ALBATROSS

Advanced Light-weight BATteRy systems Optimized for fast charging, Safety, and Second-life applications

OCTOBER 2023

Contents

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WP5 - Dismantling, Second life, Re-use and Recycle

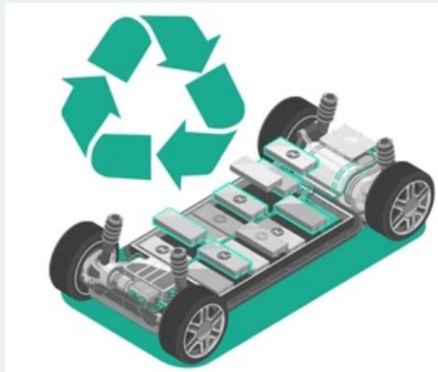
This newsletter aims to provide an in-depth look into the developments of the activities carried out for the different tasks of Work Package (WP) 5. We hope that you enjoy to read and know about them, as much as we have enjoyed working on them!

Secondary Use/Reuse Approaches

To assess the suitability of the ALBATROSS battery for second life purposes, a procedure for the transition between first life and second life is hereby presented. Firstly, the framework of the battery assessment procedure and how it is related to the life cycle of the battery is explained. Finally, the battery assessment procedure is applied to the ALBATROSS battery pack design.

The battery assessment procedure is composed of three stages, which assess the main uncertainties of the transition from first life to second life:

- State of the battery – analysis of the battery degradation conditions, including energy, power, and external wear.
- Technical viability – assessment of the requirements for various applications and exploration of potential configurations for EV batteries.
- Economic evaluation – analysis of the economic feasibility of the possible solutions.



The proposed battery assessment can be conducted at any point during the life cycle of the battery using available information, prior to its removal from the vehicle. Ideally, initiating the procedure before battery removal minimizes additional costs and improves the chances of achieving the desired outcome.

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WP5 - Dismantling, Second life, Re-use and Recycle

Each stage of the battery assessment procedure is mapped in Figure 1.

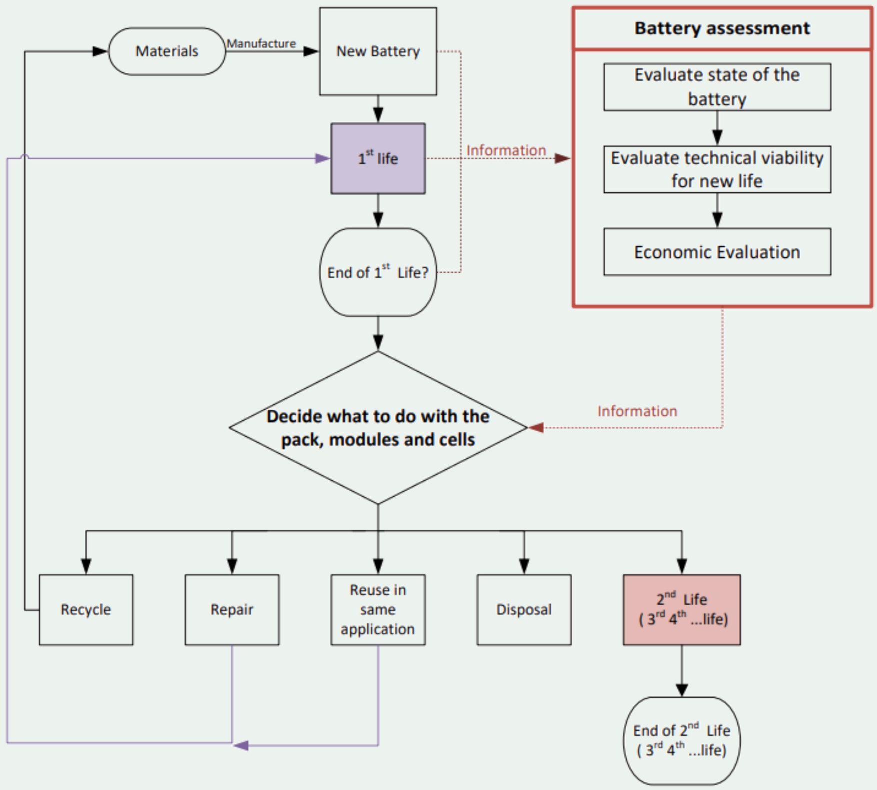

Figure 1. The proposed battery assessment procedure as part of a simplified battery life cycle.

After each stage and based on the available information, the future of the battery can finally be decided. The available options include:

- Recycle/disposal - If the battery is beyond repair, it can be recycled or disposed. If the recycling technology is not yet available, there is insufficient recycling capacity, or there are no legal obligations for battery recycling, immediate disposal after its first life may be a potential option.

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WP5 - Dismantling, Second life, Re-use and Recycle

- Repair/reuse - Depending on the battery architecture and financial considerations, the battery pack or individual modules can be repaired and continue its first life either in the same vehicle or in another.

- Explore second life possibilities - If the battery is still in good condition or can be repaired but does not have enough remaining life to meet its original requirements, the battery assessment can be used to explore potential second life applications.

The previous battery assessment procedure was applied to the ALBATROSS battery pack. In fact, the consideration for second life has been embedded from the start of the design phase, and therefore, several features have been included in the battery pack that will help the evaluation of the state of the battery:

- Advanced algorithm and cloud computing – one of the main problems for second life batteries is the lack of first life information when the battery is assessed. This problem is solved by ALBATROSS through the storage of information in the cloud about the battery usage, that will then be able to be accessed for the second life business. This will allow relevant stakeholders to save time and money testing the performance of batteries after the end of their first life. The algorithms developed will provide information both at the battery pack level and at the module level. Moreover, the cloud system is an advancement that complies with new regulations of batteries, which will require information about the battery to be shared with the owner (e.g., Battery Passport, which includes information about the state of the battery and its history).

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WP5 - Dismantling, Second life, Re-use and Recycle

- State of Health (SOH) - a trustable SOH indicator is important to analyse the actual capabilities of the battery and be able to decide which application is the most appropriate.

- End of Life (EOL) and Remaining Useful Life (RUL) prediction - enhancing these characteristics allows for a better prediction of the RUL, which provides an approximate indication of when the battery will no longer be useful for the first life. Scheduling could be done by the OEM or the second life company to predict the arrival of battery packs and distribute them to the appropriate facilities.

To assess the technical viability of the ALBATROSS battery pack, it will be determined which battery configurations are viable to be used in second life applications, and in which possible applications they could be used.

The battery configuration is an essential aspect for second life, although many battery packs are not initially designed for reuse. The possible configurations are:

- *Stacking used EV battery packs – which involves their connection with minimal modifications.*

- *Refurbished battery pack made from used modules – which are disassembled down to the module level, tested, certified and integrated in a new battery pack suitable for the intended application.*

- *Refurbished modules from used cells – similar to the previous configuration, but in this case, the battery pack is disassembled to the individual cell level. The cells are then repackaged into new modules and battery systems.*

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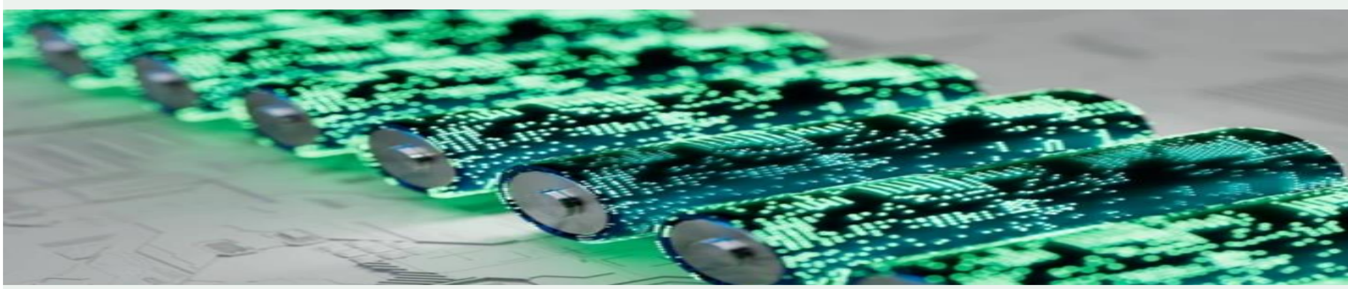
WP5 - Dismantling, Second life, Re-use and Recycle

The critical characteristics of the ALBATROSS battery pack were studied in terms of:

- **Design** - ALBATROSS battery pack follows the principles of modularity, being designed to allow for a safe disassemble of the modules by unscrewing their mounting screws. However, removing cells from the modules is more complicated as the cells are welded. Some operations to separate the batteries are being explored and the safety of the procedure will be discussed in a following newsletter.

- **Communications and battery management** - the hardware controlling the ALBATROSS battery pack has been designed to be reused in a second life application. Depending on the configuration chosen, to reuse the Cell Monitoring Unit (CMU), a Battery Management Unit (BMU) is demanded for its control. The BMU can also communicate with a power converter and the Energy Management System (EMS) to allow connection and control of the battery on the grid. Depending on the power converter chosen, a gateway may be needed to translate the protocols and messages between the BMU and the converter.



- **Performance** - The power and energy characteristics will be reduced when the battery reaches the end of its first life, but if the application allows for it, more batteries could be added to get the desired energy or power. In ALBATROSS, the final characteristics of the battery pack and module are still to be defined, since although the developed thermal management system allows for higher power and energy specifications, it is still not clear how this will affect its life. The chosen cells are more suitable for applications where the power does not exceed 0.2 times their energy capacity (e.g., the rated energy capacity would provide 5 hours of operation at rated power).

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WP5 - Dismantling, Second life, Re-use and Recycle

- **Thermal management:** for second life applications it becomes crucial to consider the thermal management of the battery, since as the internal resistance of the cells rises, also the heat generated in the cells increases. The cooling system design in ALBATROSS can be reused under different configurations, given that each module has its own inlet and outlet of the cooling circuit. In order to reuse the thermal circuit, the orientation of the battery pack/modules should be similar to its design for the EV, as its working possibilities with a vertical deployment have not been tested yet. The orientation deployment of the battery may be a space limitation to consider, if the existing thermal management system is to be reused.

Overall, each of the different possibilities that appears from the match between the viable applications and available applications, should be economically assessed to choose the best option. This economic evaluation will be done using a scenario to be further explored, where a module will be connected to an inverter simulating an energy arbitrage application of some small consumer. All the assumptions for the economic evaluation are shown in Table 1.

Table 1. ALBATROSS case study for the economic evaluation.

Configuration	Refurbished battery made from one module
Power	2.5 kW charge and discharge
Energy	3.5 kWh (new)
SOH beginning second life	75%
Expected life (until the end of the second life at 60% SOH)	500 cycles
Application	Residential Time Shifting

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WP5 - Dismantling, Second life, Re-use and Recycle

The first part of the economic assessment is focused on the cost of implementation of the selected configuration for the selected application. The costs considered in the economic evaluation are shown in Table 2. A discount rate of 0% was assumed for annual amortization to simplify the analysis. Since the cost of dismantling the ALBATROSS battery has not yet been calculated, a reference value was used. The scrap value that the battery owner obtained after the first life should be also added to this cost.

A deeper analysis of the cost will be done in a following newsletter, where all the costs related to the disassembly of the battery pack will be analysed.

Table 2. ALBATROSS costs for the economic evaluation.

	Unit Cost	Units	Amortization	Total Cost
Dismantling battery to module level	35.26 €/kWh	3.5 kWh	500 cycles	0.246 €/cycle
Power Equipment	66 €/kW	2.5 kW	10 years	16.5 €/year
Controls & Communication	13 €/kWh	3.5 kWh	10 years	4.55 €/year
System Integration	33 €/kWh			11.55 €/year
Engineering, Procurement and Construction (EPC)	45 €/kWh			15.75 €/year
BATTERY COST			0.246 €/cycle + 48.35 €/year	

Once the costs associated are calculated, the next step is to estimate the revenues for the given application. An optimization process is recommended for calculating the revenues, and therefore an optimization problem was defined and solved for the selected case.
From this economic analysis, the configuration chosen and the application do not seem very profitable to be selected. Moreover, the scrap value (i.e., the price that must be paid to the old owner) of the battery pack has to be subtracted from the mentioned revenues.

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WP5 - Dismantling, Second life, Re-use and Recycle

With the selected configuration, the cost of disassembly of the battery pack is assumed in this stage and not in the recycling stage, as it could happen if the whole battery pack were used without being disassembled. By combining with other applications, like peak shaving or renewables integration, the incomes could improve, thus increasing the profitability of the second life battery.

Table 3. Economic analysis for ALBATROSS case: Energy arbitrage for small consumers

Concept	Value
Annually energy costs without batteries	1815.50 €
Annually energy costs with batteries	1719.03 €
Gross savings	96.48 €
Battery cycle cost	181 cycles * 0.246 €/cycle = 44.53€
Battery equipment yearly amortization cost	1 year * 48.35 €/year = 48.35€
Benefit	96.48 € - 48.35 € - 44.53€ = **3.60 €**

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