REFURBISHING ELECTRIC VEHICLE BATTERIES
About:
SOLUTIONSplus Toolkit
Catalogue of E-mobility Solutions

Title:
Refurbishing electric vehicle batteries

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1. Project Information

Integrating Urban Electric Mobility Solutions in the Context of the Paris Agreement, the Sustainable Development Goals and the New Urban Agenda

The SOLUTIONSplus project enables transformational change towards sustainable urban mobility through innovative and integrated electric mobility solutions. The project boosts the availability of electric vehicles, foster the efficiency of operations and support the integration of different types of e-mobility in large urban areas and addressing user needs and local conditions in Europe, Asia, Africa and Latin America.

The project SOLUTIONSplus has set up a global platform for shared, public and commercial e-mobility solutions, and to kick start the transition towards low carbon urban mobility. The project has encompassed city level demonstrations to test different types of innovative and integrated e-mobility solutions, complemented by a comprehensive toolbox, capacity development and replication activities.

SOLUTIONSplus brings together highly committed cities, industry, research, implementing organisations and finance partners. Through numerous synergistic projects, networks and a strong technical experience, the project will be able to deliver its highly ambitious goals. Direct co-funding contributions will be provided by partner cities and SOLUTIONSplus works closely with UN Environment and the International Energy Agency (IEA) on a joint global urban e-mobility programme that will significantly boost replication and impact of this Innovation Action. Through the regional platforms, a global programme and local teams, the project aims to develop highly effective and innovative approaches to urban e-mobility ensuring that mobility systems and interventions from this project deliver on the Paris Agreement, meet the Sustainable Development Goals and address the New Urban Agenda.

Boost capabilities of local and national authorities, public transport operators and entrepreneurs about innovative urban e-mobility solutions across various transport modes by informing them about tools to plan, assess, implement and operate e-mobility solutions.

Foster the take-up of e-mobility innovations by businesses, start-ups, local and national governments and transport operators by inspiring officials, operators, industry and businesses through peer-to-peer exchange on innovative e-mobility products and services.

Strengthen policy and business collaboration by initiating partnerships between local and national governments and local and European entrepreneurs and supporting the development of new e-mobility models business implementation plans.

Create reference models for e-mobility innovation by implementing demonstration actions to test innovative e-mobility technologies and services, foster their replication and ensure their long-term sustainability.
2. In Brief

The question of the end of life (EoL) management of electric vehicle batteries (EVB) becomes critical since the number of EVs is permanently increasing. The EoL management consists of three main steps: repurposing or reusing batteries, refurbishing and finally recycling them (Figure 1). This factsheet covers the refurbishing of batteries, what takes place once a failure occurs or when a lithium-ion battery has reached the end of its automotive use (70%-80% of its initial capacity, depending on the manufacturer specification or the user requirements as well) and no second life is possible because of faulty cells or modules. Power and energy requirements can be significantly affected when an EVB fails, with undesirable consequences on driving range, final velocity, acceleration and slope compensation. Nevertheless, failed EVBs can still be useful if the damage is not total and if an adequate refurbishing is carried out.

Due to the fact that each Original Equipment Manufacturer (OEM) has its specific battery chemistry, cell type, module structure, and package solution, it will be difficult to replace faulty cells from other OEMs. Additionally, safety concerns during inspection, package disassembly and assembly, and cell replacement require professional approaches, trained technicians, Specialized teams, and some specific equipment. Concerns regarding liability are further challenges faced in refurbishing processes.

Figure 1: Refurbishing within the circular battery value chain [adapted from World Economic Forum, 2019]
3. Battery pack assembly

Depending on the overall dimensions of the vehicle as well as its power and energy requirements, there are different battery configurations with different degrees of complexity. The most basic battery pack simply has a series of cells arranged in series plus a battery management system or controller (BMS or BMC), plus some safety and connection elements. All these elements are confined within a metallic receptacle that serves as an impact protector and fixing container.

A typical energy storage system is shown in figure 2, indicating some main components. On the left hand, a complete electric vehicle battery pack exploded diagram is shown including the names of the main component. Then, on the right hand, an electric vehicle battery module is shown indicating the names of the components. It should be noted that a battery pack is made up of several interconnected modules, while a battery module is made up of several interconnected cells.

Figure 2: Battery pack assembly (adapted from M. Alfaro-Algaba, F. Javier Ramirez)
4. Refurbishing process

An electric vehicle battery pack traces a cycle or path that consists of the following steps. First of all, it is manufactured by a battery assembler under the requirements of the vehicle manufacturer (OEM). The OEM requirements will be established in terms of power (kW), storage capacity (kWh), dimensions and fixing points, control and communication with the on-board computer, as well as type of connectors.

Secondly, the battery pack is installed by the OEM in the electric vehicle where it is used until it reaches a State of Health (SoH) of between 70% and 80% of its initial value, depending on the manufacturer’s specifications. At this point, the battery pack has reached the End of Life (EoL), where decisions regarding further steps need to be taken.

**Diagnosis & Classification.**

Before starting the refurbishing process, it is necessary to perform a diagnosis and classification, in order to determine if the battery pack can be repurposed, remanufactured or recycled. This result of the assessment depends on the degree of aging, degradation or damage. Extensive information originated during the battery automotive life is crucial in order to make an early diagnosis and an easier classification.

After the diagnosis, the classification depends on several factors such as the SOH, the remaining useful life (RUL), the safety conditions and specific costs of reparation. A complexity analysis that includes all those factors is made in order to define the way to follow. After classification, the refurbishing process takes place. It is composed of the following steps: 1) Screening, 2) Disassembly, 3) Repair (cell replacement & refit), 4) Reassembly and 5) Testing, before a new installation for another application. The whole process is shown in figure 3.

![Refurbishing flowchart (adapted from Yang Hua et al.)](image)

The linkages between the different levels of battery value chain have to be addressed through a circular and systemic approach across social, environmental and economic dimensions, to achieve sustainable practices and policies.
**Screening.**

The screening step in a refurbishing process is carried out in order to identify the damaged or degraded cells inside an EV battery pack. The process can be performed by using the on-board computer’s information. The BMS of the EV could provide critical information in order to determine the SoH of each cell. Testing the battery pack is another option to make the same determination, discarding useless cells.

**Disassembly.**

As it was shown before, the structure of the battery systems can be very complex. In the disassembly process, the battery system is dismantled at module or cell level. The disassembly step includes opening the battery framework, removing the electrical and mechanical connections between the components, as well as removing auxiliary electronic parts. Currently, a standard for lithium ion cells and battery packs does not exist; the disassembly of an EVB needs to be handled manually. Due to the high voltage, the disassembly process is dangerous, requiring skilled technicians and specialized equipment. Robotic battery disassembly could decrease the risk of human injury and reduce production costs.

**Cell replacement & refit.**

The repair stage in the refurbishing process is one of the critical phases in order to obtain a good refurbished product. One of the first steps is to replace cells that have been identified as defective, both by analysing the historical data or by testing modules and/or cells once the pack has been opened.

Another important step in the repair step is the verification and refit of the entire electrical circuit, including power cables, control wiring and connectors. Likewise, the BMS at the battery pack level or at the module level must be tested and verified in such a way that its correct operation is ensured to avoid future failures.

At this stage, it is important to ensure that all installed cells have identical operating characteristics to ensure that their operation is within a safe range, avoiding undervoltages and overvoltages. Programming or reprogramming of the BMS must be done in order to ensure a safe operation.

**Reassembly.**

The reassembly process is very similar to the disassembly step if the remanufactured packs are used for the same purpose. If not, a new design must be carried out to be able to build a new battery pack. The same concept applies to the original battery management system (BMS), thermal management system (TMS), and equalization management system (EMS). They do not need additional modifications if the remanufactured packs are used for the same purpose but a new design must be done to build a new battery pack.

**Testing.**

Final tests must be carried out in order to verify that the performance of the battery pack is satisfactory. For this, certain standards must be met in such a way that the test step is adequately validated by the repair agent. Certain external validation (of the process or of the product) and certifications may eventually be required.
5. Applications

Although refurbishing can save approximately 40% in costs compared to new packages, there are currently no large-scale refurbishing applications. However, case studies are being carried out in different countries.

Case Study 1

Global Battery Solutions (formerly Sybesma’s Electronics / based in the US) developed a refurbishing method which can repair defective packages by diagnosing, removing defective cells, and replacing the vacant with healthy ones. Additionally, they offer a 4R’s process (Repair, Remanufacture, Repurpose, Recycle) and provides services to large automotive OEM customers and other industry stakeholders seeking innovative and sustainable energy solutions.

Case Study 2

Spiers New Technologies (SNT), based in the US, can provide 6R services for electric vehicle battery packs. Additionally, batteries that are found to be unsuitable to be used for automotive purposes, are utilized in Energy Storage Systems (ESS). These systems can be used to store energy to use in various non-vehicle applications. Each system is environmentally prepared to resist any climate. For SNT, 6R means the following:

1. Root-cause analysis: Determining the cause and severity of battery system failure.
2. Repair: Restore the pack to operational conditions (repair affects batteries that fail during the intended lifetime).
3. Remanufacturing: Disassemble, grading, rebuild and end-of-line testing to original OEM specifications.
4. Refurbishing: Disassemble, grading, rebuild and end-of-line testing to current OEM specifications (upgrading).
5. Repurposing: Creating second-life opportunities for advanced battery packs and components. That means that a new battery pack is assembled for second-use, different from the original one.
6. Recycling Preparation and Management: Reducing volume, weight and cost by reducing battery packs to their individual components and neutralizing cells for safe and low-cost shipping.

In this terminology, the difference between remanufacturing and refurbishing is that in the case of remanufacturing, the battery pack is restored to its original specification, while for refurbishing the battery pack is restored to the current OEM specification, representing an upgrading. In other studies, refurbishing and remanufacturing are considered to be the same process.
Nissan has built an EV battery refurbishing facility in Namie, Japan, a small town near Fukushima. This is a first factory in Japan specializing strictly in recycling of used lithium-ion batteries from electric vehicles. The 4R Energy Corp. is a joint venture with Sumitomo [greentecauto.com].

Case Study 4

Berlin-based startup called “betteries” is one of the firms that are working to make a better use of used cells and batteries by upcycling them into sustainable and affordable multipurpose battery packs. The “betteries” packs have the following features:

- **Mobile**: it is a “Click and go” solution with no cabling, weighing less than 35kg
- **Modular**: it is possible to stack up to 4 battery modules for 12+ kWh
- **Multipurpose**: it is a customized application module with bi-directional inverter (AC & DC)
- **Optimized battery life**: it has an innovative, active balancing BMS optimized for 2nd life cells
- **Robust & waterproof**: it is assembled with a marinized casing (IP67).
- **Connected**: it counts with GPS plus Wi-fi and GMS connectivity, over the air updates
6. Results

Several gains can be obtained from refurbishing EV batteries, providing in summary environmental and economic benefits.

**Benefit 1: Environmental gains of EV batteries refurbishing.**
- **postpones the moment where the battery needs to be recycled**, hence making a longer and more efficient use of the materials present in lithium-ion batteries, which have substantial environmental impacts.
- **reduces the need for new batteries in ESS**, saving on raw materials and its negative impacts on the environment.

As for all circular economy levers affecting end-of-life batteries, recollection is the key gateway to allow further productive use. Thus, concerted action is needed to maximize battery collection rates – lifting them from an estimated average 61% in the base case to 79% in the target state. While consumer electronics battery recollection is historically poor (below 20%) and has shown to be difficult to increase, vehicle/stationary battery recollection is expected to be more successful at 65% in the base case and even 90% in the 2030 target case. In the target state, it is assumed that battery design for disassembly and lifetime extension is a high priority for industry, supporting repair and refurbishment (World Economic Forum, 2019).

**Benefit 2. Economic gains of EV batteries refurbishing.**
- **may enable discounts on the EV battery cost.** By extending the life of the battery and creating new revenue streams, refurbishing can reduce its life cycle costs. Companies may factor in the resale EV (refurbished) battery value by passing it on the EV battery purchase price. Such a discount could have an impact on the EV market as the high capital cost of the EV battery is one of the main deterrents to the uptake of electric mobility.
- **creates employment opportunities**, locally by installing and operating facilities, dismantling and analysing the state of health of the EV batteries, and on a broader level by reengineering as well as creating new economic models crossing over distinct sectors and stakeholders (e.g. mobility/energy, OEM/operator etc.).

Despite these arguments, it is assumed that refurbishment will be limited in the long term to 5% of end-of-life EV and ESS batteries because the trend to homogenous battery ageing undermines the business case for exchanging deteriorated modules. Limited incentives for automotive companies to optimize battery design for repair and refurbishment further shifts the case in favour of second life or recycling (World Economic Forum, 2019).
7. Technical and financial considerations

Some of the key enabling conditions for refurbishing are:

- **Battery analytics technology:** The development of this technology embedded within batteries or as separate tools, and the sharing of key information derived from them (e.g. via a battery passport), will help to efficiently determine the state of health and chemistry of battery cells or modules as well as the chain of custody, and will help to manage them appropriately.

- **Design for disassembly:** Via this design, batteries will be easy to open, and modules can be exchanged with a high degree of automation – ideally with little variation between different manufacturers, so that tools can be harmonized.

- **Logistics operators and service stations:** This ecosystem will make repairs convenient and will keep transaction costs low. Collecting batteries and sorting the diverse types can be a costly and complex step. Organisational schemes easing collection, reducing the heterogeneity of the battery types collected, and streamlining the refurbishing process, can all enable economies of scale.

Some barriers that stand in the way for refurbishing are:

- **Lack of data and uncertainty over the battery state of health (SoH).** A hurdle commonly encountered lies in the uncertainty over the lifespan to expect from these batteries in their new stationary use. Beyond aging, residual capacity depends on several factors including charge and discharge rates, temperature and state of charge of the battery. Monitoring through the battery management system (BMS), knowing its history by using storage information as well as testing the battery SoH before repurposing is key (Derousseau et al., 2017).

- **Safety and liability concerns.** As refurbishing (more than repurposing) is a recent practice and li-ion batteries may present a risk of thermal event, uncertainties over safety aspects exist especially at stages of removal, testing and disassembly (Hossain et al., 2019). This is also linked to the lack of data on their SoH mentioned above. In addition, regulatory frameworks barely exist on safety procedures, nor safety certifications. The question of liability in case of possible safety events caused by the battery poses a further challenge as the use of refurbished batteries electric vehicles.

- **Uncertain financial viability.** To be preferred instead of new batteries of a similar capacity, refurbished EV batteries need to be available at a lower price. The associated costs for these batteries are: 1) cost of purchasing the retired battery, 2) collection and transport costs, and 3) processing costs. There could be another important obstacle for the economic and financial viability since the price of new batteries is expected to decrease in the coming years (BNEF, 2019).

In the first place, the costs of acquiring damaged or defective batteries is uncertain since there is currently no market volume that allows obtaining specific values. Similarly, the costs of collecting and transporting damaged batteries may be higher or lower depending on the volumes handled and also on the logistics structure developed around the business. Finally, the processing costs for the repair and remanufacturing of batteries will be highly variable in the first instance, since it will depend on the complexity of each battery pack, the type of failure, the availability of spare parts and replacement parts, and local capacities to carry out the refurbishment.
8. Policy/legislation

For the purposes of considering policies related to the repair and remanufacturing of electric vehicle batteries, it is worth mentioning the involvement of different actors and potential stakeholders: 1) government organizations (including regulatory bodies), 2) international organizations, 3) national companies or international participants in the activity and 4) users or consumers. All these actors will have a greater or lesser degree of influence in the elaboration of policies.

The level of formality in developing countries is related to the interactions that take place between these actors as well as the regulations in force. International organizations can provide support, advice and knowledge regarding the organization and structure of the policies to be applied. The government organizations have the function of carrying out the corresponding regulations and allocating resources to ensure compliance. As for the companies involved, they must define an integrated management system (SGI) internally, which must comply with existing regulations. Finally, users or consumers play a fundamental role in the selection, use, evaluation and disposal of batteries, which should be subject to the regulations imposed.

Uncertainty over the battery state of health and future lifespan:

For all activities related to electric vehicle batteries that have reached the end of their useful life (EOL), it is necessary to evaluate the health of the battery at the time of removal of the vehicle. It is critical to know the remaining capacity [kWh], the current charging efficiency, and if there are faulty cells within the package. Ideally, a battery pack should have an end-of-life “health” assessment report from which decisions can be made. This evaluation could be an own development of the battery manufacturer, the car manufacturer or external equipment added to the vehicle.

Since the data related to the SOH of the batteries is commercial property strictly controlled by the manufacturers, there is a need to handle different scenarios to carry out remanufacturing activities, such as: 1) that the OEMs go to their networks of distributors and service authorized to provide this information at a reasonable cost, or 2) to develop tools and capabilities not related to OEMs in order to enable recycling chains to carry out such activities, evaluating the SOH of batteries and cells in other ways and issuing reports or certificates. Such a report would allow recyclers to redirect the battery pack appropriately, which would include: repurposing (for packs with usable operating capacities), refurbishing (for repairable battery packs) or recycling (for highly degraded or damaged packs).

Safety and liability concerns:

Safety issues are critical during the remotion from the vehicle, picking and storage processes since lithium-ion batteries are hazardous materials and have risks of fire and explosion. After being collected, batteries go to the inspection process where their SOH is examined, if that analysis was not done before. For that purpose, batteries are visually inspected at the plant in order to sort out damaged packs as they cannot be used in refurbishing applications (i.e. crushed batteries) and suppose an imminent safety risk. Intact packs are disassembled to component level and battery modules and cells are repaired and/or replaced for new components. To be carried out securely, all those tasks at the processing plant have to be performed above extremely safety conditions.

To be used again in e-mobility, batteries have to be properly labelled in order to guarantee a correct performance and a safe operation. Legal issues appeared in the after sale of a refurbished electric vehicle battery due to the risks of fire and explosion that this type of battery intrinsically has. An adequate system of labelling and warranties have to be implemented, based on a local (national) regulatory framework, what have to be also backed by an insurance company.

Economic feasibility:

Within the value chain of electric vehicle batteries, economic feasibility of refurbishing processes will still be a challenge in the near future. The benefits are dependent on the prices of spare parts and show a high sensitivity to the volumes. In the present, the breakeven point for an analysis carried out in Germany is approximately at 2,800 used battery packs per year (Rohra et. al.). As the mentioned study shows, refurbishing is an activity with a much lower net present value (NPV) than repurposing. However, economic feasibility of refurbishing could be a promising option for some specific battery components in the future.
9. Institutions

As regards public institutions, a large number of ministries and governmental agencies as well as parastatal agencies can be usefully involved:

- Ministry and agencies in charge of Environment;
- Ministry and agencies in charge of Industry;
- Ministry and agencies in charge of Energy;
- Ministry in charge of R&D;
- Research institutions;
- Insurances companies (private and/or public in case);
- Private companies or associations with interests in electric vehicles;
- Private companies or associations with interests in e-waste management.

Cooperation among companies and organisations can involve public or private entities dealing with e-waste management, vehicle and battery manufacturers, transport companies, universities, insurance companies, battery management software developers, development finance institutions (DFIs), international organisations, and the very comprehensive category of actors potentially interested in electric vehicle batteries.

10. Transferability, replicability

Refurbishing EV batteries for e-mobility applications is replicable in different countries and/or cities depending on various parameters such as penetration of EVs in the local market, active stakeholders, conditions and volume of e-waste collection, and regulatory environment.
11. References


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