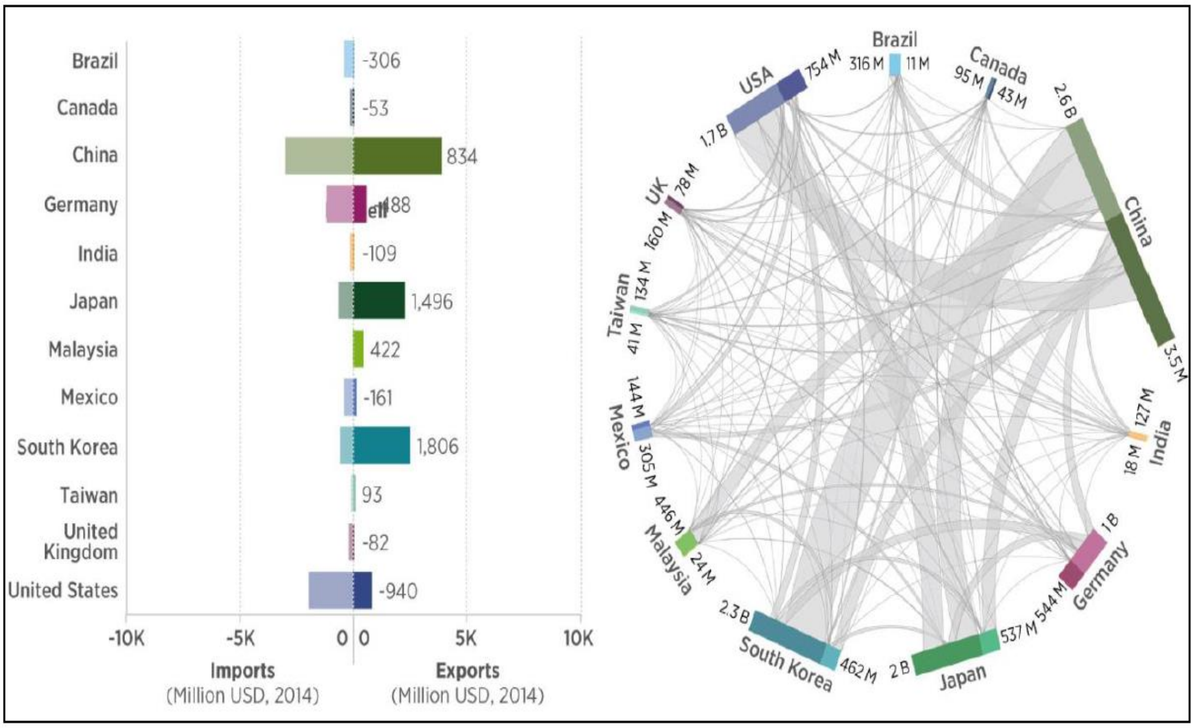

Fig 3.1: Flow of Li B Cells MFG 2014 Trading Trends Source: (Clean Energy Analysis, 2015)

3.2 Li Batteries European Manufacturers

Building up and strengthening European activities in Li batteries raw material supply chain may pay-off future dependences on imported Li batteries component and materials such as Cobalt (Co), Li and high purity Ni which are critically required for the manufacturing of the Li Cells. An EU activity so far includes;

- EU is developing a domestic supply chain of Li (Sweden, Finland, Portugal, Czech Republic, and Serbia), Co (Finland) and Graphite (Sweden) this approach established a Li Battery Mega factory in Scandinavia. [11].
- Substitution of the Cobalt, with other materials for the cathodes and production of the higher-grade Ni for the Li Cells to reduce 20% cost of the production unit.
- Increasing the volumes of the Li Batteries sites that can recycle, reused, repaired and remanufactured.

Simply having a European Li Cells raw material supply chain will not be able to meet the demand for all European Produced EVs. Therefore, security in the supply chain for raw materials is a basic requirement for the production and setting up of the Li batteries and Cells manufacturing factories in the EU. Locating Li batteries and Cell production in Europe avoids the CO2 emissions linked to the transportation to the EU of cell manufactured in Asia, with an added benefit for the Supply Chain Management in terms of reduction in Lead Time and create employment in Europe.

EVs have a record number of sales during 2017-18, over 1 million electric cars were sold in 2017 of which more than half of global sales was made in China, so far only a handful of countries have significant market share of the EVs market. As shown below in **Fig 3.2: EVs market share 2017,** Norway remains the world's most advanced market for EVs sales with over 39% of all new cars were EVs in 2017.

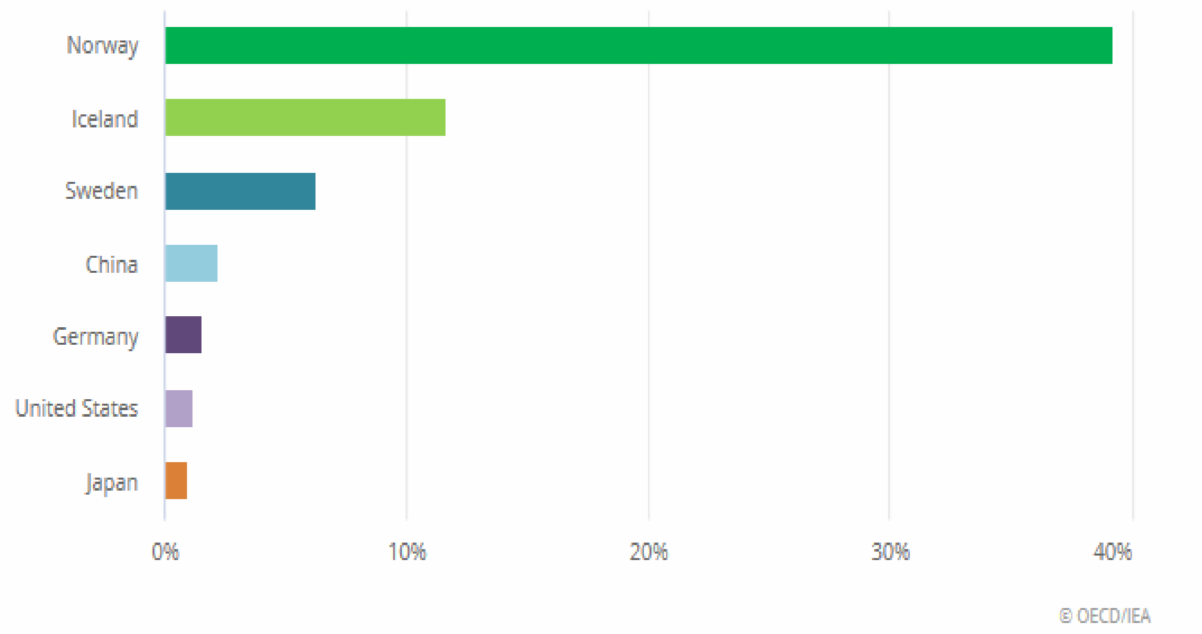

Fig 3.2: EVs Market Share 2017 **Source: (https://www.iea.org/gevo2018/, 2018)**

Most people charge their EV either at home or work, a private EV battery chargers are expected to outnumber electric cars by 10% in 2030. Considering that into account relatively few opportunities for the European householders to install chargers at home.

Therefore, as more people without access to a parking space purchase electric car, which bring a new business opportunity for the Independent Remanufacturers (BORG) in Europe to provide an EVs charging parks, public cars parking areas and install chargers at workplaces. The shift to EVs will increase demand for some raw materials such as particularly cobalt and Lithium for the Li Batteries. Ongoing developments in battery cell chemistry, aim to reduce their cobalt content in Li Batteries.

3.3 Li Batteries OEM Producers Second Life Initiatives

Portable Li Batteries have been in use for a long time without much public knowledge, batteries for EVs has become the key application segment of the Li battery market, which can be used at the EOL in other applications as, shown in the **Table 3.3: EV Batteries EOL Remanufacturing** done by the following car manufacturers.

Car Manufacturer	**Li Batteries – Second Life Initiatives**
General Motor	Remanufacturing
Nissan	Remanufacturing, C&I energy storage, EV Charging
Tesla	Remanufacturing
Volvo Cars	Residential energy storage

Table 3.3: EV Batteries EOL Remanufacturing

In **China** new regulations **call** for Li battery and EV companies to arrange for **both** recycling and assessments for second life requirements. Within that framework an agreement has been signed by the largest telecom infrastructure company and several batteries and auto-motive manufactures are using retired end-of-life Li Batteries to replace Lead-Acid batteries in the backup systems of base stations. Number of Li batteries used in the second life application are still very small.

Not all of EVs and Li batteries makers have embraced the idea of a second life cycle of the EV Batteries, which is understandable keeping their business interest in mind and a usual argument is that the Li B will last for more than 10 years and at which point, where the Li battery will not be competitive compared to newer, more efficient Li battery design that would be available in the market.

An entire new business is created around the second life cycle of the Li batteries in Europe and Asia. Due to the high demand of the Li batteries for use in vehicles, buses and other power source applications as required in today usages.

Therefore, a second life cycle of Li batteries is predicted to be key source income for the IR in automotive industries for secondary applications, such as energy storage and stationary battery application in EV cars. As shown below in the **Fig 3.3: EV Battery Second Life Capacity Trends.**

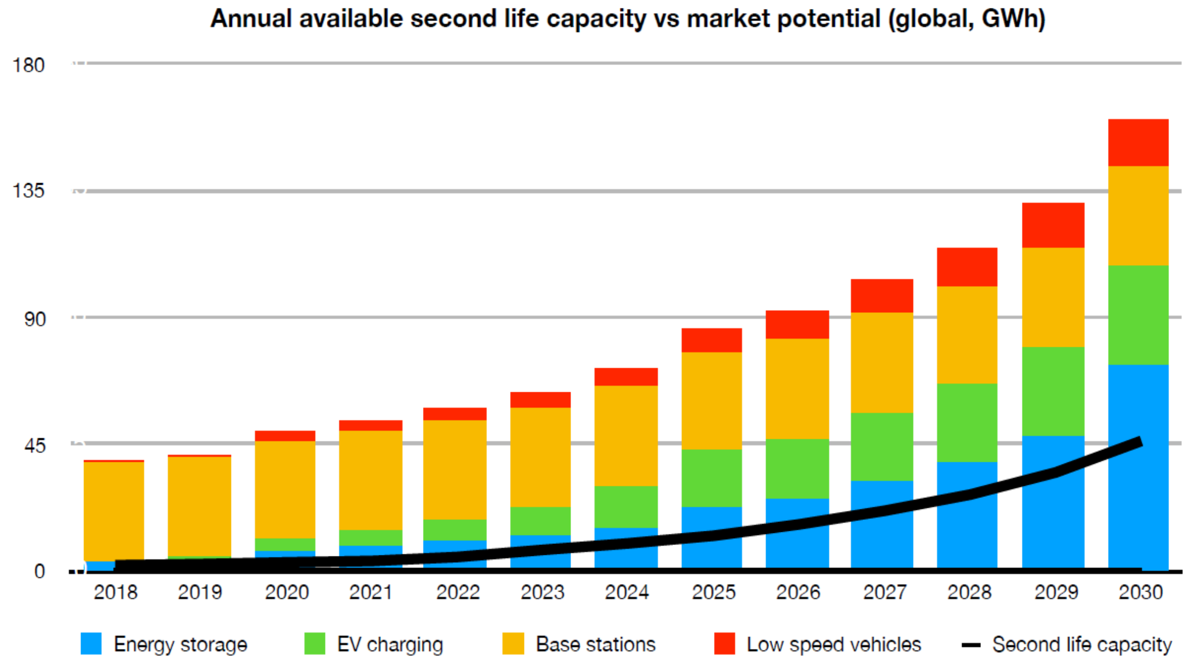

Fig 3.3: EV Batteries second Life Capacity Trends Source: (Circular Energy Storage, 2018)

With the strong growth of the Li batteries market, it is predicted that the volume of the second life cycle of the Li batteries will be defined by the supply of the used batteries return to the remanufacturers rather than just its market demand. The demand, together with the supply and cost efficiency of new Li battery is going to define the value of the product in the market. The value of remanufactured Li Battery is close to what materials are used in the Li batteries are worth today. If the cost reduction is enabled by material substitutions, primarily a change of material from cobalt might pay the same or higher prices for the remanufactured Li Batteries.

3.4 EV Batteries Price Vs Expected Reman Price

Following formula used to calculate the brand-new OEM batteries Price Vs Reman Li Battery valuation price. Maximum salvage value of the used Li battery will always be less than a new battery with the same capability. In-order to calculate the maximum value of the used Li battery, it depends on the state of health of the Li B. New Battery and Remanufactured Li B cost drivers, as shown in **Fig 3.4: EV Batteries Life Cycle Years.**

Assumptions

- Profitable 2nd life cycle is available for the EV Li batteries.
- EV batteries production cost to 400 k/year by 2025 and stabilize, failing in cost to $560/ kWh.

Equations

- **V salvage = (1 - Kr - Ku) * (Kh * Cnew)**
- **Net Present Value (NPV) salvage = Vsalvage * (1-r)n**

Whereas Variables are; C*new* = ***Cost*** *of* ***new Li B, r****= discount rate* ***2.5****%,* ***Kh****=* ***health*** *factor* ***3%/year****,* ***Kr****= Remanufacturing Cost* ***15%/year****,* ***Ku****= Used discount 15%/year.*

V salvage= Li battery salvage value at EOL & **NPV salvage**= Net Present Value with discount rate r over number (n) of years in service.

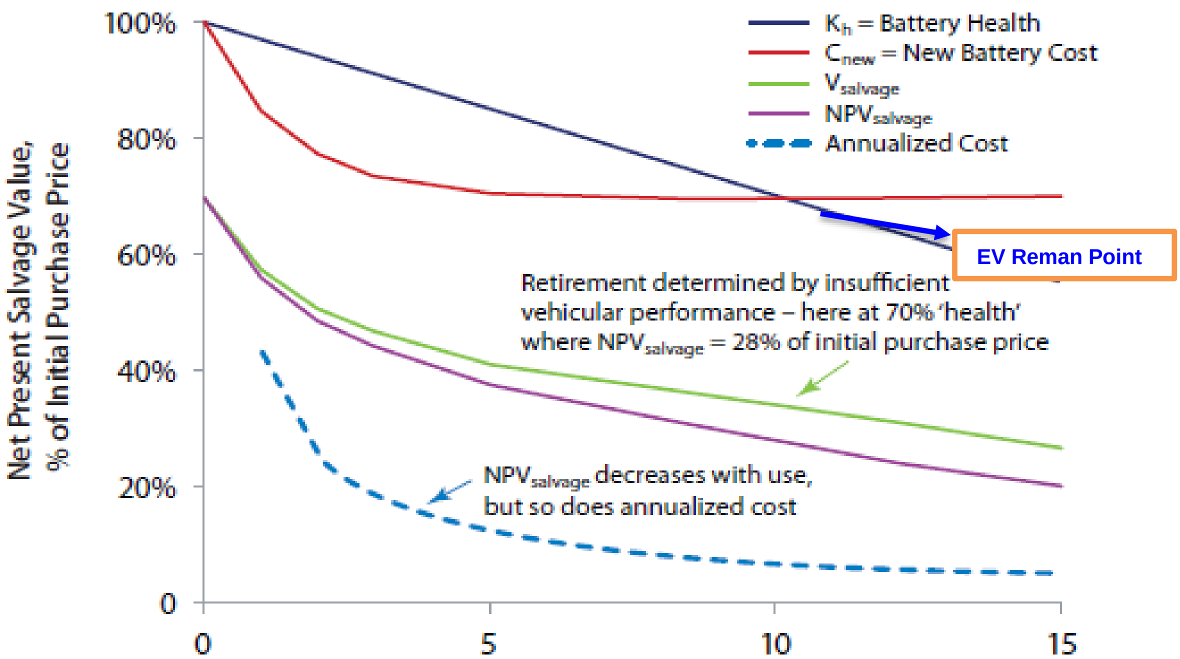

Fig 3.4: EV Batteries Life Cycle Years Source: (NREL Li Battery Second Use, 2010)

Above graph and formula is going to allow Remanufacturers to calculate the actual value of the Li Batteries values any given time up to 10 years, which can be reused in the EV / Buses at the EOL, simply by applying these NPV salvage values based on a condition of the battery, in the Remanufacturing return centres during goods inwards inspection decided before starting the remanufacturing process. Key factors are;

- The maximum salvage value of a used Li Battery will always be less than a new battery of the same capability.
- Forecast future EV / PHEV battery cost.
- Calculate Max Salvage Value of used battery based on state of health, new battery Cost and Refurbished Cost.
- Calculate the maximum initial purchase discount from the net present value of the battery's max salvage value.

As shown in above Li batteries life cycle valuation trends. The solution is a re-use of the Li Batteries in the EVs for 0-10 years cars and after that recycle them for the Power Bank from the age of 10-15 years for factories, which makes a valuable business case based on the demand for the applications, as required by the customers.

4.0 Environmental Impact of Remanufacturing Li Batteries

There are several environmental considerations in relation to electric cars. Overall the greenhouse gas emissions of electric vehicles, with the current EU energy mix and over the entire vehicle life cycle, are about 17-30 % lower than the emissions of petrol and diesel cars. Therefore, important to be aware of where the environmental impacts occur in the life cycle of an electric vehicle. (EEA Report)

From local air pollution point of view electric cars can help to make towns and cities cleaner, quieter and more pleasant. This is due to the reduced exhaust emissions.

Production of electric cars uses more energy than conventional cars, this is largely due to the energy used in the production of the Li batteries which is energy intensive as well as the energy required to extract the necessary raw materials – a lithium ion battery requires lithium and cobalt – rare earth metals that need to be extracted from different parts of the world e.g. Australia, China and South America.

Energy is also needed to charge the EV batteries and depending on where the vehicle is charged, then this can come from renewable or non-renewable sources or a combination of both. EV and battery production may be energy intensive at the start of life, but once the vehicle is in operation then the carbon footprint will reduce and catch up with petrol- or diesel-powered cars. This benefit generated depends on the total car mileage over its life. Where the energy mix is approximately 40% coal and 30% renewable then a mid-sized electric car must be driven for 125,000 km, on average, to break even with a diesel car, and 60,000 km compared to the petrol car. (World Economic Forum)

EVs can help to avoid substantial CO2 emissions, even without grid de-carbonisation. But the decarbonisation of the power grid could happen, more than double the well-to-wheel CO2 emissions reductions from the electrification of transport, as shown below in the **Fig 2: GHG emissions in 2030.**

Fig 1.1: GHG emissions in 2030 **Source: (https://www.iea.org/gevo2018/, 2018)**

Battery production is energy intensive and has wider environmental considerations, e.g. wastewater, air pollution and wider mining impacts on ecosystems and communities from cobalt and lithium extraction. The negative environmental effects of batteries are reduced as the battery lifetime extends. Where electric batteries from vehicles can be remanufactured or re-used in a different industry, this could double the battery life cycle of approximately 20 years. When the capacity of electric car batteries drops below 70-80% after about 10 years of use, they are no longer strong enough to power the car. Instead the batteries retain enough capacity for stationary storage in various contexts: e.g. to store solar power for household and commercial premises, as electric bike batteries or to electrify off-grid communities in rural areas.

The current cost of recycling or remanufacture of Li batteries is high compared to the raw material prices to manufacture new ones. As the demand for EV batteries increases and so the raw material prices increase then this cost dynamic will change. So as demand for recycling and remanufacture increase then so will be environmental benefits.

Recycling or remanufacture of batteries has a positive environmental benefit from a natural resources point of view. For example, lithium is a valuable raw material. To reclaim one tonne, 28 tonnes of batteries have to be recycled. But to extract one tonne of virgin lithium from the Chile is 1,250 tons of earth must be dug up. (World Economic Forum)

The infrastructure required to recycle or remanufacture Li ion batteries does not currently exist to be able to meet the predicted future demand for electric vehicle batteries. Car companies (e.g. Nissan, Toyota, Fiat, Chevrolet) and other commercial organisations (Acceleron, LiCycle, Powervault, Box of Energy) are already beginning to develop business models and solutions that can recycle or reuse/remanufacture EV car batteries and as the number of batteries that require EOL management increases then so will the infrastructure and opportunities for business investment.

From an environmental life cycle perspective reuse or remanufacturing options are more favourable than recycling (and disposal) primarily because they are less energy intensive, use less raw materials, generate less waste and keep the existing battery in life for longer. Once reuse options have been exhausted and the battery life is spent then recycling to extract valuable materials is the next best solution. This approach follows the principles of the waste hierarchy and is supported by the Life Cycle Assessment (LCA) studies.

4.1 Recycling of Li Batteries

Today there are few Li Battery recyclers in several European countries, in the USA, Canada, South Korea, Japan, China and few other countries around the world. The processes which are used, and their efficiencies vary to each regional requirement's and methodologies and from processes where the most important yield is copper and aluminium while the rest of material goes to waste, to highly efficient EU processes that can recover close to everything from the Li batteries and refine it into the end products such as Lithium carbonate, cobalt sulphate and nickel sulphate.

Almost all processes today are Hydrometallurgical where the different elements are separated using different types of liquids which react with the different elements in the Li batteries.

In 2018 the amount of batteries that will reach recyclers is estimated to 97,000 tonnes, of which 67,000 tonnes will be processed in China and 18,000 tonnes in South Korea.

Both countries host a significant market share of the manufacturing of the EV batteries raw materials as well as the production of Battery Cells. Which is the reason, such manufacturing factories create a demand for raw material, which is fundamentally required for an important market for the recyclers and provide opportunities for the automotive Reman companies needs to work collectively with OEM, sub suppliers to become remanufacturer or recycler themselves, by setting up the Remanufacturers Global Network. As shown in **the Fig 4.1: Recycling of Li Batteries.**

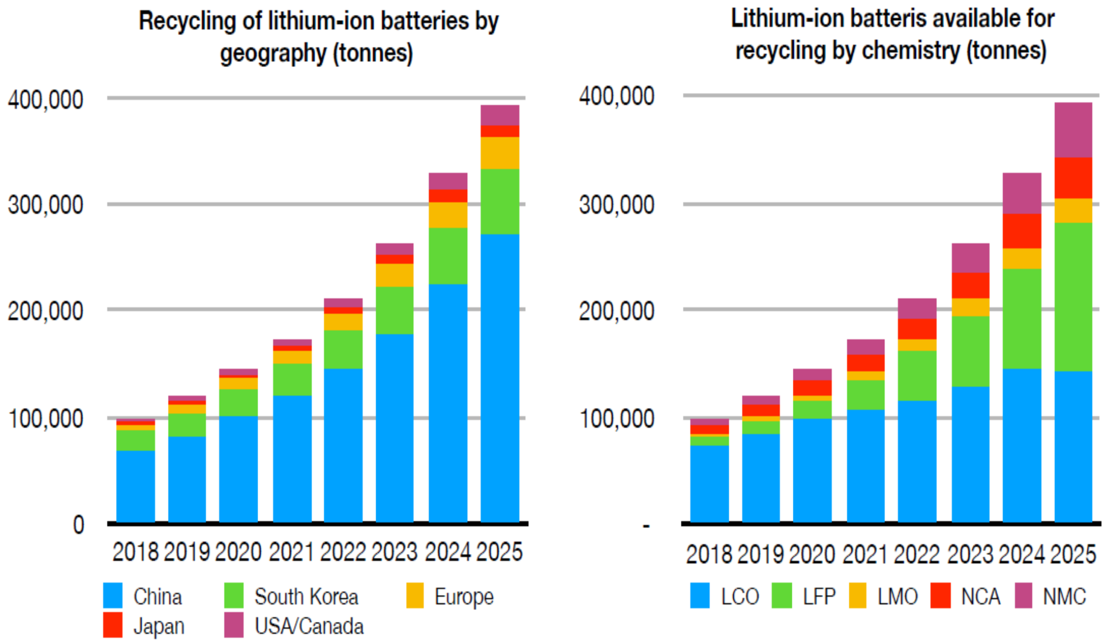

Fig 4.1: Recycling of Li Batteries **Source: (Circular Energy Storage, 2018)**

Over 20 companies are involved in recycling of waste battery management in China and at least six such companies are in South Korea. The feedstock originates both from the domestic collection and batteries from overseas, during this process several companies get benefit from the access to batteries recycle loop from refurbishment process which bring the volume of the raw materials from dismantled battery cells. Many of these companies are imported directly from collectors in other Asia, USA and Europe (Business Opportunity for the IR).

In Europe and USA, the returns process of the volumes of Li Battery is still in low scale, which has got the room for local automotive remanufacturer to get the market share. The main reason for this that Li batteries are not primarily collected through ordinary local collection schemes, but are exported, contained in equipment or sold for reuse to Asian processors / manufacturers.

5.0 Innovative E-Mobility Infrastructure in Europe

The development of E-charging platforms and supporting infrastructure is useful tool for the cities to increase the number of the Electric Vehicles driven by the consumers and commercial fleets. It’s a critical decision for the top European cities by local Gov’s to support a shift towards EVs which requires a carefully considered plan and policy to ensure that all aspects of an implementation are integrated and sustainable. As shown below in the **Fig 5: TFL London EV Charging Points.**

Fig 5: TFL London EV Charging Points **Photo: Transport for London (TFL, 2019)**

5.1 Types of Charging Points

All EVCP designs and installations should be approved by qualified electrical engineers and meet the necessary required standards. Poor design or installation can be dangerous. The basic requirements for a charging point are quite simple; electricity feed with appropriate socket. It is possible to plug an EV charging cable into a standard, domestic home socket, but this is not encouraged.

The high energy demand and time required is generally unsuitable for standard home wiring connections, which could increase the risk of fire. The key aspect to consider is that what charging speed is desired and the speed of battery recharge is constrained by the electrical input and battery capacity. There are four types of connector (Plugs) used for EV. As shown in the **Table 5.1: EVs Charging Connector Types.**

Connector Type	**Phase / Current / Voltage**
Type 1 is 5 Pins	Single Phase, Max Current 32A & Voltage 250V Auto plug J1772/2009
Type 2 is 7 Pins	Single phase at 70A / Three phase at 63A & Voltage 500V
Type 3 is 4 Pins	Single / Three Phase, 32A current used in 12 European countries.
Type 4 is Fast	Fast charger coupler system, up to 500V at 125 A, Special Connector

Table 5.1: EVs Charging Connector Types **Source: (BEAMA, 2017)**

5.2 EV Charging Timeline

Currently there is no standardised requirement in Europe for the EV charging equipment's, it's up to cities to decide which technology to install and use based on most cost-effective and long-term investment in the infrastructures.

Until such time as a European standardized unit is agreed, care should be taken when selecting a type of connectors are used to ensure local objectives based on speed, cost and access points. As shown below in the **Table 5.2: EV Charging Timeline.**

Charging time for a typical 24kWh battery	Power Supplied	Voltage	Maximum current	Mode	Speed
10.4 hours	2.3kW	230	10A	2, 3	SLOW
8.3 hours	3kW	230	13A	2, 3	SLOW
6.5 hours	3.7kW	230	16A	2, 3	SLOW
3.2 hours	7.4kW	230	32A	3	FAST
1.6 hours	14.5kW	230	63A	3	FAST
1.04 hours	23kW	230	100A	3	FAST
29 minutes	50kW	400-500VDC	100 – 400A	4	RAPID
15 minutes	100kW	400-500VDC	100 – 400A	4	RAPID

Table 5.2: EV Charging Timeline **Source: (BEAMA, 2017)**

5.3 Reman Li Batteries Challenges

Due to the rapid rise of the EVs in recent years and even faster growth is expected during next ten years, the second life-battery supply requirement for the EV batteries for the service and repair usage by the end EV customers and 2nd application for the stationary application which is expected to exceed 200 gigawatt- hours per year by 2030. This volume will exceed the demand for Lithium-ion batteries for the lowest cost and high cycle applications which constitute a market with global value of $30 billion.

However, to unlock this new pool of battery supply, several challenges are expected of the EV batteries which must be overcome. The first issue is that the large number of battery pack designs on the EVs vary in size and electrode chemistry is different. Batteries are designed by the battery manufacturers and automotive OEM according to the EV model requirements, which increases remanufacturing complexity due to the lack of standardization and fragmentation of volume. Up to 250 new EV models will exist by 2025, featuring batteries from more than 15 manufacturers. The second big challenge involves failing cost of the new batteries. As new batteries become cheaper, the cost differential between old used battery and new diminishes, given that the rate of decline in remanufacturing cost is expected to lag the rate of decline in new manufacturing cost. We estimate that, at current learning rates, the 30 to 70 percent cost advantage that second-life batteries are likely to demonstrate in 2025, which could drop to around 25 percent by 2040. This cost gap needs to remain sufficiently large warranty cost due to the performance limitations of the second life remanufactured Li Batteries compared to new alternatives' models, requires additional or different fixing and installation modification kits for the end users or customers.

6.0 Conclusions and Recommendations

From EVs life-cycle perspective, an automotive sector is in line with the climate and sustainability goals of society. At the end-of-life of EVs its critical recovery to all raw materials and recycle Li Batteries is according to local environmental requirements. The key concern is that; by the time second application of the used vehicle batteries comes to reuse it in the EV, there is a risk that the remanufactured batteries might end up becoming an obsolete, by the time required volumes are available for use in EVs batteries in large numbers.

Therefore, needs to build up the flexibility and reconfigurability of the remanufacturing process for the batteries and able to make required design changes as required for the effect recycling. It's estimated that the Li battery life cycle is 20 years between product design and material recycling, an open loop approach for recycling might be more valid for the EVs Batteries Remanufacturing.

Final recommendation for the Li Batteries Remanufacturing is that**; First solution is re-use of Li Batteries in the EVs** during the initial 10 years of the battery life, **and second solution is that recycle EVs batteries in the Power Bank** for the industrial and home applications of the batteries which are 10-15 years old in the field and **third application the recovery from the Li Battery Cells** for Raw Material to get high value material out off, for the re-manufacturing of the Li Battery Cells.

With the increase demand of EVs and the slow fade out of combustion engines. There is an ever-increasing demand for energy storage devices for the automotive industry. To answer this critical need and create value supply chain for the Europe and UK, requires developing the supply chain for materials to cell, to module and to packs. Ensuring the supply of good quality anode and cathode materials for cell production and manufacturing of the Li Batteries Packs in Europe to support the future of EVs in this sector. Project aim was highlighting the EV issues and new business opportunity for the Li batteries for the EV and other applications and commercialise new battery remanufacturing technologies for the raw materials. Ensuring a good quality material recovery from the end-of-life Li Batteries from the remanufacture, reuse, and recycle processes to get European transition to a low-carbon economics. BSI needs to create EV batteries manufacturing standards for which use European and UKs strengths of high performance, quality and customisation future EV batteries for the sector.

6.1 Acknowledgments

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