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Lions2Life

De baterías usadas al almacenamiento distribuido y sostenible de energía

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[1] https://www.recyclia.es/
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RESUMEN

De acuerdo con el informe “A Vision for a Sustainable Battery Value Chain in 2030”[3], las baterías de Litio-Ión son la tecnología clave para alcanzar el Acuerdo de Paris (mantener las emisiones globales por debajo del objetivo de 2ºC), dado que permiten reducir las emisiones de CO2 para el sector del transporte de forma directa mediante el uso de vehículos eléctricos. Además, la movilidad eléctrica va a ayudar en la transición hacia sistemas de energía renovable, gracias a la posibilidad que ofrecen las baterías utilizadas en los vehículos de acumular la energía producida una vez ya no son aptas para su uso en movilidad. Combinando ambos sectores, transporte y generación de energía, será posible conseguir que las fuentes renovables se conviertan en una solución real. De acuerdo con esto, las baterías pueden contribuir a reducir las emisiones de carbón en un 30% respecto a los valores requeridos para los sectores del transporte y la energía.

Hoy en día la movilidad eléctrica se está convirtiendo cada vez más en una práctica habitual, y aunque de momento solo un pequeño porcentaje de la población está utilizando bicicletas, motocicletas y patinetes eléctricos, este porcentaje está destinado a aumentar. Este artículo presenta el foco y los objetivos del proyecto Lions2Life: reutilizar baterías del sector del transporte en el sector de la energía. El proyecto pretende demostrar, en un eco-barrio de los alrededores de Valencia, que será posible desarrollar un modelo de negocio sostenible, tanto desde el punto de vista técnico como económico, en el cual los ciudadanos usen el transporte eléctrico y cubran sus necesidades de energía mediante paneles solares, que podrán ser utilizados gracias a los sistemas de almacenamiento de segunda vida creados a partir de baterías que provienen de vehículos de movilidad personal.

Se presentarán los resultados preliminares del proyecto y se discutirán los pasos a seguir para el desarrollo del futuro prototipo y del modelo de negocio.

El uso de baterías de segunda vida y sus beneficios, como resultado de las soluciones desarrolladas van a ser presentados teniendo en cuenta que la generación de residuos se va a reducir gracias a la extensión de la vida de las baterías, y que el precio de los sistemas de almacenamiento se va a reducir también, habilitando la creación de nuevos modelos de energía renovable que contribuyen a la economía circular, y los ciudadanos podrán ver cómo el aumento en el uso de los sistemas de movilidad eléctrica se traduce en un mayor uso de la energía renovable y, en definitiva, en una forma de vida más sostenible.

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[3] http://www3.weforum.org/docs/WEF_A_Vision_for_a_Sustainable_Battery_Value_Chain_in_2030_Report.pdf

LIONS2LIFE

Background

Due to the increasing environmental effects caused by combustion vehicles, alternative mobility is becoming a more and more common practice. Although nowadays only a small percentage of population is using e-bikes and e-scooters, this amount is destined to increase. Behind that, there is the idea that in future years people will move from rural areas to cities and available public transport will have to be extended, also considering electric and sharing mobility; in addition, the sale of e-bikes is increasing thanks to the development of new technologies and the lowering of Lithium price [1]. Combining these two reasons, it is expected that from 2020-2023 more than 130 million e-bikes will be globally sold; of which, two-fifth will be Li-ion type. Considering recent studies, Spain recorded a 55 percent year-on-year increase in e-bike unit sales in 2018 [2]: about one hundred thousand e-bikes were sold and this represents the 11% of the total bike market. A growing trend is foreseen also for e-scooters: in the first 11 months of 2019, about 45.000 two-wheeler electric vehicles were sold in Europe, which represents an increase of 64% compared with the sales in the same period in 2018 [3].

As a direct consequence of what is stated above, the battery industry is identified as a priority by the European Commission through the European Battery Alliance[4] supported by Spain. More locally, the specialization strategy of the Valencian Region has given to the recycling of batteries a major importance. In addition, the city council of Valencia and other city councils on the periphery of the city are promoting the use of electric vehicles as a priority element of their mobility policy, which is generating a growing stock of used batteries. Finally, Spain is in full expansion for what concerns the installation of solar power plants [4]. These three elements are deeply related especially in turn to the achievement of the objectives of the Paris Agreement [5] and the Circular Economy Action Plan of the European Commission[5].

According to the 2016 Deutsche Bank Lithium battery report [6], the price of batteries is decreasing at a rate of almost 10% per year. However, the price of batteries for energy storage is still very high (see Fig. 1), and this is the main factor responsible for its limited penetration in the market. On the other hand, Lions2Life partners *Recyclia* and *ERION* affirm that the number of batteries from sustainable mobility services that reach the end of their lives is growing fast (*Ecopilas* collection network's number of collected batteries increased 58% from 2018 to 2019). The reports consulted regarding the use of these batteries for energy storage applications [7] confirm the technical feasibility of the solution, and in line with this, they advise about the need of pilot experiences to validate all the aspects related to its implementation from the more technical aspects to the regulatory and business model aspects.

The project aims at demonstrating the validity of the use of second-life batteries from e-mobility in energy storage systems, both from the technical and economical point of view, through the elaboration of a new business model and the related practical demonstration, also encompassing the social and regulatory aspects of the solution.

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[4] https://ec.europa.eu/growth/industry/policy/european-battery-alliance_en
[5] https://ec.europa.eu/environment/circular-economy/

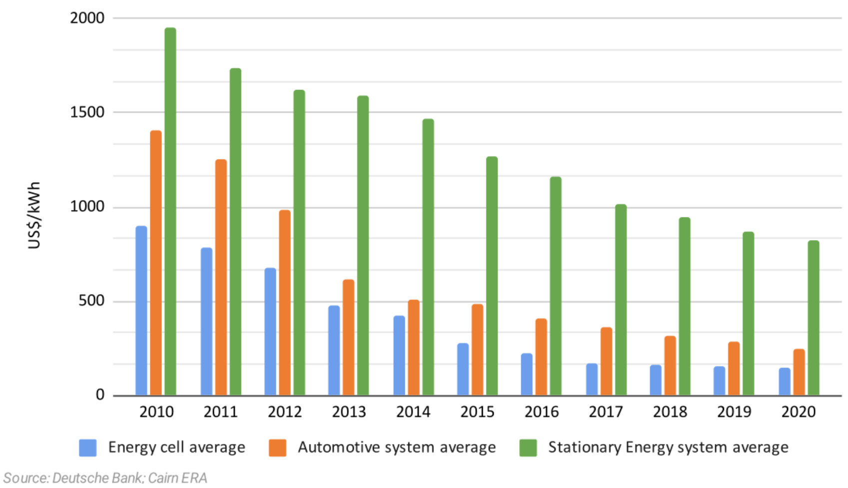

Figure 1. Evolution of Li-Ion battery cell and system costs for EV and stationary storage application [6].

This research is being developed by the Photovoltaics research group of the Nanophotonics Technology Center of the Polytechnic University of Valencia.

2nd-life batteries

Collection

The storage system prototype represents an important step towards the validations of the Lions2Life model. Thus, it is fundamental to have a large pool of batteries to draw from.

Fundación ECOPILAS (managed by *Recyclia*) is a Collective Scheme for the compliance of batteries regulation in Spain and it manages the collection and recycling of all kind of waste batteries, including industrial Lithium-Ion (Li-Ion) batteries.

End of life Li-Ion e-bike batteries are today mainly collected by dealers, technical services and manufacturers. With the collaboration of their producers[6], from the start of the project until today, we have been able to collect over than 150 lithium-ion batteries from Basque Country, Community of Madrid and Valencian Community, where 83% of those come from e-bikes.

The average collected e-bike battery has a voltage of 37 V and a capacity of 12 Ah, with 40 18650 lithium-ion cells inside, distributed in 10 blocks connected in series of 4 cells connected in parallel. Charge and discharge of these batteries are electronically managed by a so-called battery management system (BMS), which can be found inside the pack. This device implements also a protection circuit that keep the battery in a safe open-circuit-voltage range during its

[6] *Producer* means any person in an EU Member State that places batteries or accumulators, including those incorporated into appliances or vehicles, on the market for the first time within the territory of that Member State on a professional basis.

operations. The cell has to be intended as the *quantum* of a battery and the 18650 model refers to its dimensions: a cylinder of 18 mm diameter and 65mm height.

Disassembly

An important step for the remanufacture and recycling processes is the disassembly of the battery packs to cells level. However, the risks associated with battery disassembly are also numerous. For example, short-circuiting results in rapid discharge, which may lead to heating and thermal runaway [8]. Moreover, due to the fact that e-bike batteries are designed with a view to lasting as long as possible, the cells inside are densely packed, in order to avoid damage from the mechanical stress and vibrations that may be subjected to during their lives as part of a 2-wheel-vehicle. As a result, it might become very hard opening the case and taking out of the cells individually.

For example, in the case of battery shown in figure Fig. 2 we had to:

1. Open the external case;
2. Take off screws and cut all the cables;
3. Remove the BMS (it was covered by a protective silicone);
4. Strip the nickel connections off;
5. Remove the plastic supports;
6. Take off the residual nickel contacts by the electrodes.

Figure 2. Example of the disassembly of an e-bike 10S4P Li-Ion battery. a) E-bike battery case and pack; b) BMS; c) d) Detail of a nickel strip before and after its removal, respectively; e) Cells without nickel contacts and the plastic support; f) Detail of a LG MH1 18650 Li-Ion cell.

Until today, we have been capable of disassembly a 20% of the collected batteries, spending an average of 90 minutes in the disassembly of each battery. Luckily, during step-6 just in some occasion short-circuiting occurred and that was mainly due to a direct contact of the employed tools between positive and negative electrode, due to an insufficient insulation of the two. Whenever events like this happen, those cells are marked as bad.

Cells analysis process

Once a battery is disassembled and all the 18650 cells are taken out, we can go to the charging/analysis process. The simplest electrical equivalent circuit model of a lithium-ion cell is shown in Fig. 3 and is described by the figures of merit listed in Table 1:

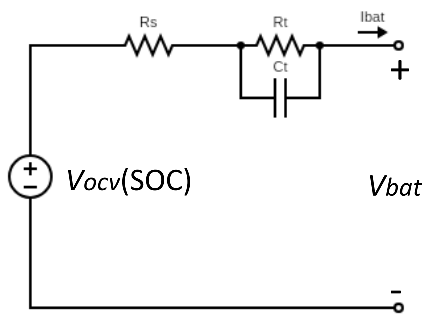

Figure 3. Thevenin-Based electrical model for a Li-Ion cell, with a series resistor R_S, an RC network (R_t, C_t) to describe basic charge transfer phenomenon, and an open circuit voltage dependent on the SOC V_{OCV} [9].

Table 1. Figures of merit of lithium-ion batteries.

Figure of merit	Description	Typical value
Nominal capacity	It represents the nominal amount of energy that can be withdrawn out from a fully-charged cell (in mAh).	/
Real capacity	It represents the real amount of energy that can be withdrawn out from a fully-charged cell (in mAh).	/
Open circuit voltage (OCV)	Difference of electrical potential between the two cell electrodes, measured with no-load.	2.6 V – 4.2 V
State of charge (SoC)	Currently available capacity as a function of the rated capacity.	0-100 %
State of health (SoH)	Condition of a battery compared to its ideal conditions, i.e. $SoH = \frac{Real\ capacity}{Nominal\ capacity} * 100.$	0-100 %
Internal resistance (IR)	Thévenin equivalent resistance Rs	>40 mΩ

Each lithium-ion cell is subjected to a “capacity-test”: the cell is firstly fully charged following the charging method CC-CV[7] (constant current, constant voltage) reaching the top OCV, that for Lithium-Ion cells is stated at 4.2 V. Then the cell-under-test is discharged at a known current until the lower OCV (usually 2.6 V), and during this process the amount of energy delivered by

[7] https://new.engineering.com/story/battery-management-systemspart-3-battery-charging-methods

the cell is measured. Finally, the cell is again fully charged and stored. Each capacity-test cycle lasts between 10 and 12 hours, depending on the cell model. In Fig. 4 a real capacity-test voltage-current plot is shown.

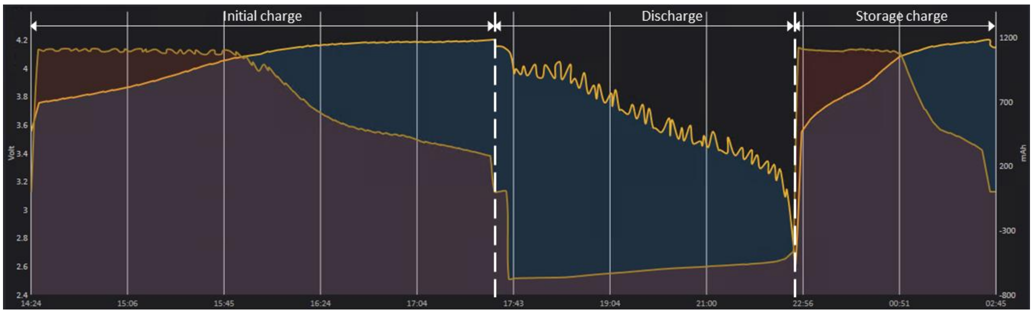

Figure 4. Voltage [blue] - Current [red] plot during a capacity-test. The cell-under-test is a LG MH1 of 3.200 mAh, tested by a MegaCellCharger charger.

All the data collected during this analysis are then saved in a database and a label is printed and attached over each characterised cell. In this way, we will be able to identify each cell by a univocal serial number.

During our tests, just a 14% of the measured cells results with a SoH lower than 85%, given that just when battery capacity goes below 80% of its original capacity then the battery is considered as non-usable for application purposes [10] (see Fig. 5).

Therefore, it is important to point out that a large percentage of the e-bike batteries collected by *Ecopilas* are in a good state. This further strengthens the idea of using second-life batteries from e-mobility in energy storage systems.

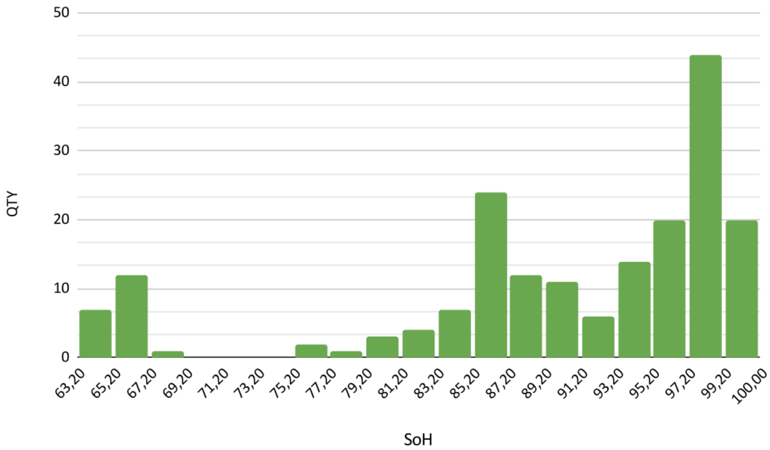

Figure 5. SoH of the tested cells taken from different e-bike batteries.

The pilot

The pilot will be done by moving the storage system built at UPV facilities to the La Pinada district location, in order to connect and operate it in real conditions. Then the system performance will be checked and compared to that of conventional commercial systems installed at the same location. Technical performance and time degradation will be evaluated, as well as the usability of the system from a user point of view. Other technical aspects such as its full storage capacity and depth of discharge will be also evaluated.

The prototype battery

As mentioned above, the prototype battery will be installed in the sustainable district La Pinada; in particular, it will substitute a conventional off-the-grid battery for solar power storage.

Considering that, we have decided to define the following specifications for our first prototype battery: 6.5 kWh – 48 V – 135 Ah , meaning an assembly of 14 modules in series of 42 3200 mAh cells each connected in parallel, i.e. a 14S42P battery (588 cells totally).

Selection of the cells

At this point, it is fundamental to define a proper selection method that may determine the state of each recovered cell as function of the figures of merit listed in Table 1.

One of the major technical issue using 2nd-life batteries is the SoH mismatch among cells that come from different battery-packs, due to their distinct previous life/history.

In the assembly of each battery block it is important to ensure that the parallel connected cells had similar SoH, with a capacity tolerance between cells of 5%. There is a strong correlation between cell balance and longevity, getting that a poorly matched battery would reach faster its end-of-life [11].

In Lions2Life we are designing a complete fuzzy-logic algorithm that will help us find the best suitable combination of parallel-series connected cells for the pilot battery assembly, choosing among the analyzed cells by means of: SoH, IR, original battery model and its position inside it, cell model and its manufacturing date, temperature performed during the capacity test, and other variables that may tell us better about their past.

What's next?

Real time SoH estimation by temperature

The principal drawback of the procedure used currently during the selection process is the capacity-test slowness: e.g., with 5 16-slots lithium-ion cell chargers we need at least one week to characterize a sufficient set of cells for the prototype. This represents an important bottleneck towards the achievement of the Lions2Life goal, to be added on top of the time needed in the disassembly of the large quantity of batteries involved.

That said and keeping in mind that we want to perform a capacity-test to get the actual capacity and SoH of each cell, the key-factor in the assembly of a battery with 2nd-life cells is the SoH characterization method. Therefore, an online estimation method of this figure of merit would provide a real-time measurement that would allow us overcoming the issue.

We are currently working on the possibility of determining the state-of-health SoH as a function of temperature, employing high-current pulses charge cycles and monitoring the battery-pack by thermographic cameras. A finding of a strong relation between temperature and SoH may give an enormous benefit since it would be hypothetically possible to analyze a battery-pack without disassembly it at cells level, neither spending more than 10 hours in the capacity-test process.

From a broader perspective, this means a faster characterization and an easily automation of the SoH estimation process.

Business model

Carrying out the project not only includes solving technical problems, but also validating the prototype from the point of view of the business model (led by Mosaik Urban Systems[8]) and its applicability to specific energy storage needs. In this sense, the project has the direct participation of municipalities (Riba-roja de Túria City Council, Paterna City Council) and indirectly from other municipalities, all of them led by AVAESEN[9], and in particular from the Smart Cities think-tank[10].

Both the municipalities and the companies consulted have shown their interest in storage solutions based on second-life batteries, an interest that is expected to be realised with the future implementation of several pilots for applications ranging from their use in municipal gyms to e-vehicle charging systems.

Conclusion

Thanks to Lions2Life, until now we have been capable of drawing some important conclusions:

- The good result in terms of SoH of the tested batteries confirms that batteries that are no longer suitable for use in mobility, are still suitable for stationary use.
- The project is following the principal strategies of the Circular Economy Action Plan adopted by the European Commission.
- The preparation for the reuse of electric mobility batteries has a double benefit: a reduction in both waste generation and prices of stationary batteries.
- More affordable stationary batteries will facilitate an expansion of the use of renewable energy, expanding also into a more sustainable society.

Lions2Life represents a small but essential step towards the realization of a fundamental change in the way the materials and the technology implied in the production of the Li-ion's batteries are sourced, produced and used; which is by the development and installation of a second-life storage system, built starting from batteries that belonged to sharing mobility vehicles, in an sustainable neighbourhood.

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[8] https://mosaiksystems.com/
[9] http://www.avaesen.es/
[10] http://www.avaesen.es/think-tank-smart-cities/

Acknowledgments

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