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Life2SLB

Giving Batteries a Second Life

Executive summary

Due to the recent regulatory push towards e-mobility, **battery electric vehicles** (BEVs) will likely represent the largest share of the market by the year 2030 [1,2]. The amount of retired **Lithium-ion batteries**, reaching the end of their first life after approximately 10 years of usage, will therefore massively increase: to maximize their value, a **second life** could be included in the device lifecycle before dismantling and recycling, with a circular economy approach [3]. **Life2SLB** project was born to further investigate this framework, together with its mother company **Free2move eSolutions**.

The immaturity of this field, lacking a unique reference framework and standardized solutions, represents both an opportunity to introduce innovative paradigms and the first roadblock that a SLB company must face. Most of the initial efforts within the project have therefore been aimed at the creation of a common **knowledge base** on such topic, leading to the publication of a scientific paper on an IEEE journal [4].

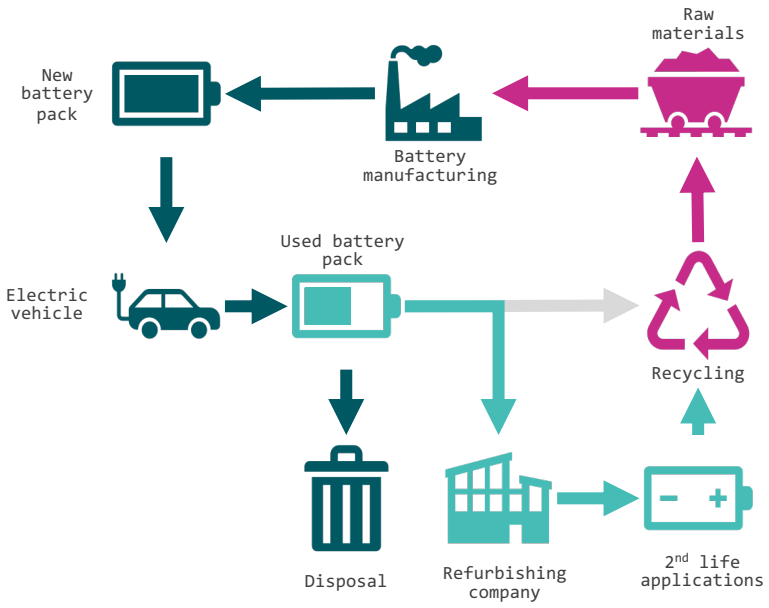
To face the uncertainty related to SLB competitiveness, a **predictive tool** has been developed by considering the main variables affecting such business. The result of this work is a flexible model enabling the comparison of several future scenarios, thus providing useful guidelines in the definition of the optimal mid- and long-term business strategy for a SLB company.

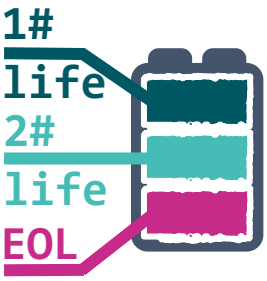
To overcome performance and reliability concerns, a **testing procedure** to assess second-life products feasibility has been designed, and it is currently under development in Free2move eSolutions' plant located in Cosio Valtellino. Furthermore, a Machine Learning algorithm able to estimate the residual value of spent battery packs by means of its **state of health** (SOH) has been developed by Life2SLB: this outcome can be directly employed in an industrial context to estimate the residual battery value in a fast and reliable way.

Key Words

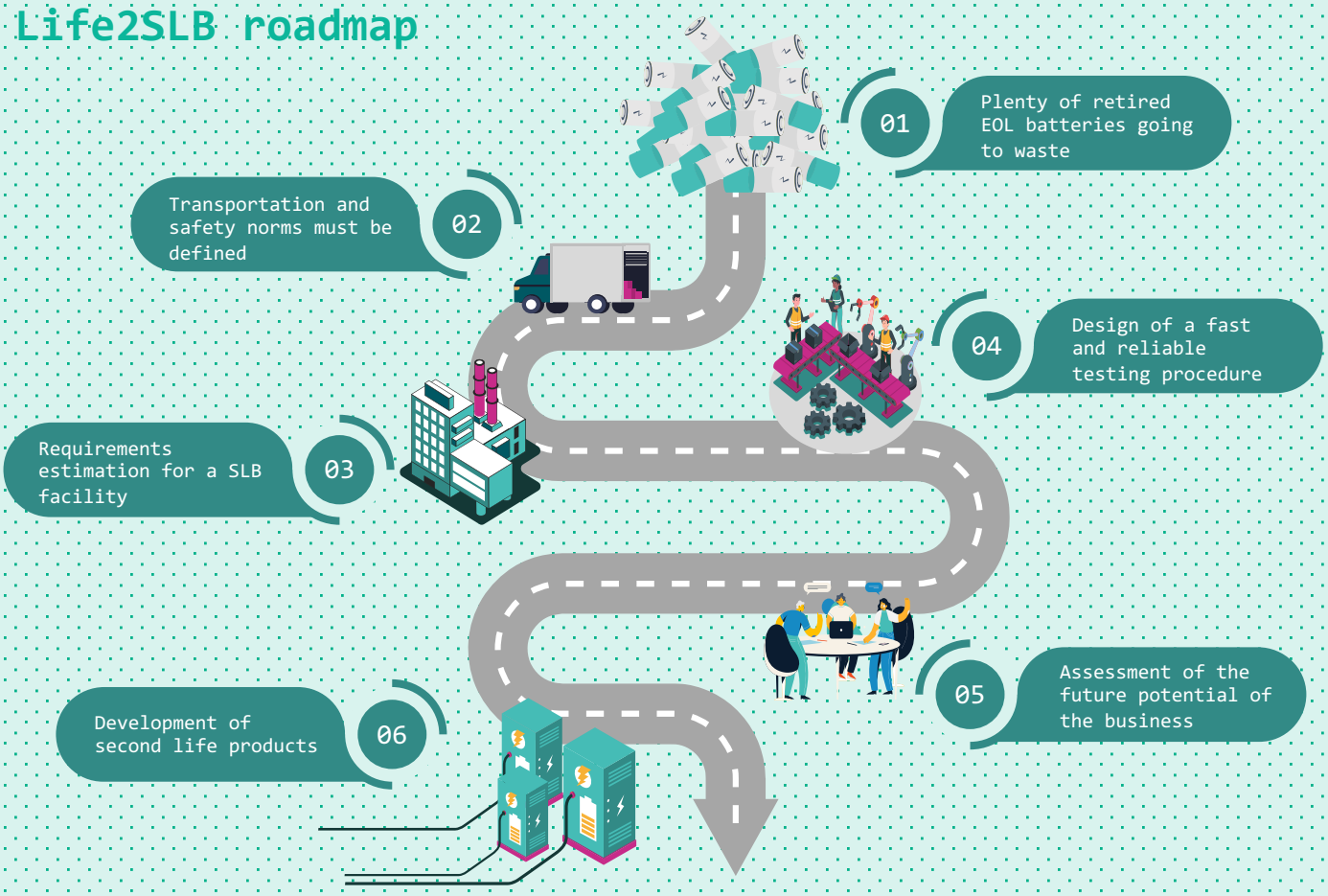
E-mobility, Lithium-Ion Batteries, Second Life, Circular Economy, Machine Learning.

In line with Free2move eSolutions' vision, Life2SLB project aims at becoming a reference in the development of innovative e-mobility solutions, facilitating a paradigm shift that would make advanced charging solutions and other energy services available on a large scale.





Life2SLB roadmap



Project description written by the Principal Academic Tutor

The European Union has decided what will be the future in the automotive sector: by 2035 it will not be possible to register fossil-fueled cars anymore. It will therefore be imperative to switch towards other alternatives, and the readiest at the moment is for sure the **electric vehicle**. The core of this already well established - yet quickly improving - technology is the electric batteries that are needed to provide the required energy to the vehicle. It is then not a surprise that any available forecast does show impressively increasing trends concerning the demand for lithium-ion batteries in the upcoming years.

In this innovative framework, the goal of the Life2SLB project was to provide a concrete push to the innovative technology of Second Life Batteries (**SLB**). When dealing with electric vehicles, it is necessary that the batteries equipped on the cars work very close to their rated performances, in a quite energy-intensive way. By doing so, batteries experience some relevant degradation processes that lead to a performance drop which is not sustainable anymore once it reaches 20-30% of the initial characteristics. At that point, the battery needs to be replaced by a new one, so traditionally the used one would be partially **recycled** when possible, and then disposed of. There is another way though: the spent battery still retains some value, being able to operate at around 70-80% of its original capacity. Many useful applications, like stationary storages and similar, are far less demanding with respect to the automotive sector, and in such fields the used batteries can still be successfully employed.

Such idea is the very base of the whole “Second Life Batteries” concept, which is extremely meaningful from various points of view. First of all, it perfectly fits in a **circular economy framework**, trying to postpone within the life cycle of a product the moment in which it is necessary to throw it away, decreasing in such a way the volume of materials to be landfilled. Secondly, many of the materials that are required in the construction of electric vehicles’ batteries (the most relevant ones being lithium, cobalt, manganese, nickel and rare-earth elements) already are, or might become, scarce resources. It goes without saying than that being able to lower the necessity of constructing new batteries for stationary storage will therefore prove to be substantial in the long term.

During the last year the Life2SLB team addressed the Second Life batteries topic by investigating the automotive market and its trends, pointing out the regulatory and technical issues that still hold back the entire field, developing tools for the estimation of a used battery’s **KPIs** to understand whether it would be suitable for a second life or not, creating a tool for the economic assessment of SLB-related activities considering different future scenarios, proposing sustainable business models for firms interested in the matter, and much more.

Team description by skill

The team is composed of five engineers. **Andrea Borgo** studies Automotive Engineering at Politecnico di Torino, he focused on the analysis of already existing pilot projects and competitors, the evaluation of the different business models available, and the draft of the techno-economic model. **Giacomo Coslop** is a student of Politecnico di Torino graduating in Energy Engineering. Inside the team, Giacomo developed a market analysis of the EV sector in the future, investigated the current European regulatory framework regarding Batteries, and joined Andrea in the building of the techno-economic model. The two of them were inserted in the Innovation branch of the external partner. **Emanuele Groppo**, Electronic Engineering student from Politecnico di Torino, was involved in the design of a suitable testing procedure to be implemented in the company's plants. **Manfredi Gangi**, Electrical Engineering student from Politecnico di Milano, focused on transportation and safety issues for batteries. **Alberto Valdes Rey**, from the MSc in Information Bioengineering of PoliMi, mostly worked on the SOH predictive model. The latter topic was the not only the most significant, but also the most time-consuming one and it required the support of all the last three members. Manfredi, Alberto and Emanuele were part of the Research and Development (R&D) section of Free2move eSolutions.

Goal

The aim of this project is the complete analysis of the economic and technical framework around second-life batteries, providing the mother company with a set of tools for entering the field. The roadmap is subdivided into 4 main stages, each one focusing on a crucial area of the SLB framework, as reported in Figure 1. At first, understanding the current electric mobility paradigm represents a crucial phase, aimed at the creation of a solid **knowledge base**. The second step is the definition of a suitable **economic model**, followed by the design of a feasible **testing pipeline**, specific for the company. The last goal is to craft a fast and reliable tool for the estimation of the batteries' state of health (**SOH**), allowing for the grading of each battery pack in order to identify the most suitable second-life application.

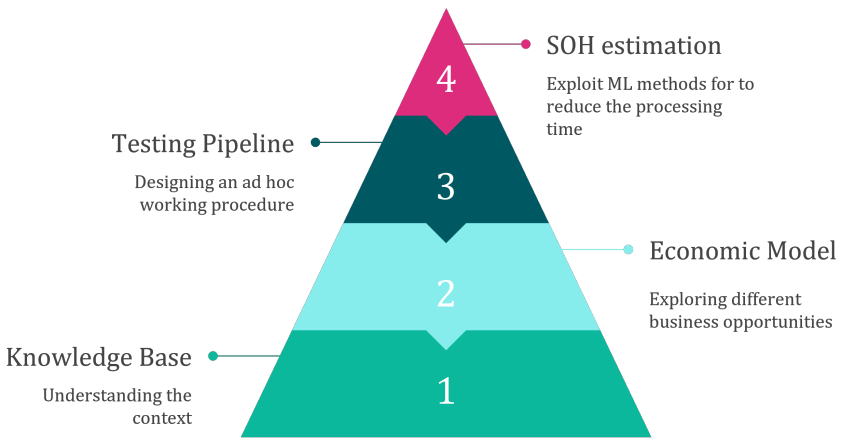


Figure 1 Goal pyramid.

Understanding the problem

The uncertainty regarding SLB market and the infancy of the concept represent the biggest obstacles to the definition of a structured business which could take full advantage from accumulation of first life batteries. A second-life approach appears to be quite convenient from a logical point of view, since its main concept is based on a circular economy model. However, the actual feasibility of this new alternative path is limited by several factors.

The actual European regulatory framework does not tackle the possibility to implement a **repurposing** process to reuse retired batteries. Therefore, companies which try to enter this field do not find any precise standard to follow. Notice that this concerns all the facets of this business, ranging from economic to more technology-related issues. As an example, Figure 2 reports the existing standards concerning safety-related issues for Battery Energy Storage Systems (**BESSs**) based on first life batteries, while no specific normatives for SLB-based ones are available

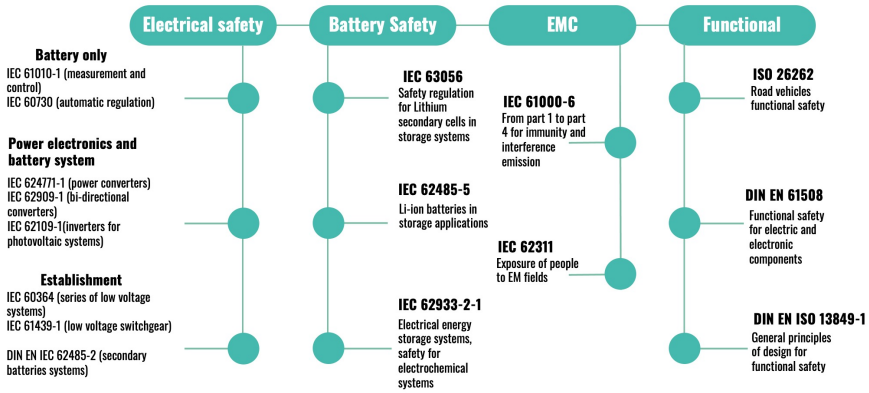


Figure 2 Summary of the existing normatives to be considered for BESSs.

In line with this overall uncertainty, the choice of a suitable business model can represent an important challenge for a SLB company, since it is not trivial to understand which one may turn out to be the most profitable and performing, simply because there are no large-scale businesses or investments solely based on Second Life yet.

Moreover, being at the frontier of this field makes it difficult to identify the most efficient testing pipeline which should also be optimized taking into account the forecast volumes of batteries which will be present in the market. Notice that this is an essential step in order to face the general mistrust with respect to second-hand product, with several concerns related to their **reliability and safety** of operation. However, the testing overhead should be reduced as much as possible, obtaining precise results with low time and resources consumption.

Exploring the opportunities

The novelty of the presented niche has been labeled as an obstacle from different perspectives, but it could also represent a big opportunity for new companies like Free2Move eSolutions entering this market in an early stage. The lack of a well-structured paradigm comes with the sparseness of possible competitors, thus opening a leading position in the market and the chance to impose technical de-facto standards. Being one of the main actors in the SLB panorama allows to directly affect the **normative framework**, directly interacting with the devoted authorities. In this perspective, international conferences and influential scientific journals represent the perfect stage to reinforce the company's position.

The high amount of available data and forecasts done for the EVs, constitutes a perfect foundation to construct efficient decisional models, which could constitute the base for the business definition. This is not to say that it should be easy to correctly assess the future potential of the **SLB business**, but in case someone would successfully do so, then the potential benefits could turn out to be great.

Data driven approaches could be a perfect tool to assess the residual potential of exhausted batteries. The main bottleneck of the existing testing pipelines is the evaluation of retired battery packs. Implementing cutting-edge data analysis methods, possibly based on machine learning models, would give the opportunity to characterize SLBs' performances and reliability in a fast and accurate way.

In order to satisfy the requirements initially stated by the company, the team decided to focus on the definition of a set of tools which could leverage on the presented opportunities.

Generating a solution

Having in mind the complexity of the investigated paradigm, Life2SLB's main purpose has been the development of a toolbox able to sustain the first steps of Free2move eSolutions in the SLB field. In this direction, aside from the contribution to the general understanding of the topic represented by the already mentioned knowledge base, we delivered two main products, respectively focused on the economic and technical area.

From the economic perspective, as it often happens when dealing with a strongly innovative context, we identified the main problem in the overall **uncertainty** about the SLB business. It is in fact as of now unclear if SLB products will prove to perform well, to be safe, to cost much less than new ones, and so on. To overcome such an important issue, a "techno-economic" model has been developed and proposed to the company. Its purpose is to provide reliable guidance in the next big decisions by Free2move eSolutions, given some potential future trends.

This approach allows to roughly simulate realistic future scenarios about the overall SLB business (e. g. some electrical components will cost more in the mid-term, or testing procedures will get much faster from a certain year on, or disposal costs will strongly decrease in the long-term…) and consequently obtain how the imagined future will affect costs and revenues related to the SLB field.
From a more technical point of view, instead, as a response to the lack of a standardized testing procedure, we outlined a suitable and reliable process in line with company requirements. In this design phase, the Python module **PyBaMM** has been employed to optimize such process in terms of temporal overhead, crucial when dealing with growing volumes of spent batteries to be characterized. The obtained testing pipeline has then been implemented in the company's facility located in Cosio Valtellino (Figure 3): batteries are evaluated using two parallel test-benches. **Bench A** is devoted to visual inspection of pack integrity, while **bench B** is the station dedicated to the in-depth electrical assessment of battery KPIs required for its SOH evaluation.

Figure 3. Testing pipeline implemented in Cosio Valtellino plant.

The final step of the project roadmap has been the elaboration of an automatic **SOH estimation** algorithm, based on **machine learning** techniques [5]. Such tool has been designed in MATLAB, and it is able to provide the state of health estimation starting from a limited set of KPIs extracted while testing the battery pack on bench B. We chose to use a data-driven approach, tested on different datasets and relying on alternative machine learning configurations and data analysis criteria. The outcome of this comparative study, which will be presented in a paper at an IEEE conference, has been the identification of the two best models (directly compared in Figure 4) providing a SOH estimation with a maximum error in the range ± 1%.

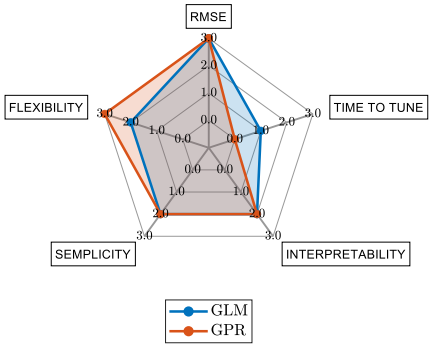


Figure 4. Comparison between Generalized Linear Model and Gaussian Process Regression in terms of 5 performance indicators.

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