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Delivering the 3b generation of LNMO cells for the xEV market of 2025 and beyond

Consolidated requirements for the 3beLiEVe battery pack

Horizon 2020 | LC-BAT-5-2019
Research and innovation for advanced Li-ion cells (generation 3b)
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Revision History

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1	08/09/2020	Michele Gosso, Raffaella Rolli & Maxime Montaru	Initial submission for internal review
2	17/09/2020	Marta Cabello & Marcus Fehse	Check for general content, consistency and style
3	29/09/2020	Maxime Montaru & Nicolas Perdriaux	Complement on requirements on circular economy
4	02/10/2020	Laida Otaegui, Marta Cabello, Marcus Fehse	First revision
5	12/10/2020	Boschidar Ganev	Final revision

Project Abstract

3beLiEVe aims to strengthen the position of the European battery and automotive industry in the future xEV market by delivering the next generation of battery cells, designed and made in Europe, for the electrified vehicles market of 2025 and beyond. The project activities are focused on three domains:

- Development of automotive battery cells that are highly performant (high energy density, fast charge capability, long cycle life) and free of critical raw materials such as cobalt and natural graphite;
- Development and integration of sensors into and onto the cells to enable smart, adaptive operating strategies and advanced diagnostics in order to extend the useful life of the battery in first and second life applications and improve safety;
- A comprehensive manufacturing approach that is designed from the outset for a circular economy and industrial volumes. This encompasses green manufacturing processes for cell, module and pack, as well as recyclability assessment of the components, and a target lifecycle cost of 90 €/kWh at scale.

The project will deliver two 12kWh-demonstrator battery packs at TRL6 and MRL8. These aim at demonstrating the 3beLiEVe technology performance for applications in light duty (i.e. passenger cars, freight vehicles) and commercial vehicles (i.e. city buses and trucks) in fully electric/plug-in hybrid (BEV/PHEV) configurations.

The strong and complementary consortium of 21 partners from 10 different European countries representing industrial companies, SMEs, RTOs and academia is coordinated by AIT Austrian Institute of Technology. 3beLiEVe is scheduled to run from January 1st, 2020 to June 30th, 2023, for a total duration of 42 months and has received funding from the European Union's H2020 research and innovation programme under Grant Agreement no. 875033. A full list of partners and funding can be found at: https://cordis.europa.eu/project/id/875033.

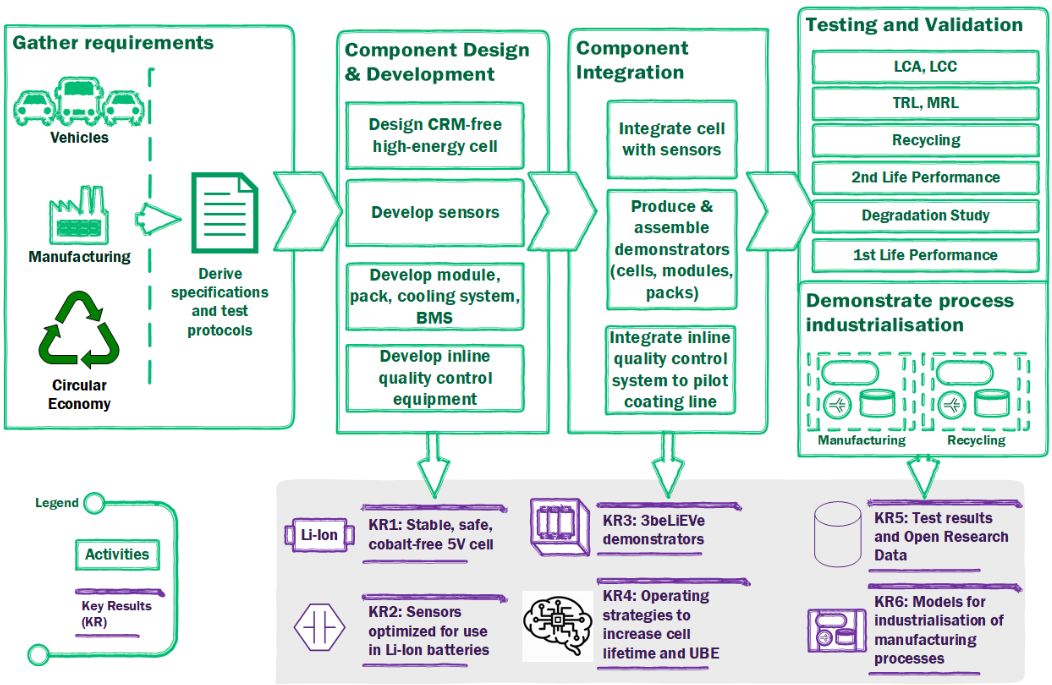

Figure 1: Overview of major 3beLiEVe project steps

Executive Summary

Batteries are widely considered to be one of the key enabling technologies of the electric mobility and renewable energy revolutions, both of which are needed to bring global greenhouse gas emissions down to levels compatible with the Paris Agreement. For Europe, research, innovation and production of batteries also represent an industrial, technological and economic opportunity. The batteries of the future are not only high-performing and safe, they are also sustainable, low-cost, and ready for mass-manufacturing. To this end, they must meet a wide range of requirements that go beyond the functional requirements for first use.

This document consolidates the requirements for the 3beLiEVe demonstrators (cells, modules, battery packs). These come from three different sources: the requirements contained in the LC-BAT-5-2019 call, under which this project has been funded (described in section 2.1); the requirements for the reference vehicles, given by the two vehicle OEMs represented in this project (section 2.2); and the requirements stemming from considerations aiming to design demonstrators and technology that are compatible with a circular economy, which cover second life and recycling (section 2.3).

The requirements are also summarized in tabular form in the annex.

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List of abbreviations

Acronym / Short Name	Meaning
AC	Alternating Current
BESS	Battery Energy Storage System
BEV	Battery Electric Vehicle
BMS	Battery Management System
BOL	Beginning of Life
BP	Battery Pack
CAPEX	Capital Expenditure
CD	Charge Depletion
CRE	Commission de Régulation de l'Énergie
DC	Direct Current
DOD	Depth of Discharge
DSO	Distribution System Operator
EOL	End of Life
EPA	Environmental Protection Agency
FTP75	Federal Test Procedure 75
HWFET	EPA Highway Fuel Economy Test Cycle
kWh	Kilowatt-hour
ICE	Internal Combustion Engine
LCC	Life Cycle Cost
LCOE	Levelized Cost of Energy
MW	Megawatt
NEDC	New European Driving Cycle
NPV	Net Present Value
OEM	Original Equipment Manufacturer
O&M	Operation and Maintenance
OPEX	Operational Expenditure
PHEV	Plug-in Hybrid Electric Vehicle
PV	Photovoltaic
RMS	Root Mean Square
RTS95	Standardized Random Test 95
SFTP-US06	US06 Supplemental Federal Test Procedure
SOC	State of Charge
SOE	State of Energy
SOH	State of Health
SPIDER	Simulation Platform for the Integration of Distributed Energy Resources
WACC	Weighted Average Cost of Capital
WLTC	Worldwide Harmonized Light Vehicles Test Cycle
WLTP	Worldwide Harmonized Light Vehicles Test Procedure
WP	Work Package

1. Introduction

An automotive battery pack must meet a multitude of requirements. Following its first life in an automotive application, and to maximize the benefits derived from the pack, reduce the environmental impact and lower the total cost of ownership, provisions must be made so that the pack or its subcomponents can be used in a second life, before being safely and easily recycled.

The objective of this deliverable is to define the requirements to be considered for the reference passenger and freight vehicles: passenger and commercial vehicles up to 3.5 tons curb weight, from the A-segment to the D-segment, and bus/truck platforms. The activity will define aspects such as available design space for the 3beLiEVe packs, as well as detailed performance, environmental, safety, cooling, and other relevant requirements. In this way, multiple end-use applications are covered, in addition to the requirements of the LC-BAT-5 call.

Furthermore, requirements for manufacturing and circular economy will be defined in order to ensure that the 3beLiEVe battery design is suitable for a cradle to cradle lifecycle, i.e. from mass manufacturing, through 1st life, 2nd life and recycling.

2. Requirements

To obtain a complete set of requirements that the prototypes developed in the project should meet, it was necessary to merge the requirements coming from the LC-BAT-5 call, the vehicle requirements provided by CRF and VOLVO, and the requirements for 2nd life and recycling provided by CEA and SNAM, respectively. These are described in the following subsections.

2.1. LC-BAT-5

This project has been developed under the Horizon 2020 LC-BAT-5 call, which defines a minimum set of requirements. Table 1 shows some of the key desired values for the requirements.

Table 1: LC-BAT-5 Requirements

Topic	Requirements	Desired Values
Energy [kWh]	Energy density on cell level	750 Wh/l
Cost [€]	Cost on pack level	<90 €/kWh
Power [kW]	Fast charging	Min. 2.5C; preferably >3C
Life Expectation	Expected No. of Cycles / Range	2,000 cycles

The main requirement is about energy density at cell level, and the desired value is quite challenging.

Analogously, the cost target on pack level is well below current values, which are two to three times higher than the project target.

The fast charging feature is considered a must today, and the desired values of current rates are in line with what is currently required.

On the same side, life expectation (2000 cycles) is linked to an expected life of 10 years and 200,000 km.

Beyond these core performance and economic requirements, Figure 2 summarizes the other requirements, the quantification and detailing of which is left to the project. We do this in the Annex.

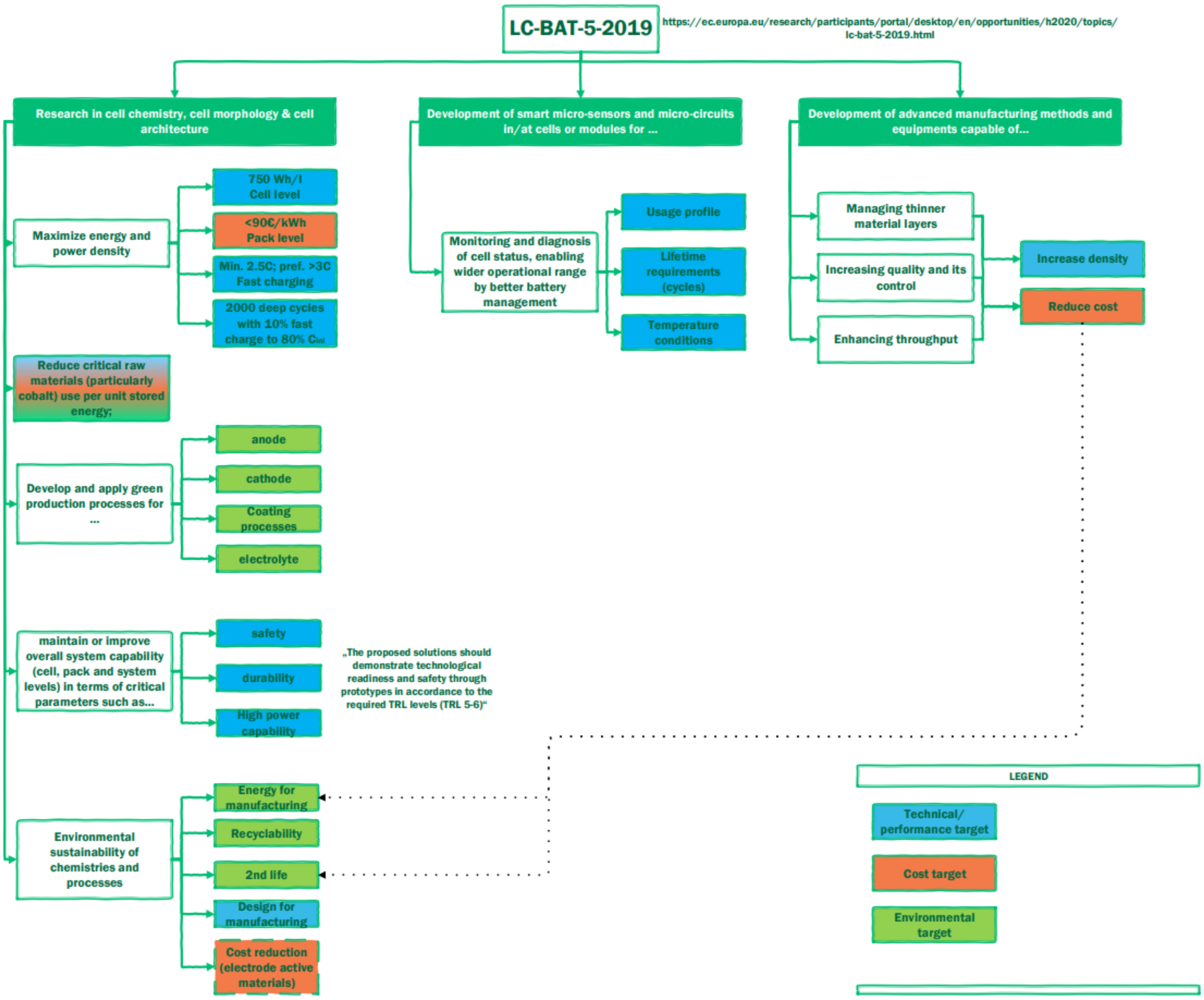

Figure 2: Summary of LC-BAT-5-2019 requirements

2.2. Vehicles

In this section, the requirements for the reference passenger and freight vehicles are defined.

For passenger and commercial vehicles up to 3.5 tons curb weight, possible vehicle typologies as 3beLiEVe application targets are

- City Car class BEV,
- Light Delivery Van BEV vehicle (up to 2 tons),
- Light Delivery Van BEV vehicle (up to 3.5 tons),
- C-segment PHEV,
- C-segment BEV,
- D-segment BEV
- SUV-segment BEV.

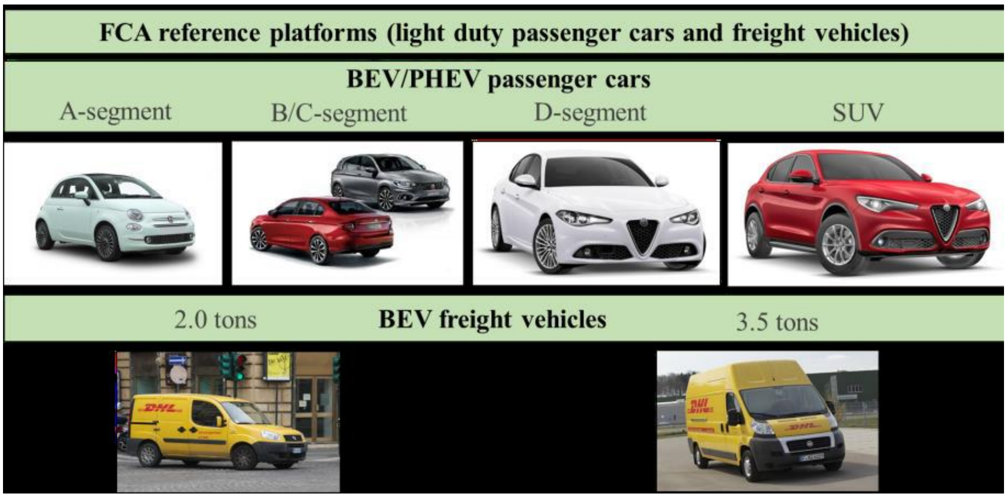

Figure 3: Possible application targets for passenger cars and light duty vehicles

For the practical scope of the project, we need to concentrate on two representative vehicle typologies, and we consider as reference vehicles a C-segment PHEV (Fiat 500X) and a City car BEV (Segment A/B, Fiat 500).

Figure 4: Passenger Reference vehicles. Left: City car BEV (Segment A/B, Fiat 500), right: C-segment PHEV (Fiat 500X)

For bus/truck platforms, the possible application vehicles are identified in Figure *5*.

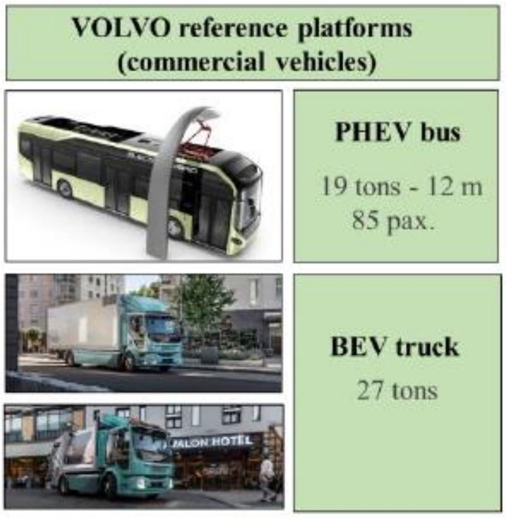

Figure 5: Possible *application* targets for bus/truck platform vehicles

VOLVO, for its development purposes, defined as reference vehicle a 16-tonne truck, depicted in Figure 6.

Figure 6: Bus/truck platform reference vehicle proposed by VOLVO

The vehicle requirements have been grouped into the following topics:

- battery performance
- mechanical
- thermal, connectors
- BMS
- additional information.

With regard to battery performance, desired values for energy, voltage, power, current, application performance, life expectation, and round-trip efficiency have been considered.

Battery Performance	**Energy [kWh]**
	Voltage [V]
	Power [kW]
	Current [A]
	Application Performance
	Life Expectation
	Round trip efficiency

Table 2: Battery Performance parameters description

With regard to mechanical, volume, weight, structural properties and performance specifications have been examined.

<table>
<tr><td rowspan="4">Mechanical</td><td>Volume</td></tr>
<tr><td>Weight</td></tr>
<tr><td>Structural</td></tr>
<tr><td>Structural Performance</td></tr>
</table>

Table 3: Mechanical parameters description

For thermal requirements, operating conditions and storage conditions have been contemplated.

<table>
<tr><td rowspan="2">Thermal</td><td>Operating Conditions</td></tr>
<tr><td>Storage Conditions</td></tr>
</table>

Table 4: Thermal parameters description

Connectors and BMS requirements will be defined in WP4.

<table>
<tr><td colspan="2">Connectors</td></tr>
<tr><td rowspan="2">BMS</td><td>Communication</td></tr>
<tr><td>Additional</td></tr>
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Table 5: Connectors and BMS parameters description

The requirements for the three reference vehicles are discussed in the next sections, and are contained in Annex 1, which is the merger of three different sets of requirements: LC-BAT-5, vehicles and circular economy.

2.2.1. From vehicle specifications to battery specifications

The battery specifications come as an output of the desired vehicle performances, like:

- **Maximum Speed:** (complying with current speed limits…)
- **Acceleration:** time required to reach 50 km/h from standstill and other parameters
- **Rated/Maximum Power:** requirements about the electric motor
- **Driving Range:** related to specific driving missions or profiles
- **Size and weight:** linked to vehicle segment

These parameters act as input into the battery design and result in the following features:

- **Battery Energy** (related to vehicle driving range)
- **Power capability** (related to speed/acceleration)
- **Recharge Time:** time required to recharge the battery pack
- **Battery Life:** how many km or how many charge/discharge cycles the battery can manage without performance degradation or damage
- **Battery size and weight constraints:** linked to available space and maximum allowed weight.

The cell definition process is the result and the meeting of two different paths, as shown in Figure 7.

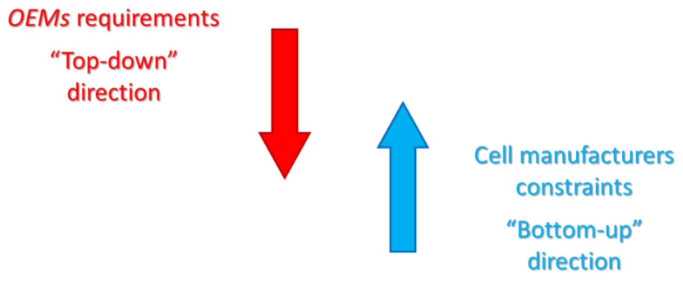


Figure 7: Top-down and bottom up path for battery requirements definition

2.2.2. Reference driving cycle for applications

A simulation of the vehicle (with conventional, hybrid or pure electric powertrain) following standard driving cycles (WLTP, NEDC, FTP75, HWFET, SFTP-US06, RTS95, …) and user defined cycles, provides performances and fuel/electrical energy consumption estimations.

In the following picture, an example of input and output results of a vehicle simulation is provided. A mathematical model of a target vehicle following a specific cycle, allows transforming the cycle's speed profile into the corresponding electrical power demand.

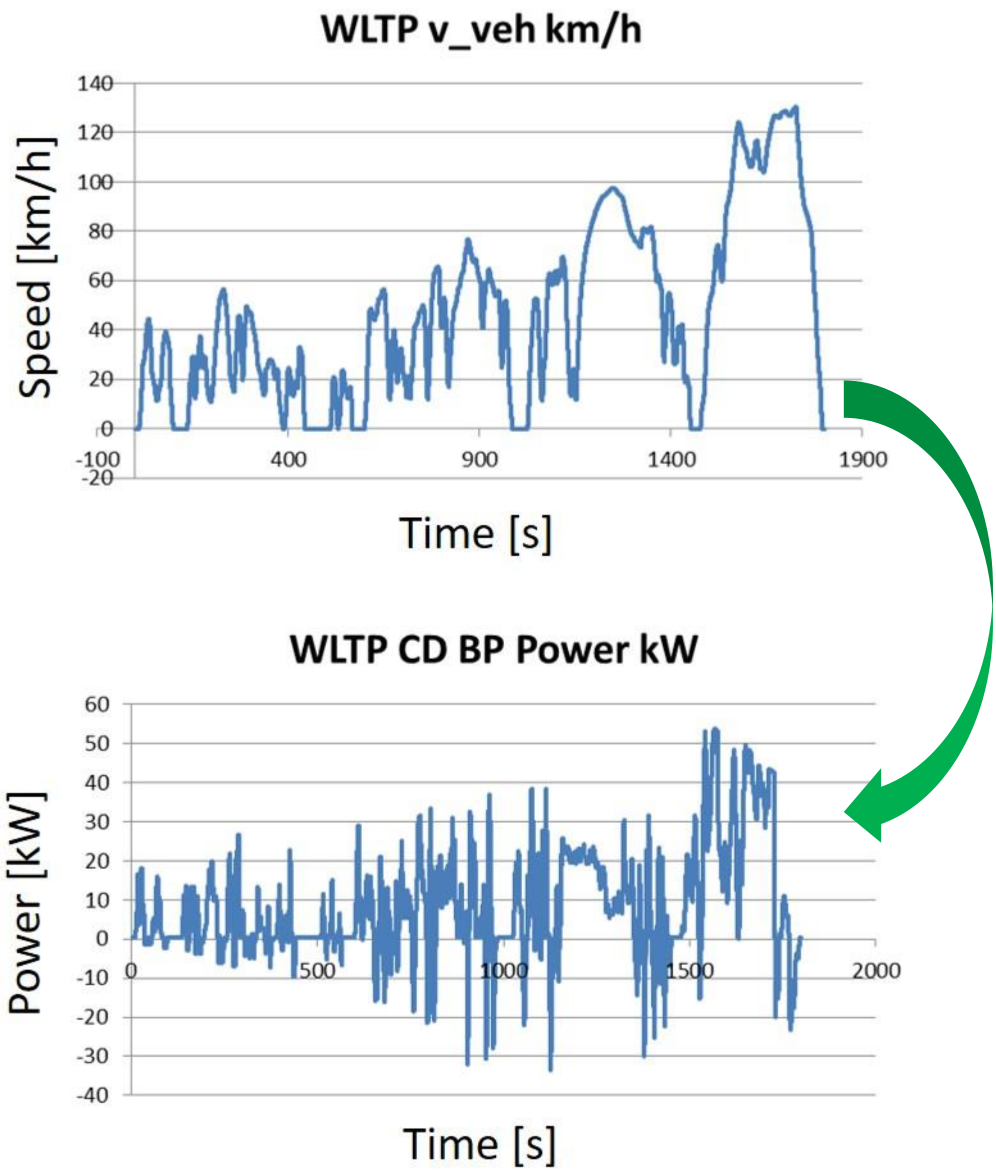


Figure 8: From driving cycle to power profile through vehicle simulation

For a large collection of simulation results, a tailored representative cycle will be chosen for the project scope.

2.2.3. C-segment PHEV requirements

From an energy point of view, we consider that the battery reaches the End of Life (EOL) condition when only 80% of initial usable energy is still available. For PHEV Fiat 500X we want to guarantee any time (and therefore also at the End of Life) 4.6 kWh of usable energy, corresponding to 5.8 kWh of usable energy at the Beginning of Life (BOL).

For PHEV application, only a certain amount (typically 75-80%, corresponding to a Charge Depletion SOC window from 100 to 20-25%) of the installed energy is considered usable, in order to extend the life of the battery pack. Therefore, the 5.8 kWh of usable energy at the BOL requires 7.2 kWh of installed energy.

For the battery system the desired voltage range is 260-400 V, while for the modular pack, the maximum module voltage has to be not higher than 60 V DC to be compliant with voltage class A limits (maintenance, service and easy disassembly for second life and/or recycling).

Peak Discharge Power (10 s) is requested to be 75 kW (10 s power required at 40% SOC at temperatures between 25° and 50°C), and continuous discharge power is requested to be 45 kW.

The continuous charge - plug-in charging power, which is the power requested when the vehicle is connected to the grid for external charging, is requested to be 6.6 kW (@240 V / 30 A). This value is not related to the charging rates applied to the battery pack when the charge occurs during vehicle driving conditions.

The estimated pack RMS power is 11.5 kW, and it is an average between NEDC and WLTC Class 3 Duty cycles. The requested energy throughput before EOL is 21 MWh, and it comes from combination of charge depleting mode (ICE off) and charge sustaining mode (HEV).

Calendar life is required to be 10 years (@ 30 °C, 100% SOC and 80% of initial capacity).

Target weight for the battery pack is 95 kg, and structural performance regulations are based on UN-ECE R100.

The operating temperature range is requested to be -10 - 55 °C for discharge, and 0 - 45 °C for charge.
The storage temperature range is requested to be -20 - 55 °C.

More information and the values of all the requirements defined for C-segment PHEV (Fiat 500X) are shown in Table 6 and Annex 1.

Table 6: Requirements for C-segment PHEV Fiat 500X (see also Annex 1)

Specifications / Requirements	**Desired Values**
Host Application / Battery Type	PHEV (Fiat 500X)
Nominal Energy at Beginning of Life (Battery System)	7,2 kWh
Usable Energy at Beginning of Life (Battery System)	5,75 kWh
Usable Energy at End of Life (Battery System)	4,6 kWh
Nominal Voltage (Battery System)	350-360 V
Voltage Range - Full Performance (Battery System)	260 to 400 V
Nominal and Voltage Range (Modular Pack)	<60 V
Peak Discharge Power (2 s) - BOL	85 kW
Peak Discharge Power (10 s) - BOL	75 kW
Continuous Discharge - BOL	45 kW
Peak Charge Power (2 s) - BOL	50 kW
Peak Charge Power (10 s) - BOL	40 kW
Continuous Charge - BOL	6 kW
Continuous Charge - Plug-in Charging	6.6 kW (@240 V / 30 A)
Continuous Charge - Fast Charge - SOC range and time	24 kW
Cold Crank Discharge Power at (-30°C)	3.75 kW (for 0.5 s)
Duty cycles	WLTC Class 3 (Charge Depletion+Charge Sustaining)
Expected No. of Cycles / Range in Charge Depletion Mode	1,000 cycles / 80% SOC 9,2 MWh
Expected No. of Cycles / Range in Charge Sustaining Mode	150,000 cycles / x SOC 11,75 MWh
End of Life	80% of initial capacity
Calendar Life	10 years
Pack dimensions (LxWxH; in mm)	850 x 390 x 190 mm
Battery Pack Weight [kg]	95 kg
Typical Operating Temperature - Discharge (min, max)	-10 to 55 °C
Typical Operating Temperature - Charge (min, max)	0 to 45 °C

2.2.4. City car BEV (segment A/B) requirements

Starting from the consideration that the battery reaches the End of Life (EOL) condition when only 80% of initial usable energy is still available, for city car BEV the 36 kWh of usable energy requested at the EOL corresponds to 45 kWh of usable energy at the Beginning of Life (BOL).

For this application, the usable SOC window amounts to 90% and ranges from 95% to 5%.

For the battery system, the desired voltage range is 300-400 V for full performance, and 260-400 V for reduced performance; for the modular pack, the maximum module voltage has to be not higher than 60 V DC to be compliant with voltage class A limits (maintenance, service and easy disassembly for second life and/or recycling).

Peak Discharge Power (10s) at BOL is requested to be 100 kW (10s power required at 40% SOC at temperatures between 25° and 50 °C) and continuous discharge power at BOL is requested to be 70 kW.

Continuous charge - plug-in charging power is requested to be 22 kW (@380 V / 32 A).

The estimated pack RMS power is 8 kW, from WLTC Class 3 Duty cycles.

The requested energy throughput before EOL is 45 MWh, entirely coming from charge depleting mode.

Calendar life is required to be 15 years (@ 30 °C, 100% SOC and 80% of initial capacity).

Target weight for the battery pack is 300 kg, and structural performance regulations are based on UN-ECE R100.

Operating temperature range is requested to be -25 - 55 °C for discharge, and 0 - 45 °C for charge.
Storage temperature range is requested to be -20 - 55 °C.

More information and the values of all the requirements defined for for the City car BEV - segment A/B, are shown in Table 7 and Annex 1.

Table 7: Requirements for City car BEV – segment A/B (see also Annex 1)

Specifications / Requirements	Desired Values
Host Application / Battery Type	BEV (Segment A/B)
Nominal Energy at Beginning of Life (Battery System)	50 kWh
Usable Energy at Beginning of Life (Battery System)	45 kWh
Usable Energy at End of Life (Battery System)	36 kWh
Nominal Voltage (Battery System)	350-360 V
Voltage Range - Full Performance (Battery System)	300 to 400 V
Nominal and Voltage Range (Modular Pack)	<60 V
Peak Discharge Power (2 s) - BOL	120 kW
Peak Discharge Power (10 s) - BOL	100 kW
Continuous Discharge - BOL	70 kW
Peak Charge Power (2 s) - BOL	150 kW
Peak Charge Power (10 s) - BOL	120 kW
Continuous Charge - BOL	100 kW
Continuous Charge - Plug-in Charging	22 kW (@380 V / 32 A)
Continuous Charge - Fast Charge - SOC range and time	100 kW
Cold Crank Discharge Power at (-30°C)	N/A
Duty cycles	WLTC Class 3
Expected No. of Cycles / Range in Charge Depletion Mode	1000 cycles / 90% SOC 45 MWh
Expected No. of Cycles / Range in Charge Sustaining Mode	N/A
End of Life	80% of initial capacity
Calendar Life	15 years
Pack dimensions (LxWxH; in mm)	1500 x 1100 x 150 mm
Battery Pack Weight [kg]	300 kg
Typical Operating Temperature - Discharge (min, max)	-25 to 55 °C
Typical Operating Temperature - Charge (min, max)	0 to 45 °C

2.2.5. 16-tonne truck requirements

For VOLVO the targeted vehicle is a 16-ton full electric distribution truck. The detail specification of the battery pack is shown in Table 8. The Volvo FL Electric is launched recently and designed for urban delivery and communal service. The electric range of the vehicle is range up to 300 km. The truck will have an electric motor with a top performance of 185 kW, and a regular performance of 130 kW. Energy storage will be covered by 2 to 6 lithium-ion battery packs, with a 100 to 300 kWh capacity.

For commercial vehicle the nominal operating voltage range is 600 V. The desired battery should fulfil the power requirement of the electric machines installed in the vehicle. Usually, single battery pack hardly fulfils the requirement of vehicle; therefore, multiple battery packs are generally needed for commercial electric vehicles.

Table 8 and Annex 1 contain the requirements for Volvo 16-tonne truck.

Table 8: Requirements for 16-tonne track (see also Annex 1)

Specifications / Requirements	Desired Values
Host Application / Battery Type	EV (Volvo truck FL 16 tons)
Nominal Energy	100-300kWh
Nominal Voltage (Battery System)	600V
Voltage Range - Full Performance (Battery System)	500-750V
Nominal and Voltage Range (Modular Pack)	<60V
Continuous Discharge - BOL	100-130kW
Continuous Charge - BOL	22kw(AC)/150kW(DC)
Duty cycles	Volvo dynamic cycle
Expected No. of Cycles / Range	>5000
End of Life	80% of initial capacity
Calendar Life	8-10 years
Pack dimensions (LxWxH; in mm)	1500-1700 x700-800 x200-230mm
Battery Pack Weight [kg]	1000-3000kg
Extreme Storage Temperatures (min, max)	-30 to 60°C

An example of the dynamic cycle for the commercial vehicle is shown in the figure below. This cycle will be the reference point for estimating the lifetime of the pack for the commercial vehicle specified above. Practically, lifetime of the pack would be estimated from the testing on the cell level using this dynamic cycle with downscaling of the current profile according to the cell specification.

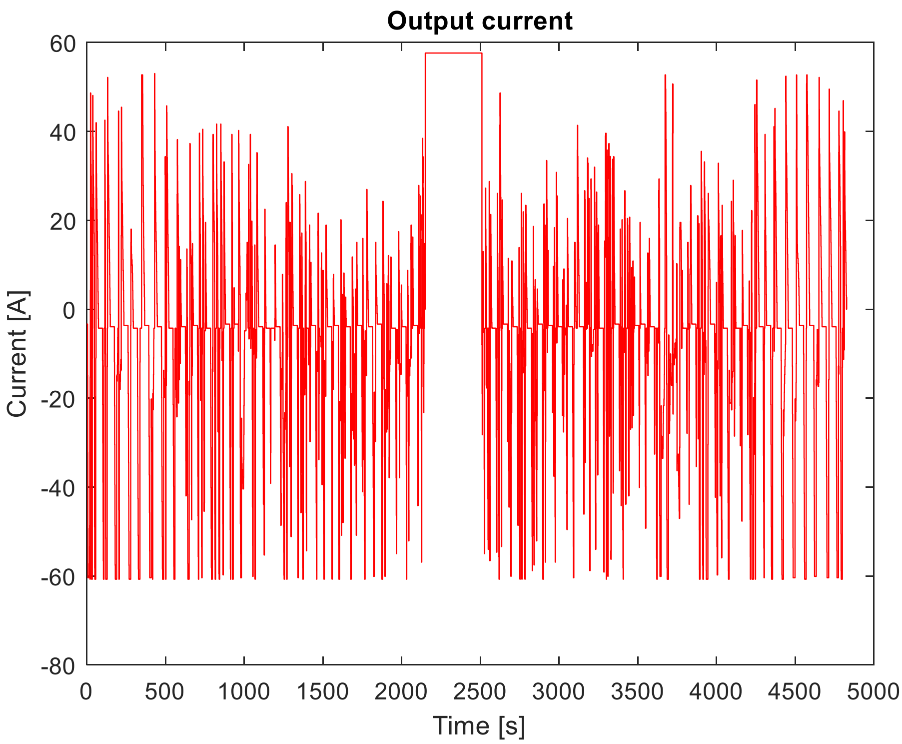


Figure 9: Simulated dynamic driving cycle to current profile for Volvo application

2.3. Circular economy

2.3.1. Overview of Requirements Topics

The concept of a circular economy encompasses all the practices and techniques that make it possible to optimize the use of a resource before planning to recycle it. In the case of electric vehicle batteries, this consists of specifying requirements on different topics such as:

- Mechanical & electrical conception
- Battery performance
- BMS
- Environmental.

The mechanical & electrical conception needs to take into account dismantling constraints during recycling but also the possibility to reuse a module or even a cell inside a pack. Inside a module, the main difficulties for a modular conception are the power connections between cells, which are typically welded, and the cooling component if it is integrated inside the module. At module level, the cooling system needs to be easy to plug and unplug in order to treat the cooling refrigerant during recycling/refurbishing or enable direct reuse by another operating system.

The battery performance needs to be known at end-of-first life at pack level but also at module and cell levels in order to decide if dismantling is of interest for a potential 2nd life. Furthermore, life expectancy should be estimated in 2nd life usage. For 3beLiEVe project, a specific 2nd life use case has been chosen and is detailed in section 2.3.2. To enhance lifetime, it could be possible to increase BESS size in order to reduce power and energy demands during 2nd life usage; an adapted charge protocol for low state-of-health should also be considered.

The battery management system (BMS) ensures that cells inside the pack are used in normal conditions (voltage, temperature, …). It gives also different indicators on pack battery capability needed for the system management in terms of:

- available power on discharge and charge
- state-of-charge (SOC)
- state-of-health (SOH).

Currently, these indicators are designed for electric or hybrid vehicle usage in a narrow validity domain, i.e. for state-of-health greater than 70%. If the same BMS is used, it will be necessary to validate that these indicators are still relevant for 2nd life applications until very low state-of-health, i.e. 50% or lower. The BMS needs also to detect and declare electronic parts failures. To access this information, the communication protocol of the BMS needs to be shared. Otherwise, in the case of module or cell reuse, the delocalization of BMS indicators calculation to the closest could be considered. If indicators or electronic parts are failing, the BMS has to be re-programmed or substituted. This requires, at least, easy access to voltage and temperature sensors or data, and also calibration tests on 2nd life battery. In any case, adaptive indicators algorithms will be well-adapted to take into account ageing performance disparities. In complement to classical functionalities of BMS described previously, the concept of a battery passport is emerging [1]: "It consists on giving an easy access to the assessment of a battery's performance after its first life and analytical tools that provide relevant battery state-of-health data and chemistry, and thus enable the selection and assessment of suitable batteries".

Environmental topics concerns more specifically recycling, which aims to recover a major part of the materials inside a battery pack. This becomes affordable by facilitating the complete dismantling of components and limiting the use of non-recyclable materials such as plastics.

In complement to introduction on electric vehicle battery circular economy, the process flowchart of battery pack at end-of-life illustrates the main steps of routing battery packs at end-of-life (Figure 9). A key point of this flowchart is the diagnosis step, which enables to determine if battery packs, modules and cells are promoted to recycling or second life. This representation helps to identify how different topics listed above can interact with the industrial process towards recycling or 2nd life.

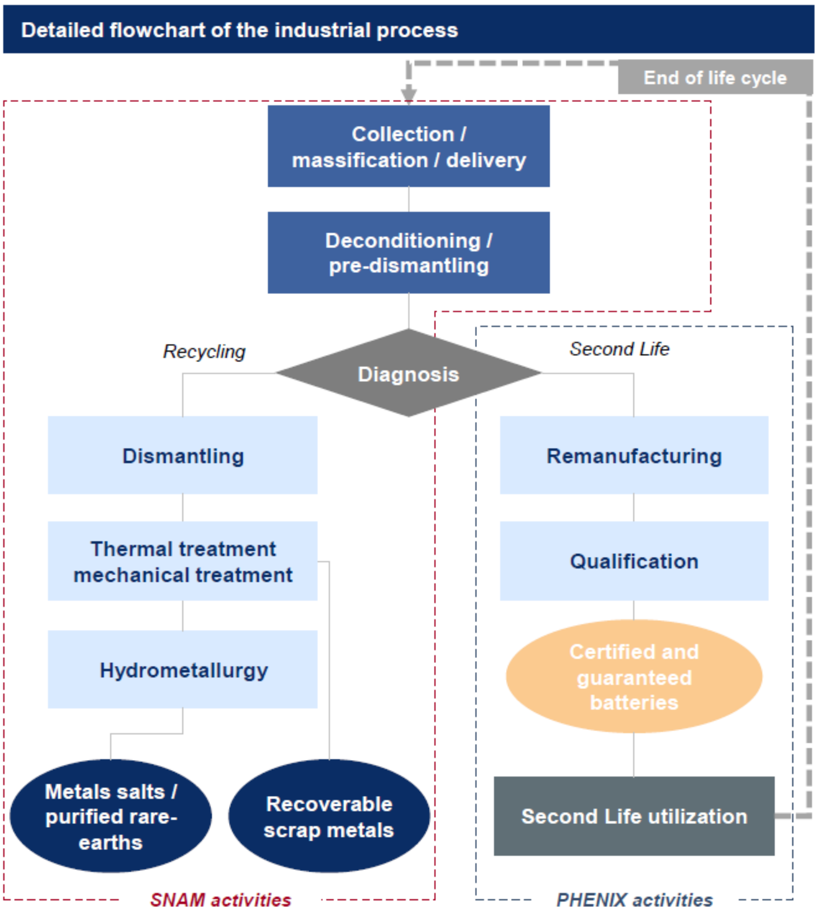


Figure 10: SNAM process flowchart of end-of-life battery pack.

In order to go further on the circular economy requirements, the rest of the report tackles the challenges of battery 2nd life usage, the way of 2nd life usage, the description of the 2nd life use case, and finally the recycling aspects. In each part, an effort is made to refer to the different topics listed above.

2.3.2. Second Life

2.3.2.1. Challenges of 2nd life battery

Despite the obvious attractions of 2nd life use of EV/HEV batteries, the second life battery market poses an equally large number of challenges to which it is necessary to provide answers to make this market viable in the medium / long term. These challenges are grouped here again in three main points:

- the life and safety of second life batteries;
- the disparity in the characteristics of the batteries entering the second life sector;
- competing solutions.

The challenges to be raised nevertheless exist with the collection and testing to sort the batteries, as well as the competitiveness of second life batteries compared to new-marketed batteries with better performance and sharp drop in price (ex. Tesla [2], GM and LG Chem [3]).

Lifetime and safety of second life batteries

Depending on carmaker, second life batteries have a capacity / energy of around 75%; 80% in some cases as for BMW [4], 70% in others as for Endesa [5], or 6 years in other cases as Man for electric buses [6]. However, this simple information does not allow us to forecast the performance of these batteries in terms of service life or safety.

On the first point, we can point out that vehicle batteries used in strictly identical conditions beyond 75% of state of health are very likely to present the phenomenon known as “sudden death”, which consists of significant acceleration of performance degradations. Figure 11 presents a certain number of endurance tests carried out at CEA on different Li-ion batteries and under different aging conditions, highlighting this phenomenon of accelerated degradation rate.

Such degraded performance would imply that the second life of the batteries would have no technical reality and therefore no economic viability.

The CEA has however carried out studies on the aging of used batteries, testing many aging conditions from a level of 85% of SOH. The experimental results as well as the simulations carried out from models established on the basis of these experimental tests, clearly show the technical potential of second life batteries (Figure 11 & 12). Very useful lifetimes have indeed been obtained, from 2 years to more than 10 years depending on the conditions of use in second life.

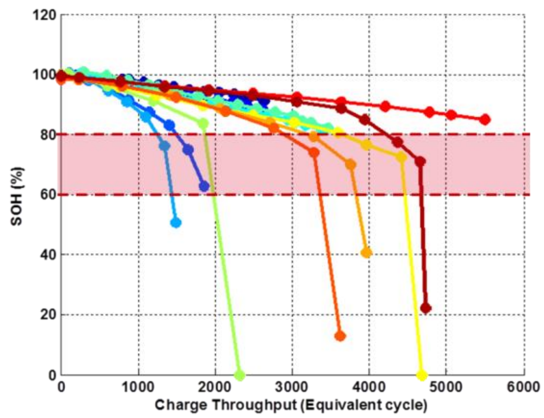


Figure 11: Experimental tests carried out at CEA, highlighting a phenomenon of acceleration of degradation rate around 75% of state of health, when the aging conditions are maintained identical beyond.

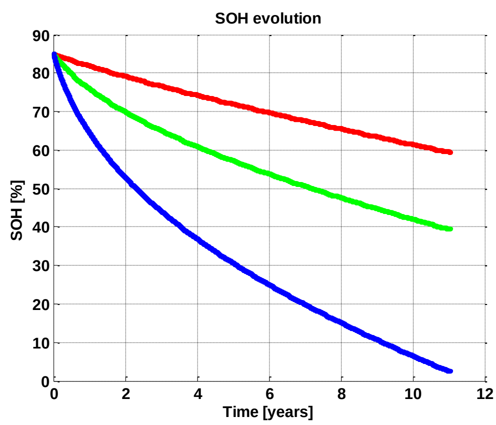


Figure 12: Simulation results obtained by the CEA, the model having been established from aging tests on used batteries removed from an electric vehicle at SOH = 85%.

On the safety side, it is still too early to predict or guarantee the safety of second-life batteries. At this level, however, it can be emphasized that first-life batteries are themselves inherently unsafe. The risks in terms of safety are managed by electronics known as BMS, for Battery Management System, making it possible to avoid any overcharging / under-discharging of cells that could potentially lead to fire starts.

The second life will therefore not be exempt from the need for a BMS. The question raised today is whether the dangerousness will be the same, greater or less than for new batteries. The first elements of response that we can indicate is that it will probably be a function of the mechanisms which led to the degradation of the battery. Certain modes of aging seem in fact to improve the stability of the batteries when others on the contrary tend to deteriorate them. No systematic study is available to date and research is underway.

Another aspect which should be verified is the mechanical state of the pack and modules inside the pack. Indeed, due to ageing degradations, cells are subject to swelling. Depending on importance of this phenomena and module mechanical conception, this could lead to module deformation or leakage of electrolyte or gas. If cell, module and pack have been qualified for first life usage, it could be necessary to check also for 2nd life usage and determine precautions during a dismantling step.

It is expected that the boom in the second life market will lead to new needs in terms of labelling of batteries, so that reconditioned batteries can have specifications guaranteeing performance levels in terms of service life and safety with similar specifications made for first-life batteries such as the standard emanating from the American organization Underwriters Laboratories (UL) [7].

Disparity of the characteristics of second life packs

In terms of state of health, if the criterion of 75% is currently the preferred threshold by default, we know that this criterion will depend among other things on the use of the vehicle (linked to the need for range), and potentially on modes of degradation associated with these conditions. Two batteries of the same SOH will not necessarily have reached this state under the same conditions of use, with potentially therefore very different internal battery states, which could then have a major influence on the performances discussed in the previous section.

Competing solutions

Finally, although the attractiveness of the recovery of second-life batteries is because of their remaining capacity / energy, the industry must not lose sight of competing solutions which will undoubtedly slow down the penetration of second-life batteries in stationary markets.

The first solution in direct competition with the second life is in fact recycling. In Europe since 2006, the law requires automobile companies to recycle at least 50% of the mass of Li-ion batteries [8]. Depending on the possible margins on one side via the recirculation of used batteries, and on the other via the possible recovery of materials, for some of which soaring prices and volatility can be observed, for instance cobalt, the differential will be more or less favourable to the second life sector, and we can expect fluctuations over time.

The other solutions competing in the second life sector are first life batteries sold for the same target markets. We first think of lead, low CAPEX batteries with less favourable OPEX, which will undoubtedly be the main competition for markets where CAPEX is the first decision criterion.

The fact remains that new Li-ion batteries will themselves compete with used older ones, insofar as at least initially, their price will continue to decrease and their performance will increase. The second life is therefore more likely to prevail when both the prices and performance of Li-ion batteries have stabilized.

In terms of costs, forecasts show that the decrease in prices for EV batteries has been spectacular, namely a price divided by three in the 10 years from 2005 to 2015, but which would tend to stabilize by 2020 around

200 € / kWh; 3beLiEVe target is 90 € / kWh for 2030 (cf. section 2.1). Albeit, the 3beLiEVe target is a lifecycle cost, which means that it also factors in revenues from second life and recycling, as opposed to the pure manufacturing cost. In any case, this prospect of stabilization will be a favourable element for the introduction of second life batteries.

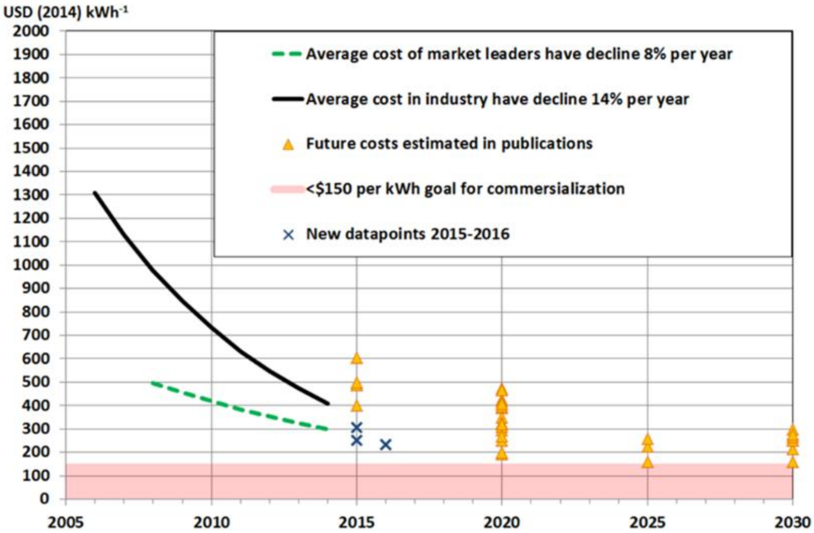


Figure 13: Evolution of the cost of electric vehicle batteries [9].

2.3.2.2. Way of 2nd life usage

To conclude on 2nd life usage, we need to address the different ways of implementing, differentiated into two ways:

- direct reuse of aged packs, without reconditioning;
- the repackaging of aged packs into second life packs.

Note that we will not discuss here the repair of first life packs for reuse in first life, which remains a third option considered, but therefore not including in this case a second life use, in the sense of reuse in a different application from the first.

Usage without reconditioning

The first case of implementation of second life batteries consists in re-using whole packs, without disassembly. This is one of the preferred routes in fact by car manufacturers, so as to avoid reconditioning costs.

The main disadvantage of this approach is that it does not maximize the performance of second life packs, since the overall performance of a pack will potentially be reduced by one or more limiting modules. However, mastery of the cell manufacturing quality on one hand, and of the balancing and thermal management of packs and systems on the other hand, should make it possible to tend towards increasingly homogeneous inter-packaging.

We also emphasize at this level the advantage of car manufacturers in these second-hand markets by their possible mastery of the conditions of use in first life, allowing a more precise estimation of residual performance in knowledge of these conditions. This is particularly highlighted by Renault on its website: “With 93% of users who rent their batteries, Renault remains the majority owner of the batteries of its electric vehicles and can therefore optimize their use and end-of-life phases" [10].

It should be emphasized, however, that even in such an approach, the constitution of large second-life packs, combining a number of used packs, will still require the development of electronics and specific management procedures capable of dealing with the diversity of performance of the packs as a minimum, or even the diversity of the chemistries as discussed above.

This approach is the one adopted in the majority of second life system demonstration or exploitation projects, notably at Nissan [11] [12] [13], GM [14] [15], BMW [16] [17] [18] [19] [20] [21] [22] [23], Mercedes [24] [25] [26], Seat [27] or Audi [28]. Daimler even goes so far as to use EV packs or EV pack modules with the original BMS as well as the original thermal management system enabling performance levels equivalent to first life to be achieved.

Usage with reconditioning

The second approach, complementary to the first, consists of dismantling the packs at the end of first life and then repackaging into new packs for a second life application.

This is in particular the route taken by pack builders such as NISSAN, on the basis of its own packs, or even that of new incoming players such as SNAM, battery recycler and therefore ideally placed in the chain to ensure collection, sorting, and repackaging packs when it makes more sense than recycling them.

The advantages / disadvantages of this approach are the symmetrical advantages / disadvantages of the previous approach, namely here the possibility of maximizing the performance of second life packs by discarding any less efficient or defective module, while having associated costs for dismantling / reconditioning.

This second path being more expensive than the first, it will therefore have to be able to offer additional performance compared to the first, potentially in terms of a second life duration guarantee.

This is the approach adopted in particular in certain projects by Nissan [29] [30] [31] or by BMW with Bosch [32].

Reconditioning is also retained by companies wishing to develop custom storage systems such as Powervault or Box Of Energy [33] [34].

SNAM [35] [36] [37] [38] [39] and Spiers New Technologies [40] [41] [42] also do this for the reconditioning of batteries from batteries at the end of first life and normally ready to be recycled. However, this requires the development of advanced skills and tools for assessing the residual performance of batteries without having access to the history of these batteries.

Dismantling a pack down to cell level is not yet clearly proven to be economically sustainable. First of all, dismantling a 2nd life battery module is of interest if the constituent cells have sufficient state-of-health dispersion. If it’s not the case, it’s more efficient to directly reuse the module itself. Otherwise, the greater the number of cells in a module, the more interesting it is to dismantle the module because a larger proportion can be valorised. However, the actual tendency is to reduce ageing performance dispersion of cells by enhancing cell manufacturing and reducing thermal dispersion inside a pack during usage. Secondly, it requires material and human resources whose cost must be controlled. Finally, a modular mechanical conception that helps to facilitate module refurbishing is useful. However, in the case of pouch cells as the format chosen for 3beLiEVe project, the main difficulties are the power connection between cells, classically welded, and the cooling component if it is integrated inside the module.

2.3.2.3. 2nd life use case: Battery Energy Storage System for massive PV integration on Island

This part presents a 2nd life use case corresponding to the stationary application of PV smoothing and peak shaving. It takes over the work carried out as part of the European project OSMOSE described in public deliverable D7.5 [43]. Due to lack of field data, this use case has been evaluated by simulation considering a fresh battery. During the 3beLiEVe project, these simulations will be performed also by considering a 2nd life battery with its own performance properties.

General description

Massive integration of renewable energy in the electric grid is a challenging task for the next decades and storage options are emerging as tools for increasing flexibility where there is a very high share of intermittently generated renewable energy. The share of intermittent renewable electricity is still relatively low on the European continent on average and grid support capabilities are sufficiently robust to absorb it. However, in the case of some island grids, not connected to mainland electric grids, the share of renewable electricity has already attained a high level. In a certain way, battery energy storage systems (BESS) to support the integration of this intermittently generated electricity can be considered representative of stationary battery usage in future scenarios on the European continent.

Until now, fuel-powered generators account for the major part of electricity generation on non-connected islands, however at an estimated 225 €/MWh on average, this is expensive [44] and the expected rise in CO_2 emission tax will further increase this price. Due to competitive PV prices, more and more PV systems have spread over the last fifteen years. However, since 2008, in order to reduce the risk of network instability, Distribution System Operators (DSO) of French Islands can limit PV injection to 30% of the total production in the whole grid [45]. With the aim of increasing renewable integration and increasing the share of renewable electricity (to 35% in 2018 and to 45% in 2023 at La Reunion), the French energy regulation commission (CRE) has published several calls for tender (AO CRE-ZNI) for PV + storage system since 2011 [46]. Specifically, the 2015 call for tenders specifies that the BESS should help to follow a production plan fixed the previous day and to contribute to an evening consumption peak (Figure 14) [47]. For a PV installation of 1 MW peak capacity, the minimal size of BESS is also specified to be 0.5 MW and 500 kWh for the entire operating life of 25 years. By considering 90% of useable capacity due to SOC limitation and 30% degradation during operating lifetime, the required BESS sizing at the beginning of 2nd life is 0.7 MWp[1] and 0.8 MWh, which corresponds to a P/E ratio of 0.88 P[2], with the aim of providing almost 260 cycles/year[3]. Considering lifetime and cycling requirements, the replacement of BESS pack(s) must be considered in a Life Cycle Cost (LCC) analysis.

[1] MWp represents the maximum peak power that can provide PV installation expressed in MegaWatts.

[2] P-rate corresponds to normalization of storage system power by storage system energy. By analogy to C-rate, the unit is represented by P.

[3] These values vary slightly with BESS sizing at the beginning of 2nd life and available energy during lifetime.

Operating condition & Production plan prevision

In order to sell the injected electricity at the agreed feed-in tariff, the following main constraints must be respected:

- **Power injection profile must be announced in advance**
  - The daily injection profile must be known in advance (the day before, at 16h00 at the latest) by the grid operator and the producer shall respect it (outside a tolerance range of ±5% of the installed PV power (Ppeak), some financial penalties are applied). It has to be noted that the need to announce the profile the day before means that a PV production forecast for the day D+1 is necessary on day D.

  - The producer may update the injection plan 3 times during day D (according to updated weather forecast for instance) but only at precise time-slots defined as follows:
    - before 4h: possible delivery of an updated plan for period [6h00 ; 23h59]
    - before 10h: possible delivery of an updated plan for period [12h00 ; 23h59]
    - before 14h: possible delivery of an updated plan for period [16h00 ; 23h59]

- **PV smoothing: the PV fluctuations must be limited to specific ramp rates**
  The values of maximum rates for power increase and decrease are defined as follows, according to specific periods in the day:

Period in day	Ramp rates to be respected
0h00 – 10h00	Power increase at a rate not greater than 0.6% of the PV installed capacity (Ppeak) per minute Power decrease at a rate not greater than 0.3% of the PV installed capacity per minute
10h00 – 14h00	Power increase and decrease at a rate not greater than 0.3% of the PV installed capacity per minute
14h00 – 19h00	Power increase at a rate not greater than 0.3% of the PV installed capacity per minute Power decrease at a rate not greater than 0.6% of the PV installed capacity per minute

Table 9: 2nd life usage - Maximum ramp rates values for injection to grid.

- **Peak shaving: power injection during peak period**
  In order to contribute at the mitigation of the daily peak power demand, the PV solar plant including the energy storage system must inject energy every day during the two hours of the peak period (19h00 – 21h00) at a minimum power output of 20% of the PV installed capacity (20% of Ppeak). For the energy injected to the grid during the peak period, a bonus equal to 200€/MWh is added to the agreed feed-in tariff.

To sum up, the requested operation is illustrated in figures 14 & 15. Figure 14 illustrates the planning rules to be observed when announcing the power injection profiles, whereas Figure 15 gives an example of PV production and resulting grid injection profile for a typical clear day.

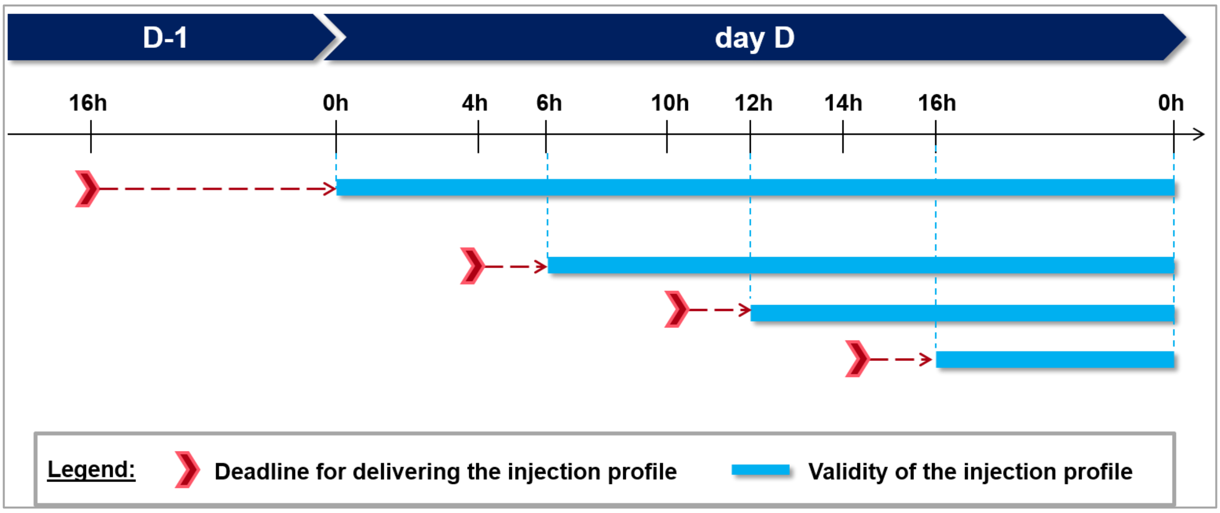


Figure 14: Planning rules for grid injection announcement.

In Figure 15, the illustrative feed-in tariff of 200€/MWh leads to a price of 400€/MWh during peak period due to the peak bonus of 200€/MWh.

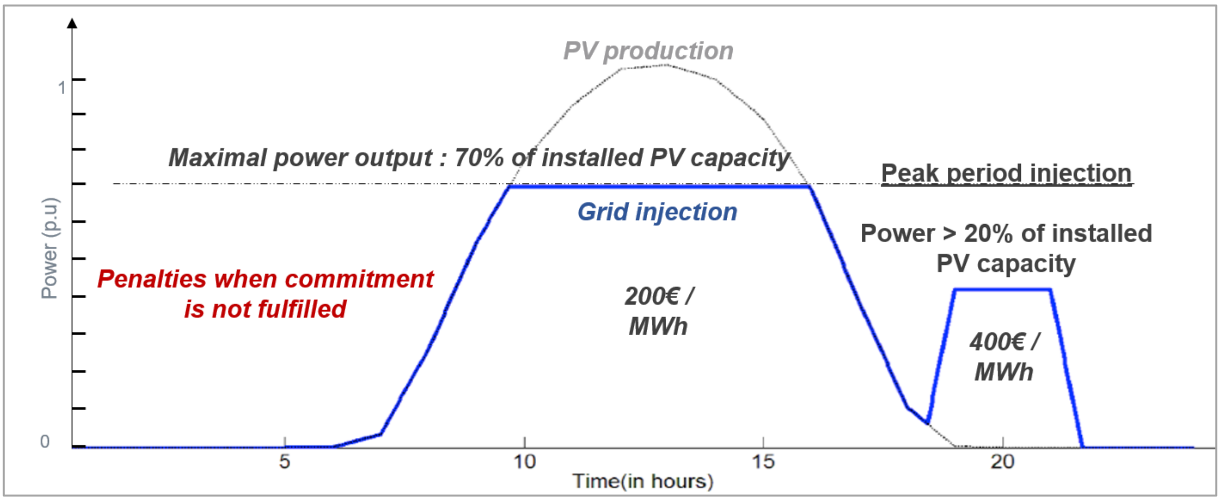


Figure 15: Example of a daily injection profile.

Scenario configuration

The simulation scenario has been set up for a 1 MW PV plant and a BESS composed of Li-ion batteries, whose total storage capacity varies between approximately 800 kWh (minimal size imposed by the call of tenders) and 1300 kWh. The main component configuration parameters are listed in table 10. The PV + BESS system is represented with DC/AC converter in Figure 16. As illustrated in Figure 17, a BESS container is composed of battery racks, power electronics including DC/AC converter and thermal management system. In practise, the container is thermalized around 25°C to guarantee battery lifetime.

PV Plant	Installed capacity (peak power)	1 MWp
	PV degradation rate	0.5% per year
	PV producible dataset	1 year measurement data from a monitored PV plant in Corsica
	PV forecast dataset	1 year historical irradiance forecasts of the Corsica plant location
BESS	Battery technology	Li-ion / app. 6.5 kWh per battery module
	Depth of discharge	90% (from $SOC_{min} = 5\%$ to $SOC_{max} = 95\%$)
	Battery replacement	Replacement when SOH is 70% (for 2nd life, nominal capacity is considered at beginning of 2nd life, i.e. the SOH at end-of-life is 56%).
	Battery capacity	From app. 800 kWh (minimal size imposed) up to app. 1300 kWh / 10 size configurations made of series/parallel modules assembly in coherence with converter DC voltage range
	DC/AC converter power	Up to 700 kVA

Table 10: 2nd life usage - System components setup

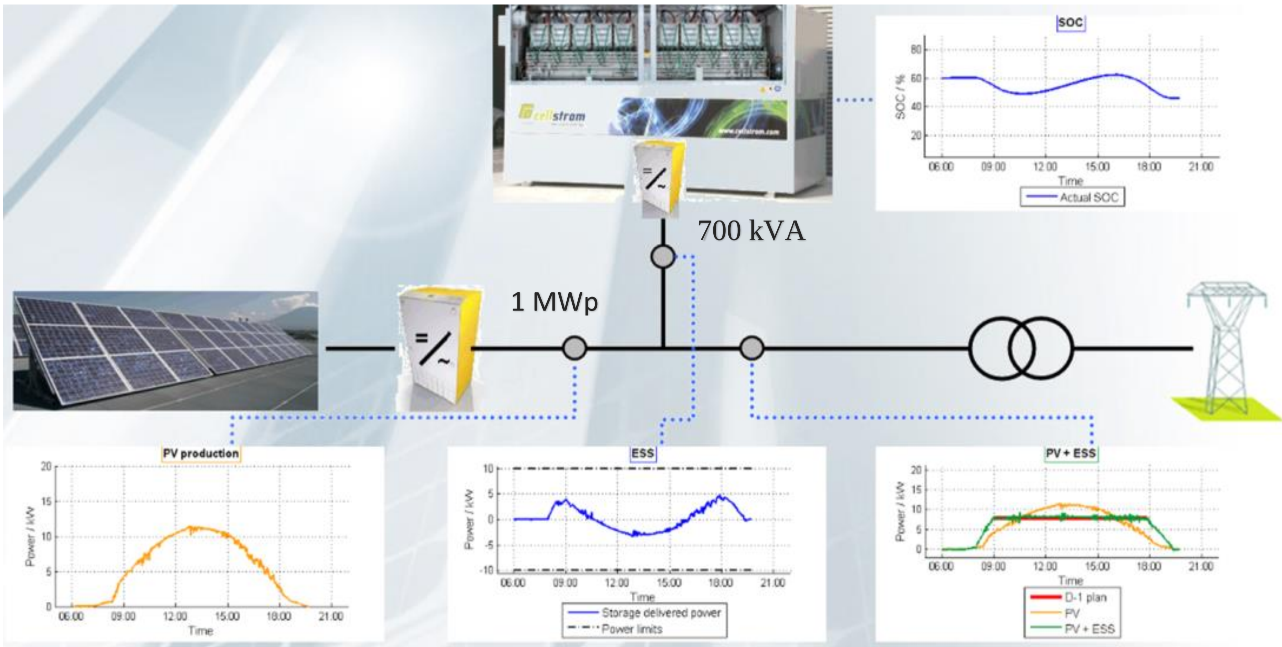


Figure 16: Illustration of PV + BESS system.

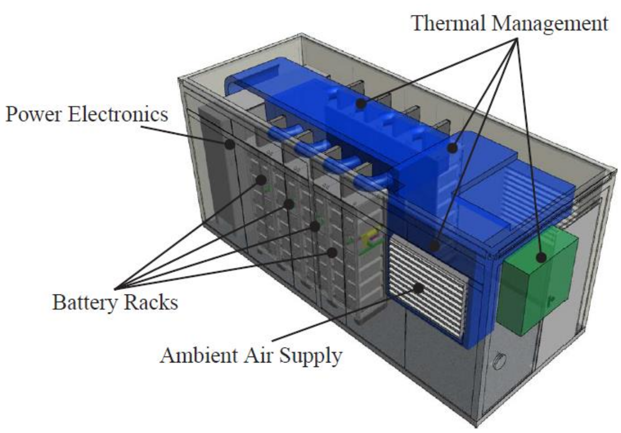


Figure 17: Container storage system Energy Neigbhor. Picture from [48].

Use case simulation tools

The method implemented for BESS optimal sizing relies on a numerical simulation platform called SPIDER (Simulation Platform for the Integration of Distributed Energy Resources), which has been developed at CEA in a Matlab / Simulink environment. In practice, the optimal sizing tool developed in the SPIDER platform enables to define a range of BESS size values for launching the automatic processing of the defined sizing indicators over the entire search area. At the end of this processing, an overview graphic is produced to visualize the variation of the sizing criteria along with the BESS size (as illustrated on Figure 18), as well as synthetic tables containing all values of intermediate and final indicators for each of the simulated configurations.

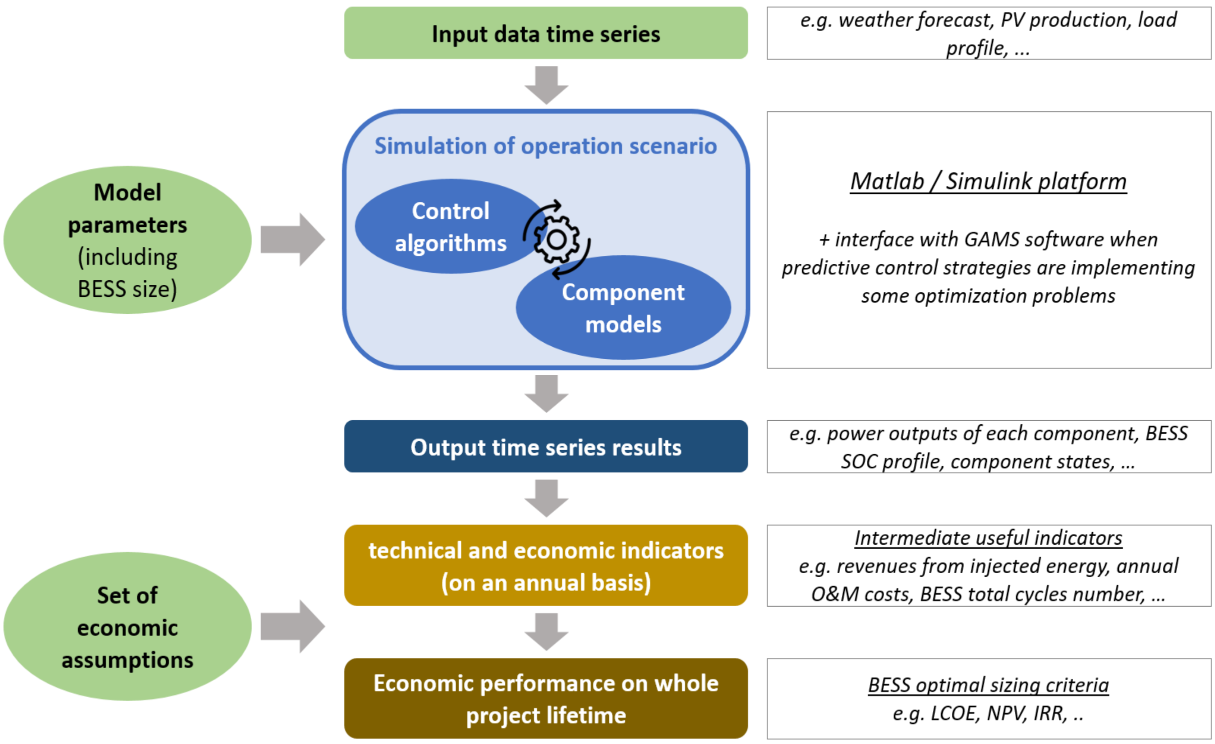


Figure 18: Overview of the deterministic method used for BESS optimal sizing and developed by CEA

Simulation of operation

Figure 19 illustrates the simulation of the operation for a sequence of three particular days of the same year, which has been used for graphical verification of the correct behaviour of the simulated system:

- Day 1 is a sunny clear day with a typical bell-shaped curve for PV production
- Day 2 is a mixed day of alternating sunny and cloudy periods
- Day 3 is a very dull day with a heavy cloud cover.

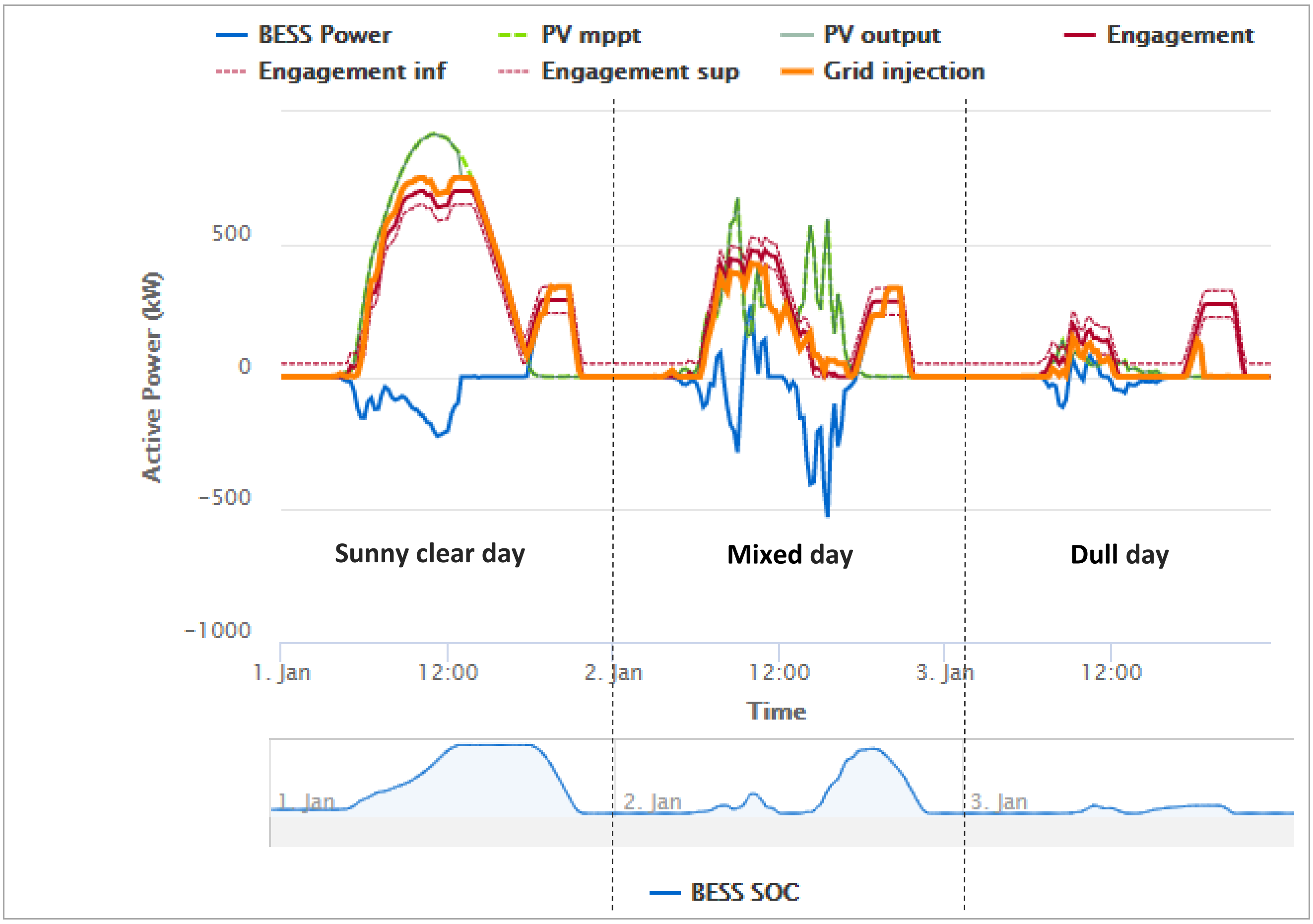


Figure 19: 2nd life usage – Illustration of simulated operation, sequence of three different cases: sunny clear day, mixed day and dull day.

This simulation figure shows that there are significant differences in operation, depending on the type of day.

- Day 1 (sunny) corresponds to the baseline expected behaviour: the PV production which is over the 70% injection limit is used to charge the battery (BESS power <0) during the day and then discharged during the peak period. The engagement is respected within the tolerance of ±5% (on this illustrative example, the injection profile is higher than the announcement, at +5% tolerance, because the PV forecast was a bit pessimistic for this day).

- For day 2 (mixed), it is noticeable that the battery has to discharge at the middle of the day to compensate the lack of PV, thus attempting to respect the engagement and avoid the penalties. The battery is rapidly emptied (low SOC) and nothing can then be done to avoid penalties until there is enough PV production to charge again the BESS. PV production at the end of afternoon enables the battery to charge enough electricity to respect the engagement for the peak period in the evening.

- Day 3 (dull) corresponds to the worst case, for which PV production is so low that the BESS cannot charge enough energy to respect the peak period injection constraints, leading to a high level of penalties.

These noticeable differences emphasize the need for taking into account the full variety of day types when computing the optimal size of the BESS, rather than performing an estimation only on a standard day case or even on the worst case. The use of a full year PV production measurement is therefore of great interest for the optimal size determination.

BESS Sizing Criteria

The economic model of this application, for which the income arises from the sale of electricity at a specified feed-in tariff reduced by any penalties applied when the announced power profile is not respected, leads to the choice of the **NPV (Net Present Value) as the sizing indicator**.

In accordance with the NPV formula (reminded in Equation 1 below):

- The cash flow of year zero (CF_0) is defined as the total initial capital investment, i.e. PV plant and BESS procurement and installation costs,
- The cash flows of the following years (CF_n) are computed as the difference between annual incomes and expenses. The annual income corresponds to the amount paid by the grid operator during the year (sale of electricity reduced by any penalties applied). Annual expenses sum all OPEX costs for the specific year (O&M costs, including replacement costs when necessary).

Net Present Value Determine the present value of all future cash flows generated by a project, including the initial capital investment	$\boldsymbol{NPV} = \sum_{n=0}^{N} \frac{CF_n}{(1+r)^n}$	CF_n : cash flow (difference between incomes and expenses) of year n r : discount rate N : project lifetime

Equation 1: 2nd life usage - NPV indicator used as optimal sizing criteria

The economic assumptions used to compute the NPV are listed in Table 11.

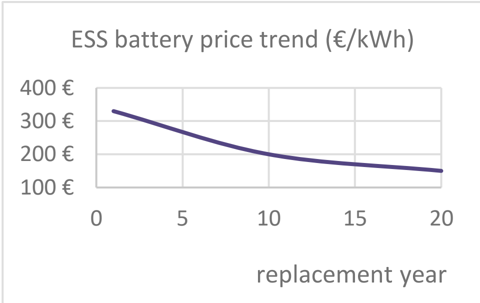
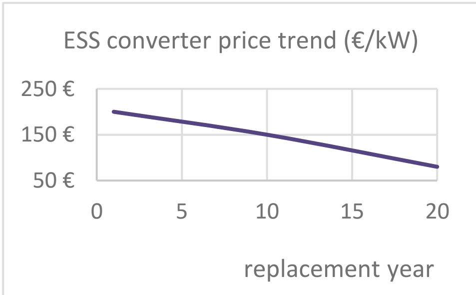
Category	Designation	Value
Project	Project lifetime	20 years
	Discount rate	5 %
Initial investment	PV plant	825 € / kWp
	ESS battery & auxiliaries	350 € / kWh
	ESS converter & auxiliaries	200 € / kW
Electricity sale	Feed-in tariff	200 € / MWh
Operation costs	PV plant	Per year, 3% of initial investment
	ESS battery	Per year, 3% of initial investment
	ESS converter	Per year, 3% of initial investment
Replacement costs	ESS battery lifespan	Until SOH reaches 70% of initial capacity at beginning of 2^{nd} life i.e. 56% of capacity at beginning of life
	ESS battery replacement cost	Decrease trend over the 20 next years 
	ESS converter lifespan	10 years
	ESS converter replacement cost	Decrease trend over the 20 next years 

Table 11: 2nd life usage – Economic assumptions

Optimal sizing reference curve

Figure 20 depicts the NPV values obtained along the BESS size range explored through the simulations repetition process for the reference scenario. This reference scenario is summarized in Table 12.

Influencing factor	Reference scenario
Precision of the BESS efficiency behaviour	BESS model parameters include tables of precise efficiency values varying according to temperature, current and SOC
Degradation of battery capacity due to ageing	BESS model parameters include ageing data enabling the simulation to take into account the battery capacity degradation over time
Technical modelling of the BESS component	In-depth performances battery modelling based on electrical equivalent-circuit equations (EC_model)
Simulation time-step	Time-step of 1 mn
Control algorithms	Advanced control algorithms (including GAMS optimization)
Forecast quality	A standard PV forecast is used

Table 12: 2nd life usage - Reference scenario

Figure 20 shows that the evolution of the sizing indicator as a function of the BESS size does not have an optimum curve shape, but is rather quite linear, with the minimum battery size imposed being the most profitable configuration. It can indeed be demonstrated that, because of the economic framework defined by the call of tenders (cf. further above in this section), **additional battery capacity costs are always higher than the additional incomes generated by a larger storage system**. The optimal size of storage system is always the smallest for this application. In other words, there is no benefit to enlarging BESS capacity for this specific use case. Unlike in other use cases [43], this will unfortunately prevent the sensitivity study from identifying when an influencing factor has an impact strong enough to change the value of the optimal size. Nevertheless, the impact on the sizing criteria (Net Present Value) can be quantified.

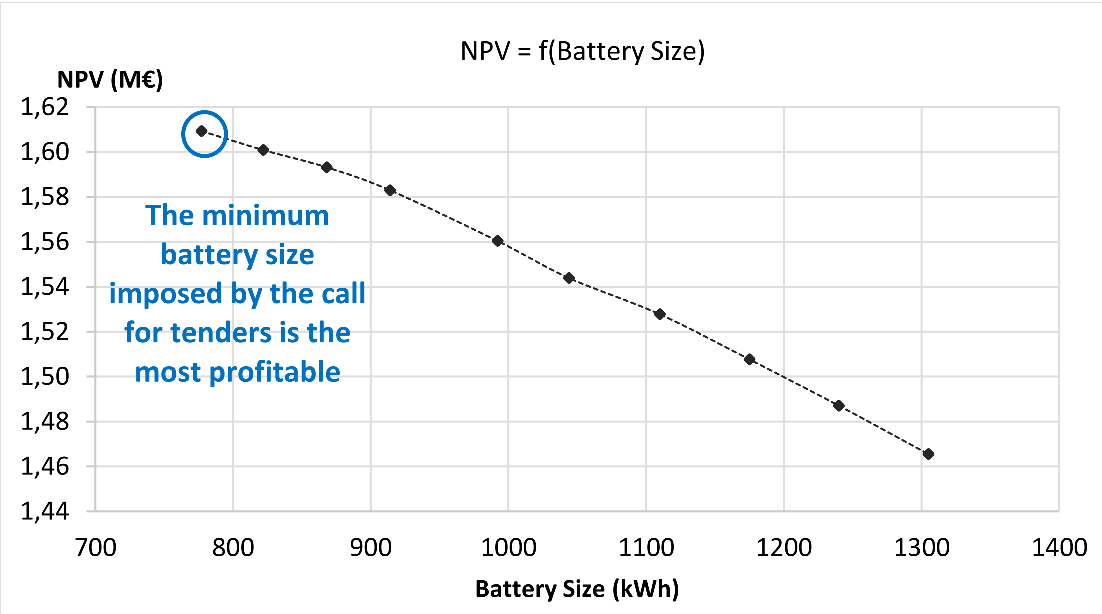


Figure 20: 2nd life usage – Optimal sizing reference curve.

Battery usage analysis of optimal size BESS

As explained in previous sections, solicitations for PV + BESS system and, more particularly for BESS, will vary depending on BESS sizing, sunshine forecasts, real (actual) sunshine, and control algorithms. By considering the usage of the minimum battery size of 777 kWh during a whole year with a one-way efficiency of 91% for the BESS [43], which corresponds to 94% for the converter and 96.8% for the battery, the maximum and minimum attained SOC per day will vary as represented in Figure 21.a. The state-of-charge varies between 5% and 95%. All year, the minimum state-of-charge attained is 5% because the BESS provides peak power demand at the end of the day. However, the maximum state-of-charge is highly variable. The difference between maximum and minimum attained SOC per day gives an indication of maximal daily DOD; distributions of this variable are shown in Figure 22. The DOD attains 90% for 30% of time and it is higher than:

- 75% for 50% of time,
- 45% for 75% of time,
- 20% for 90% of time.

Otherwise, in order to quantify the energy having passed through the battery during a full year, the equivalent cycles number is defined as the ratio between discharged energy throughput and its nominal energy (Figure 21.b). In one year, the battery cumulates 260 equivalent cycles with an almost linear trend.

Finally, in order to define one or several representative profiles for ageing tests, battery solicitations for different days are really different with different power pattern (Figure 23). Globally, the battery is charged during the day, in 5.5h on average, and completely discharged for the 7 p.m. peak consumption, in 3.3h on average. However, the power profile can differ between 5 a.m. and 6 p.m. with continuous demand (Figure 23.b-d) or more intermittent (Figure 23.e-f). In the first case, the average power rate is around 0.15 P in charge with a bump shape, while in the second case, it reaches 0.3 P in charge with peak variation on charge 0.6 P and discharge -0.9 P.

By analysing all the days (Figure 23.a), we can evaluate:

- Maximum charge P-rate : 0.85 P
- Maximum discharge P-rate : 0.9 P
- Discharge P-rate during 7 p.m. peak : 0.2-0.4 P.

Based on this analysis, it is possible to define an average profile with the following sequence: rest 8.5h / complete charge 5.5h / rest 6.7h / complete discharge 3.3h. This profile can be used for cell or pack testing in order to evaluate roundtrip efficiency. Long-rest time can be reduced if self-discharge is limited.

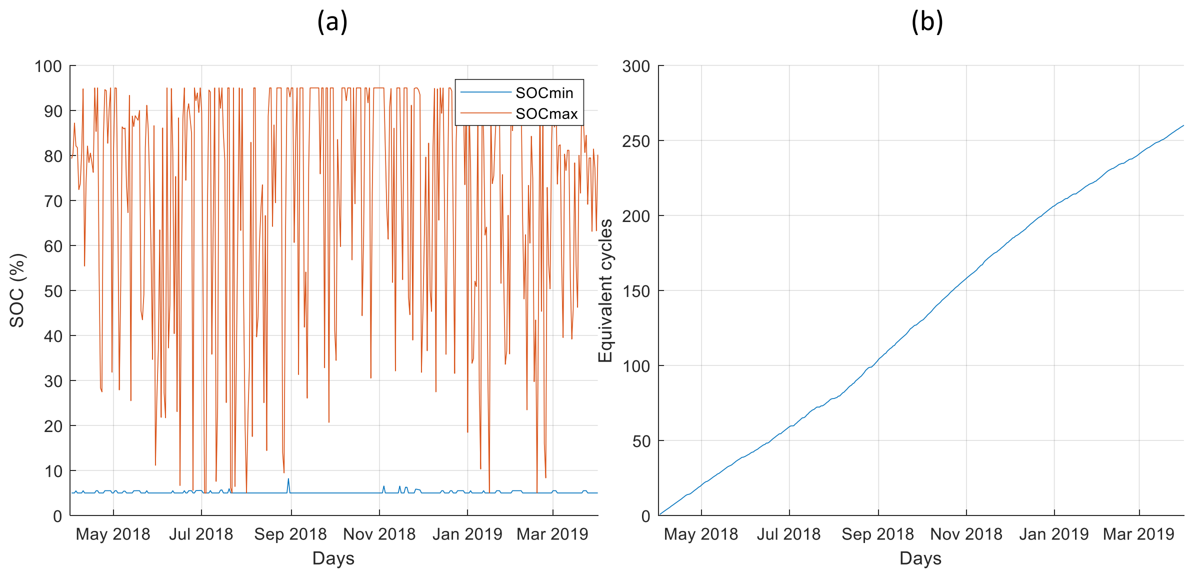


Figure 21: 2nd life usage – (a) Maximum and minimum SOC evolution and (b) Equivalent cycle evolution from 1st April 2018 to 31st March 2019.

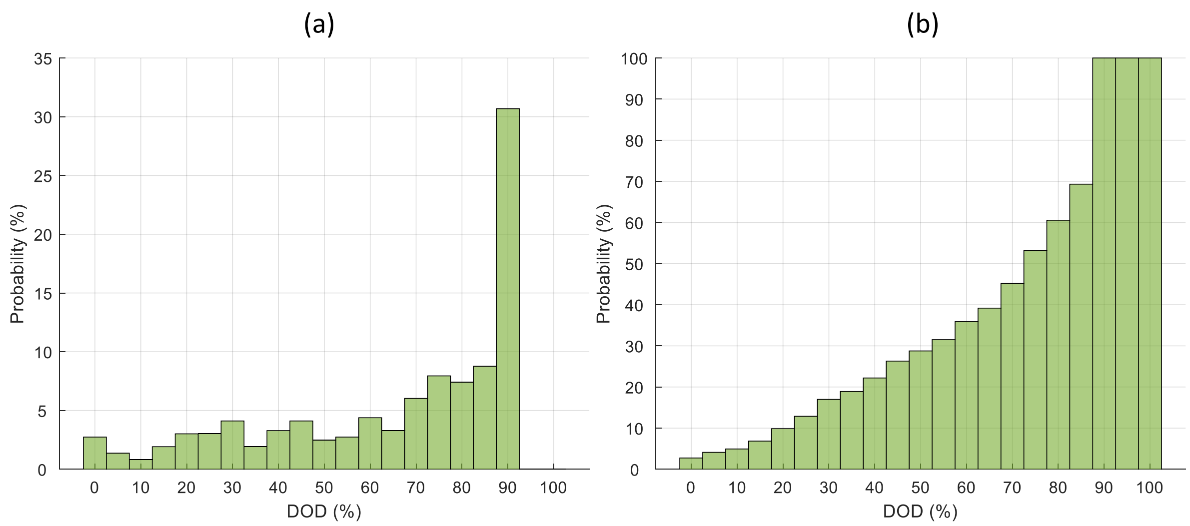


Figure 22: 2nd life usage – Daily DOD repartition during one year of operation: (a) distribution and (b) cumulative distribution.

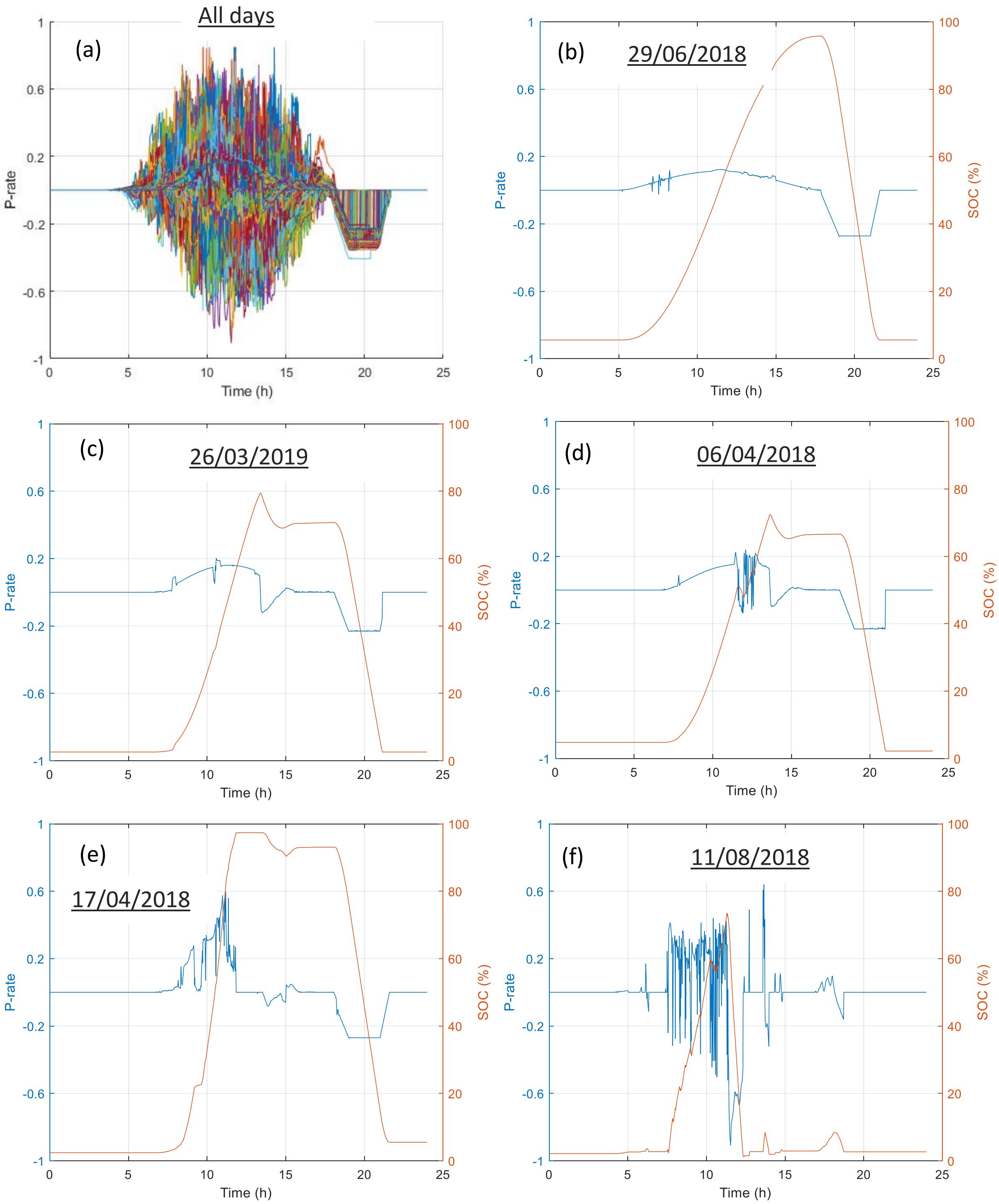


Figure 23: 2nd life usage – Battery power and SOC profiles by day: (a) all superimposed days, (b-f) typical days with different levels of intermittence from low to high level.

2.3.3. Recycling

The recycling requirements derive from two concerns: safety for operators and economical final value of the battery to be recycled.

The first concern means that in order for the batteries to be dismantled safely and with no added risks for the operator, those requirements relate mostly to the structural disassembly of the pack. Although this category of requirements will also be used in the next concern, some of them are directly applicable to the operational safety. For example, sometimes when thermal paste is used to dissipate heat more evenly, when the cells need to be removed from their casing, this action can tear off the cover of the cell, resulting in the loss of the cell and exposed materials. Another example is when metallic inserts are used to reinforce plastics: this voids completely the use of an angle grinder lest sparks be produced and short-circuits happen. Other examples of what to avoid in order to facilitate recycling can include glued or welded surfaces, which require the use of destructive force.

The second concern means that to obtain a good residual value of the battery, it is necessary to avoid losing too much time and expending too much effort in the remanufacturing phase. For example, multiplying the number and specifications of screws, nuts and bolts actually hinders a lot the remanufacturing process, due to the constant need to change tools (e.g. screwdrivers). As the process still relies heavily on manual labour, this constant need to change lowers the OEE (Overall Equipment Effectiveness) of the station. At the edge of this concern is the final recycling efficiency, which also has consequences on the usage of plastics, silicon, graphite etc.

3. Conclusions

The main objective of this deliverable was to consolidate all the requirements that will be applied to the 3beLiEVe demonstrators, in so far as known at time of writing. These stem from three different sources: the requirements given in the LC-BAT-5 call; the requirements from the reference vehicle uses cases; and the requirements pertaining to circular economy. These were described in sections 2.1, 2.2 and 2.3, respectively.

For the reference passenger and freight vehicles requirements, we considered passenger and commercial vehicles up to 3.5 tons curb weight, from the A-segment to the D-segment, and bus/truck platforms. The requirements, tailored to specific vehicle applications, have been defined considering the mandatory target values of the LC-BAT-5 call. From a large collection of possible vehicle applications, we identified three representative case studies:

- A class BEV passenger car
- C class PHEV passenger car
- 16 tonne truck.

The results of this activity were high-level requirements regarding mainly the electrical battery performances, the mechanical properties and the thermal aspects. Other topics, like connectors and BMS, will be considered in detail in Work Package (WP4).

A considerable merging effort has been made to share the fundamental requirements among all the partners involved, verify the feasibility of the solutions identified and reduce the number of possible variants of the basic elements of the battery pack, including mainly the cells.

Regarding the requirements for manufacturing and circular economy, the aim was to ensure that these are captured so that they can be taken into consideration at early stages in the design and manufacturing processes, and to ensure that the project output is compatible with a circular economy in Europe, specifically: avoidance or minimization of critical raw materials, design for ease of use in a second life application, and design for easy and cost-effective disassembly and recycling.

After introducing the main topics of requirements for circular economy of electric vehicle batteries (section 2.3.1), the main challenges of 2nd life battery were presented (section 2.3.2). They concern performance and safety, disparity management and competing solutions. Following this, a detailed second life use case and its requirements were described in section 2.3.2.3. The use case corresponds to a BESS for massive PV integration in an island electrical grid, corresponding to a stationary PV smoothing and peak shaving application. Based on PV+BESS system model developed by CEA in the European project OSMOSE, simulations were realized for different sizes of BESS in order to evaluate operating conditions and derive representative usage profiles and system economics, with NPV as the main economic metric for BESS sizing.

Finally, requirements for recycling were derived from two concerns: safety for operators and economical final value, and were described in section 2.3.3.

The consolidated requirements described in this document are used as a basis for defining specifications and testing protocols for the cells, modules and packs, which are documented separately in the project's *D1.2 Technical specifications and test protocols for the battery* and should inform further development work in this project.

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Annex: Consolidated Requirements

Lifecycle stage	System level	Host Application/Battery Type/So	Topic	Subtopic	Requirements	Desired Values	Note
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Energy [kWh]	Nominal Energy at Beginning of Life (Battery System)	7,2	BoL energies (installed and usable) to satisfy the desired EoL usable energy considering a CD SoC window of 75-80% (from 100 to 20-25%) for usable energy and a loss of capacity of 20% on the life
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Energy [kWh]	Usable Energy at Beginning of Life (Battery System)	5,8	
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Energy [kWh]	Usable Energy at End of Life (Battery System)	4,6	
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Voltage [V]	Nominal Voltage (Battery System)	350-360	as high as possible in the respect of the defined voltage window
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Voltage [V]	Voltage Range - Full Performance (Battery System)	260 to 400	
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Voltage [V]	Voltage Range - Reduced Performance (Battery System)		to be fixed on the basis of the selected solution capability
1st life	Module	PHEV (Fiat 500X)	Battery Performance	Voltage [V]	Nominal and Voltage Range (Modular Pack)	<60	maximum module voltage not hgher than 60 Vdc to be compliant with voltage class A limits (maintenance, service and easy disassembly for second life and/or recycling)
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Power [kW]	Peak Discharge Power (2 s) - BoL	85	nice to have
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Power [kW]	Peak Discharge Power (10 s) - BoL	75	10 s power required at 40% SoC at temps between 25° and 50°C
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Power [kW]	Continuous Discharge - BoL	45	1 min to mantain the max speed in EV Mode (hyp. Starting from 95%SOC to 15%SOC)
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Power [kW]	Peak Charge Power (2 s) - BoL	50	2 s regenerative charge acceptance power possibly required at upper defined % SOC at temps between 25° and 50°C.
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Power [kW]	Peak Charge Power (10 s) - BoL	40	10 s regenerative charge acceptance power possiby required at upper defined % SOC at temps between 25° and 50°C.
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Power [kW]	Continuous Charge - BoL	6	Continuous charge acceptance power at temps between 25° and 50°C.
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Power [kW]	Peak Discharge Power and Duration (2s) - EoL	85	nice to have
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Power [kW]	Peak Discharge Power and Duration (10s) - EoL	75	nice to have
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Power [kW]	Continuous Discharge - EoL	45	nice to have
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Power [kW]	Peak Charge Power and Duration (2s) - EoL	50	nice to have
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Power [kW]	Peak Charge Power and Duration (10s) - EoL	40	nice to have
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Power [kW]	Continuous Charge - EoL	6	nice to have
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Power [kW]	Continuous Charge - Plug-in Charging	6.6 (@240 V / 30 A)	Delivered from On-Board Charger, DC Input to Battery, 30°C
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Power [kW]	Continuous Charge - Fast Charge - SoC range and time	24	for 360 s
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Power [kW]	Cold Crank Discharge Power at (-30°C)	3.75 (for 0.5 s)	values extrapolated (in terms of power) following German Standard LV124
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Current [A]		290	maximum current that system will see for 10 s, limited by wiring and fusing.
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Current [A]	Max. Current in Charge (10 s pulse)	190	maximum current that system will see for 10 s limited by wiring and fusing.
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Application Performance	Duty cycles	WLTC Class 3 (Charge Depletion + Charge Sustaining)	Reference Cycles are NEDC and WLTP Class 3
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Application Performance	Usage Pattern		as external temperatures profile we will apply a Turin-like climate mean values. The number of duty cycles as well as the down time periods per daily routine will be representatives of typical vehicle usage
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Application Performance	Estimated Pack RMS Power [kW]	11,5	Average between NEDC and WLTC
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Life Expectation	Expected No. of Cycles / Range	1,000 cycles / 80% SoC 9,2 MWh	Charge Depleting mode (ICE off)
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Life Expectation	Expected No. of Cycles / Range	150,000 cycles / x SoC 11,75 MWh	Charge Sustaining mode (HEV)
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Life Expectation	Range before EoL (SoC window)		Please explain
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Life Expectation	Calendar Life	10 years	Ok @ 30 °C, 100% SoC and 80% of initial capacity
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Life Expectation	Energy Throughput before EoL [MWh]	21	coming from cells D34 and D35 values. --> See R_ID 28 and 29
1st life	Battery Pack	PHEV (Fiat 500X)	Battery Performance	Round trip efficiency	Energy Efficiency [%]	90%	
1st life	Battery Pack	PHEV (Fiat 500X)	Mechanical	Volume	Pack dimensions (LxWxH; in mm)	850 x 390 x 190 mm	
1st life	Battery Pack	PHEV (Fiat 500X)	Mechanical	Weight	Battery Pack Weight [kg]	95	Target
1st life	Battery Pack	PHEV (Fiat 500X)	Mechanical	Structural	Battery Location within Host Application		Trunk compartment
1st life	Battery Pack	PHEV (Fiat 500X)	Mechanical	Structural	Will the battery be part of the structural integrity of the host application?		No
1st life	Battery Pack	PHEV (Fiat 500X)	Mechanical	Structural	What is the method for securing the battery pack in the host application?		
1st life	Battery Pack	PHEV (Fiat 500X)	Mechanical	Structural Performance	Bending		consider ISO standards as reference - based on customer specifications if needs are different compare to UN-ECE R100
1st life	Battery Pack	PHEV (Fiat 500X)	Mechanical	Structural Performance	Torsion		
1st life	Battery Pack	PHEV (Fiat 500X)	Mechanical	Structural Performance	Fatigue		
1st life	Battery Pack	PHEV (Fiat 500X)	Mechanical	Structural Performance	Vibration	See UN-ECE R100	
1st life	Battery Pack	PHEV (Fiat 500X)	Mechanical	Structural Performance	Drop test		
1st life	Battery Pack	PHEV (Fiat 500X)	Mechanical	Structural Performance	Impact / Crash Resistance		
1st life	Battery Pack	PHEV (Fiat 500X)	Mechanical	Structural Performance	Fastener Shear Test		
1st life	Battery Pack	PHEV (Fiat 500X)	Mechanical	Structural Performance	Intrusion Resistance / Impact		
1st life	Battery Pack	PHEV (Fiat 500X)	Thermal	Operating Conditions	Typical Operating Temperature - Discharge (min, max)	-10 to 55 °C	

Lifecycle stage	System level	Host Application/Battery Type/So	Topic	Subtopic	Requirements	Desired Values	Note
1st life	Battery Pack	PHEV (Fiat 500X)	Thermal	Operating Conditions	Typical Operating Temperature - Charge (min, max)	0 to 45 °C	
1st life	Battery Pack	PHEV (Fiat 500X)	Thermal	Operating Conditions	Extreme Operating Temperatures (min, max)		**Extreme conditions are not relevant**
1st life	Battery Pack	PHEV (Fiat 500X)	Thermal	Operating Conditions	Provision needed for Thermal Management	<6kW	
1st life	Battery Pack	PHEV (Fiat 500X)	Thermal	Operating Conditions	Coolant for Thermal Management	Liquid (option refrigerant)	
1st life	Battery Pack	PHEV (Fiat 500X)	Thermal	Operating Conditions	Flow Rates and Inlet Temperatures for Cooling	<800L/h	
1st life	Battery Pack	PHEV (Fiat 500X)	Thermal	Operating Conditions	Supplementary Information		**N.A.**
1st life	Battery Pack	PHEV (Fiat 500X)	Thermal	Storage Conditions	Storage Temperature (min, max)	**-20 to 55 °C**	**values updated for demonstrator**
1st life	Battery Pack	PHEV (Fiat 500X)	Thermal	Storage Conditions	Extreme Storage Temperaures (min, max)		**extreme conditions are not relevant**
1st life	Battery Pack	PHEV (Fiat 500X)	Thermal	Storage Conditions	Max Allowable Self Discharge (Wh/month)	≤100 Wh / month	
1st life	Battery Pack	PHEV (Fiat 500X)	Connectors	Connectors	High Voltage connector		
1st life	Battery Pack	PHEV (Fiat 500X)	Connectors	Connectors	Low Voltage connector		
1st life	Battery Pack	PHEV (Fiat 500X)	Connectors	Connectors	Fast Charge DC connector		**tbd**
1st life	Battery Pack	PHEV (Fiat 500X)	Connectors	Connectors	Charger connector		
1st life	Battery Pack	PHEV (Fiat 500X)	Connectors	Connectors	DC/DC connector		
1st life	Battery Pack	PHEV (Fiat 500X)	Connectors	Connectors	Manual Service Disconnect		
1st life	Battery Pack	PHEV (Fiat 500X)	BMS	Communication	Host Application Communication / System Protocol		
1st life	Battery Pack	PHEV (Fiat 500X)	BMS	Communication	Number of CAN interfaces		
1st life	Battery Pack	PHEV (Fiat 500X)	BMS	Communication	Baud rate of CAN 1		
1st life	Battery Pack	PHEV (Fiat 500X)	BMS	Communication	ID of CAN 1		
1st life	Battery Pack	PHEV (Fiat 500X)	BMS	Communication	Termination of CAN 1 in battery pack?		
1st life	Battery Pack	PHEV (Fiat 500X)	BMS	Communication	Baud rate of CAN 2		**tbd**
1st life	Battery Pack	PHEV (Fiat 500X)	BMS	Communication	ID of CAN 2		
1st life	Battery Pack	PHEV (Fiat 500X)	BMS	Communication	Termination of CAN 2 in battery pack?		
1st life	Battery Pack	PHEV (Fiat 500X)	BMS	Communication	Wake up by		
1st life	Battery Pack	PHEV (Fiat 500X)	BMS	Communication	DBC		
1st life	Battery Pack	PHEV (Fiat 500X)	BMS	Communication	HVIL		
1st life	Battery Pack	PHEV (Fiat 500X)	BMS				
1st life	Battery Pack	PHEV (Fiat 500X)	BMS	Additional	Supplementary Information		**N.A.**
1st life	Battery Pack	PHEV (Fiat 500X)	BMS				
1st life	Battery Pack	PHEV (Fiat 500X)	Additional Information	Auxiliary Power	Will the Battery Pack Provide Auxiliary Power to other Host Application Functions?		**tbd**
1st life	Battery Pack	PHEV (Fiat 500X)	Additional Information		Supplementary Information		**N.A.**
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Energy [kWh]	Nominal Energy at Beginning of Life (Battery System)	50,0	
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Energy [kWh]	Usable Energy at Beginning of Life (Battery System)	45,0	**BoL energies (installed and usable) to satisfy the desired EoL usable energy considering a CD SoC window of 90% (from 95 to 5%) for usable energy and a loss of capacity of 20% on the life**
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Energy [kWh]	Usable Energy at End of Life (Battery System)	**36**	
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Voltage [V]	Nominal Voltage (Battery System)	350-360	as high as possible in the respect of the defined voltage window
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Voltage [V]	Voltage Range - Full Performance (Battery System)	**300 to 400**	
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Voltage [V]	Voltage Range - Reduced Performance (Battery System)	260-400	to be fixed on the basis of the selected solutiom capability
1st life	Module	BEV (Segment A/B)	Battery Performance	Voltage [V]	Nominal and Voltage Range (Modular Pack)	**<60**	**maximum module voltage not hgher than 60 Vdc to be compliant with voltage class A limits (maintemance, service and easy disassembly for second life and/or recycling)**
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Power [kW]	Peak Discharge Power (2 s) - BoL	120	nice to have
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Power [kW]	Peak Discharge Power (10 s) - BoL	**100**	**10 s power required at 40% SoC at temps between 25° and 50°C**
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Power [kW]	Continuous Discharge - BoL	**70**	1 min to mantain the max speed in EV Mode (hyp. Starting from 95%SOC to 15%SOC)
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Power [kW]	Peak Charge Power (2 s) - BoL	**150**	**2 s regenerative charge acceptance power possibly required at upper defined % SOC at temps between 25° and 50°C.**
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Power [kW]	Peak Charge Power (10 s) - BoL	**120**	**10 s regenerative charge acceptance power possiby required at upper defined % SOC at temps between 25° and 50°C.**
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Power [kW]	Continuous Charge - BoL	**100**	Continuous charge acceptance power at temps between 25° and 50°C.
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Power [kW]	Peak Discharge Power and Duration (2s) - EoL	96	nice to have
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Power [kW]	Peak Discharge Power and Duration (10s) - EoL	**80**	**nice to have**
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Power [kW]	Continuous Discharge - EoL	**56**	**nice to have**
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Power [kW]	Peak Charge Power and Duration (2s) - EoL	**120**	**nice to have**
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Power [kW]	Peak Charge Power and Duration (10s) - EoL	**96**	**nice to have**
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Power [kW]	Continuous Charge - EoL	**80**	**nice to have**
1st life	Battery Pack	BEV (Segment A/B)	Battery Performance	Power [kW]	Continuous Charge - Plug-in Charging	**22 (@380 V / 32 A)**	Delivered from On-Board Charger, DC Input to Battery, 30°C

Lifecycle stage	System level	Host Application/Battery Type/So	Topic	Subtopic	Requirements	Desired Values	Note
1st life	Battery Pack	**BEV (Segment A/B)**	**Battery Performance**	**Power [kW]**	Continuous Charge - Fast Charge - SoC range and time	100	**for 1500 s**
1st life	Battery Pack	**BEV (Segment A/B)**	**Battery Performance**	**Power [kW]**	Cold Crank Discharge Power at (-30°C)	**N/A**	**values extrapolated (in terms of power) following German Standard LV124**
1st life	Battery Pack	**BEV (Segment A/B)**	**Battery Performance**	**Current [A]**		**350**	**maximum current that system will see for 10 s, limited by wiring and fusing.**
1st life	Battery Pack	**BEV (Segment A/B)**	**Battery Performance**	**Current [A]**	Max. Current in Charge (10 s pulse)	400	maximum current that system will see for 10 s limited by wiring and fusing.
1st life	Battery Pack	**BEV (Segment A/B)**	**Battery Performance**	**Application Performance**	Duty cycles	WLTC Class 3	**Reference Cycles are NEDC and WLTP Class 3**
1st life	Battery Pack	**BEV (Segment A/B)**	**Battery Performance**	**Application Performance**	Usage Pattern		**as external temperatures profile we will apply a Turin-like climate mean values. The number of duty cycles as well as the down time periods per daily routine will be representatives of typical vehicle usage**
1st life	Battery Pack	**BEV (Segment A/B)**	**Battery Performance**	**Application Performance**	Estimated Pack RMS Power [kW]	**8**	**Average between NEDC and WLTC**
1st life	Battery Pack	**BEV (Segment A/B)**	**Battery Performance**	**Life Expectation**	Expected No. of Cycles / Range	1,000 cycles / 90% SoC 45 MWh	Charge Depleting mode (ICE off)
1st life	Battery Pack	**BEV (Segment A/B)**	**Battery Performance**	**Life Expectation**	Expected No. of Cycles / Range	N/A	Charge Sustaining mode (HEV)
1st life	Battery Pack	**BEV (Segment A/B)**	**Battery Performance**	**Life Expectation**	Range before EoL (SoC window)	5% - 95%	**Please explain**
1st life	Battery Pack	**BEV (Segment A/B)**	**Battery Performance**	**Life Expectation**	Calendar Life	**15 years**	**Ok @ 30 °C, 100% SoC and 80% of initial capacity**
1st life	Battery Pack	**BEV (Segment A/B)**	**Battery Performance**	**Life Expectation**	Energy Throughput before EoL [MWh]	**45**	**coming from cells D34 and D35 values. --> See requirement ID (R_ID, col. A) 28 and 29**
1st life	Battery Pack	**BEV (Segment A/B)**	**Battery Performance**	**Round trip efficiency**	Energy Efficiency [%]	95%	
1st life	Battery Pack	**BEV (Segment A/B)**	**Mechanical**	**Volume**	Pack dimensions (LxWxH; in mm)	1500 x 1100 x 150 mm	
1st life	Battery Pack	**BEV (Segment A/B)**	**Mechanical**	**Weight**	Battery Pack Weight [kg]	300	Target
1st life	Battery Pack	**BEV (Segment A/B)**	**Mechanical**	**Structural**	Battery Location within Host Application	Under-body	**Under body**
1st life	Battery Pack	**BEV (Segment A/B)**	**Mechanical**	**Structural**	Will the battery be part of the structural integrity of the host application?	No	**No**
1st life	Battery Pack	**BEV (Segment A/B)**	**Mechanical**	**Structural**	What is the method for securing the battery pack in the host application?	by screw	
1st life	Battery Pack	**BEV (Segment A/B)**	**Mechanical**	**Structural Performance**	Bending		**consider ISO standards as reference, based on UN-ECE R100**
1st life	Battery Pack	**BEV (Segment A/B)**	**Mechanical**	**Structural Performance**	Torsion		
1st life	Battery Pack	**BEV (Segment A/B)**	**Mechanical**	**Structural Performance**	Fatigue		
1st life	Battery Pack	**BEV (Segment A/B)**	**Mechanical**	**Structural Performance**	Vibration	See UN-ECE R100	
1st life	Battery Pack	**BEV (Segment A/B)**	**Mechanical**	**Structural Performance**	Drop test		
1st life	Battery Pack	**BEV (Segment A/B)**	**Mechanical**	**Structural Performance**	Impact / Crash Resistance		
1st life	Battery Pack	**BEV (Segment A/B)**	**Mechanical**	**Structural Performance**	Fastener Shear Test		
1st life	Battery Pack	**BEV (Segment A/B)**	**Mechanical**	**Structural Performance**	Intrusion Resistance / Impact		
1st life	Battery Pack	**BEV (Segment A/B)**	**Thermal**	**Operating Conditions**	Typical Operating Temperature - Discharge (min, max)	-25 to 55 °C	
1st life	Battery Pack	**BEV (Segment A/B)**	**Thermal**	**Operating Conditions**	Typical Operating Temperature - Charge (min, max)	0 to 45 °C	
1st life	Battery Pack	**BEV (Segment A/B)**	**Thermal**	**Operating Conditions**	Extreme Operating Temperatures (min, max)	-30 to 60 °C	**Extreme conditions are not relevant**
1st life	Battery Pack	**BEV (Segment A/B)**	**Thermal**	**Operating Conditions**	Provision needed for Thermal Management	<6kW	
1st life	Battery Pack	**BEV (Segment A/B)**	**Thermal**	**Operating Conditions**	Coolant for Thermal Management	Liquid	
1st life	Battery Pack	**BEV (Segment A/B)**	**Thermal**	**Operating Conditions**	Flow Rates and Inlet Temperatures for Cooling	<800L/h	
1st life	Battery Pack	**BEV (Segment A/B)**	**Thermal**	**Operating Conditions**	Supplementary Information		**N.A.**

Lifecycle stage	System level	Host Application/Battery Type/So	Topic	Subtopic	Requirements	Desired Values	Note
1st life	Battery Pack	BEV (Segment A/B)	Thermal	Storage Conditions	Storage Temperature (min, max)	**-20 to 55 °C**	**values updated for demonstrator**
1st life	Battery Pack	BEV (Segment A/B)	Thermal	Storage Conditions	Extreme Storage Temperatures (min, max)		**extreme conditions are not relevant**
1st life	Battery Pack	BEV (Segment A/B)	Thermal	Storage Conditions	Max Allowable Self Discharge (Wh/month)	≤100 Wh / month	
1st life	Battery Pack	BEV (Segment A/B)	Connectors	Connectors	High Voltage connector		
1st life	Battery Pack	BEV (Segment A/B)	Connectors	Connectors	Low Voltage connector		
1st life	Battery Pack	BEV (Segment A/B)	Connectors	Connectors	Fast Charge DC connector		**tbd**
1st life	Battery Pack	BEV (Segment A/B)	Connectors	Connectors	Charger connector		
1st life	Battery Pack	BEV (Segment A/B)	Connectors	Connectors	DC/DC connector		
1st life	Battery Pack	BEV (Segment A/B)	Connectors	Connectors	Manual Service Disconnect		
1st life	Battery Pack	BEV (Segment A/B)	BMS	Communication	Host Application Communication / System Protocol		
1st life	Battery Pack	BEV (Segment A/B)	BMS	Communication	Number of CAN interfaces		
1st life	Battery Pack	BEV (Segment A/B)	BMS	Communication	Baud rate of CAN 1		
1st life	Battery Pack	BEV (Segment A/B)	BMS	Communication	ID of CAN 1		
1st life	Battery Pack	BEV (Segment A/B)	BMS	Communication	Termination of CAN 1 in battery pack?		
1st life	Battery Pack	BEV (Segment A/B)	BMS	Communication	Baud rate of CAN 2		**tbd**
1st life	Battery Pack	BEV (Segment A/B)	BMS	Communication	ID of CAN 2		
1st life	Battery Pack	BEV (Segment A/B)	BMS	Communication	Termination of CAN 2 in battery pack?		
1st life	Battery Pack	BEV (Segment A/B)	BMS	Communication	Wake up by		
1st life	Battery Pack	BEV (Segment A/B)	BMS	Communication	DBC		
1st life	Battery Pack	BEV (Segment A/B)	BMS	Communication	HVIL		
1st life	Battery Pack	BEV (Segment A/B)	BMS				
1st life	Battery Pack	BEV (Segment A/B)	BMS	Additional	Supplementary Information		**N.A.**
1st life	Battery Pack	BEV (Segment A/B)	BMS				
1st life	Battery Pack	BEV (Segment A/B)	Additional Information	Auxiliary Power	Will the Battery Pack Provide Auxiliary Power to other Host Application Functions?		**tbd**
1st life	Battery Pack	BEV (Segment A/B)	Additional Information		Supplementary Information		**N.A.**
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Energy [kWh]	Nominal Energy at Beginning of Life (Battery System)	100-300kWh	**BoL energies (installed and usable) to satisfy the desired EoL usable energy considering a CD SoC window of 75-80% (from 100 to 20-25%) for usable energy and a loss of capacity of 20% on the life. Volvo: 2- 6 battery pack installed in the vehicle.**
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Energy [kWh]	Usable Energy at Beginning of Life (Battery System)		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Energy [kWh]	Usable Energy at End of Life (Battery System)		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Voltage [V]	Nominal Voltage (Battery System)	600V	as high as possible in the respect of the defined voltage window
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Voltage [V]	Voltage Range - Full Performance (Battery System)	500-750V	
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Voltage [V]	Voltage Range - Reduced Performance (Battery System)		to be fixed on the basis of the selected solutiom capability
1st life	Module	EV(Volvo truck FL 16 tons)	Battery Performance	Voltage [V]	Nominal and Voltage Range (Modular Pack)	**<60V**	**maximum module voltage not hgher than 60 Vdc to be compliant with voltage class A limits (maintemance, service and easy disassembly for second life and/or recycling)**
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Power [kW]	Peak Discharge Power (2 s) - BoL		nice to have
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Power [kW]	Peak Discharge Power (10 s) - BoL		**10 s power required at 40% SoC at temps between 25° and 50°C**
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Power [kW]	Continuous Discharge - BoL	**100-130kW**	1 min to mantain the max speed in EV Mode (hyp. Starting from 95%SOC to 15%SOC)
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Power [kW]	Peak Charge Power (2 s) - BoL		**2 s regenerative charge acceptance power possibly required at upper defined % SOC at temps between 25° and 50°C.**
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Power [kW]	Peak Charge Power (10 s) - BoL		**10 s regenerative charge acceptance power possiby required at upper defined % SOC at temps between 25° and 50°C.**
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Power [kW]	Continuous Charge - BoL	**22kw(AC)/150kW(DC)**	Continuous charge acceptance power at temps between 25° and 50°C.
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Power [kW]	Peak Discharge Power and Duration - EoL		nice to have
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Power [kW]	Peak Discharge Power and Duration - EoL		**nice to have**
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Power [kW]	Continuous Discharge - EoL		**nice to have**
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Power [kW]	Peak Charge Power and Duration - EoL		**nice to have**
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Power [kW]	Peak Charge Power and Duration - EoL		**nice to have**
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Power [kW]	Continuous Charge - EoL		**nice to have**
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Power [kW]	Continuous Charge - Plug-in Charging		Delivered from On-Board Charger, DC Input to Battery, 30°C
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Power [kW]	Continuous Charge - Fast Charge - SoC range and time		**for 360 s**
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Power [kW]	Cold Crank Discharge Power at (-30°C)		**values extrapolated (in terms of power) following German Standard LV124**
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Current [A]			**maximum current that system will see for 10 s, limited by wiring and fusing.**
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Current [A]	Max. Current in Charge (10 s pulse)		maximum current that system will see for 10 s limited by wiring and fusing.
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Application Performance	Duty cycles	Volvo dynamic cycle	**Reference Cycles are NEDC and WLTP Class 3**

Lifecycle stage	System level	Host Application/Battery Type/So	Topic	Subtopic	Requirements	Desired Values	Note
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Application Performance	Usage Pattern		as external temperatures profile we will apply a Turin-like climate mean values. The number of duty cycles as well as the down time periods per daily routine will be representatives of typical vehicle usage
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Application Performance	Estimated Pack RMS Power [kW]		Average between NEDC and WLTC
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Life Expectation	Expected No. of Cycles / Range	>5000	Charge Depleting mode (ICE off)
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Life Expectation	Expected No. of Cycles / Range		Charge Sustaining mode (HEV)
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Life Expectation	Range before EoL (SoC window)		Please explain
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Life Expectation	Calendar Life	8-10 years	Ok @ 30 °C, 100% SoC and 80% of initial capacity
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Life Expectation	Energy Throughput before EoL [MWh]		coming from cells D34 and D35 values
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Battery Performance	Round trip efficiency	Energy Efficiency [%]		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Mechanical	Volume	Pack dimensions (LxWxH; in mm)	1500-1700 x700-800 x200-230mm	one pack
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Mechanical	Weight	Battery Pack Weight [kg]	1000-3000 kg	Target
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Mechanical	Structural	Battery Location within Host Application		Trunk compartment
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Mechanical	Structural	Will the battery be part of the structural integrity of the host application?		No
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Mechanical	Structural	What is the method for securing the battery pack in the host application?		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Mechanical	Structural Performance	Bending		consider ISO standards as reference
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Mechanical	Structural Performance	Torsion		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Mechanical	Structural Performance	Fatigue		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Mechanical	Structural Performance	Vibration		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Mechanical	Structural Performance	Drop test		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Mechanical	Structural Performance	Impact / Crash Resistance		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Mechanical	Structural Performance	Fastener Shear Test		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Mechanical	Structural Performance	Intrusion Resistance / Impact		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Thermal	Operating Conditions	Typical Operating Temperature - Discharge (min, max)		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Thermal	Operating Conditions	Typical Operating Temperature - Charge (min, max)		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Thermal	Operating Conditions	Extreme Operating Temperatures (min, max)		Extreme conditions are not relevant
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Thermal	Operating Conditions	Provision needed for Thermal Management		tbd
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Thermal	Operating Conditions	Coolant for Thermal Management		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Thermal	Operating Conditions	Flow Rates and Inlet Temperatures for Cooling		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Thermal	Operating Conditions	Supplementary Information		N.A.
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Thermal	Storage Conditions	Storage Temperature (min, max)	-30 to 60 °C	values updated for demonstrator
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Thermal	Storage Conditions	Extreme Storage Temperaures (min, max)		extreme conditions are not relevant
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Thermal	Storage Conditions	Max Allowable Self Discharge (Wh/month)		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Connectors	Connectors	High Voltage connector		tbd
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Connectors	Connectors	Low Voltage connector		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Connectors	Connectors	Fast Charge DC connector		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Connectors	Connectors	Charger connector		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Connectors	Connectors	DC/DC connector		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Connectors	Connectors	Manual Service Disconnect		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	BMS	Communication	Host Application Communication / System Protocol		tbd
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	BMS	Communication	Number of CAN interfaces		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	BMS	Communication	Baud rate of CAN 1		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	BMS	Communication	ID of CAN 1		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	BMS	Communication	Termination of CAN 1 in battery pack?		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	BMS	Communication	Baud rate of CAN 2		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	BMS	Communication	ID of CAN 2		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	BMS	Communication	Termination of CAN 2 in battery pack?		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	BMS	Communication	Wake up by		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	BMS	Communication	DBC		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	BMS	Communication	HVIL		
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	BMS	Additional	Supplementary Information		N.A.
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	BMS	Additional			
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	BMS	Additional			
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Additional Information	Auxiliary Power	Will the Battery Pack Provide Auxiliary Power to other Host Application Functions?		tbd
1st life	Battery Pack	EV(Volvo truck FL 16 tons)	Additional Information		Supplementary Information		N.A.
1st life	Cell	LC-BAT-5-2019 call	Battery Performance	Energy [kWh]	Energy density on cell level	750 Wh/l	
Whole lifecycle	Battery Pack	LC-BAT-5-2019 call	Additional Information	Cost [€]	Cost on pack level	<90 €/kWh	

Lifecycle stage	System level	Host Application/Battery Type/So	Topic	Subtopic	Requirements	Desired Values	Note
1st life	Cell	LC-BAT-5-2019 call	**Battery Performance**	**Power [kW]**	Fast charging	Min. 2.5C; preferably >3C	Fast charging. Need to clarify whether this should be continuous or peak charging?
1st life	Cell	LC-BAT-5-2019 call	**Battery Performance**	**Life Expectation**	Expected No. of Cycles / Range	2,000 cycles	2000 deep cycles with 10% fast charge to 80% of initial capacity. Need to define "deep" cycle. Also need to determine whether this requirement applies to cell or to pack level. Need to define "fast charge" protocol
Manufacturing	Cell	LC-BAT-5-2019 call	**Additional Information**	**Battery chemistry**	Reduce critical raw materials (particularly cobalt) use per unit stored energy		
Manufacturing	Cell	LC-BAT-5-2019 call	**Additional Information**	**Battery chemistry**	Develop and apply green production processes for anode		
Manufacturing	Cell	LC-BAT-5-2019 call	**Additional Information**	**Battery chemistry**	Develop and apply green production processes for cathode		
Manufacturing	Cell	LC-BAT-5-2019 call	**Additional Information**	**Battery chemistry**	Develop and apply green production processes for coating processes		
Manufacturing	Cell	LC-BAT-5-2019 call	**Additional Information**	**Battery chemistry**	Develop and apply green production processes for electrolyte		If this is applicable (i.e. if "green(er)" production processes are used, it should be documented in D2.2
Whole lifecycle	Cell / Module / Battery Pack	LC-BAT-5-2019 call	**Additional Information**	**Safety**	Maintain or improve overall system capability (cell, pack and system levels) in terms of critical parameters such as safety		Need to operationalize this requirement. Baseline=? How is determination of safety done? In the proposal we wrote that we will reference EUCAR hazard levels. R100 contains flammability tests...
1st life	Cell / Module / Battery Pack	LC-BAT-5-2019 call	**Battery Performance**	**Life Expectation**	Maintain or improve overall system capability (cell, pack and system levels) in terms of critical parameters such as durability		Note: compare with life expectation requirements by OEMs - maybe this requirement is superseded by more specific/detailed requirements. "Improve" means performance (improvement) vs. a BASELINE - to be defined
1st life	Cell / Module / Battery Pack	LC-BAT-5-2019 call	**Battery Performance**	**Power [kW]**	Maintain or improve overall system capability (cell, pack and system levels) in terms of critical parameters such as high power capability		Redundant/deprecated? Is this covered e.g. by R_ID 238 (and other power requirements given by OEMs)? If not, then at least a baseline would make sense here.
Manufacturing	Cell / Module / Battery Pack	LC-BAT-5-2019 call	**Environmental**	**Energy [kWh]**	Energy for manufacturing		Environmental sustainability of chemistries and processes. Presumably: "reduce" energy for manufacturing? But what is the baseline? Need to discuss whether we can do or state something substantial here, or whether to leave this unadressed.
Recycling	Cell / Module / Battery Pack	LC-BAT-5-2019 call	**Environmental**	**Recycling**	Recyclability		Presumably: "improve" recyclability? But what is the baseline? Perhaps we can use materials recovery rates for known chemistries. Perhaps NMC, but which one (811, or other?) . And on what system level? Cell, module, pack?
Whole lifecycle	Cell / Module / Battery Pack	LC-BAT-5-2019 call	**Sensors**	**Application Performance**	Monitor /diagnose cell status/usage profile		Development of smart micro-sensors and micro-circuits in/(at cells or modules for monitoring and diagnosis of cell status, enabling wider operational range by better battery management
1st life	Cell	LC-BAT-5-2019 call	**BMS**	**Life Expectation**	Increase number of cycles that are possible using information from sensors		Need to set a baseline without sensors. Suggestion: WP2/WP3/WP6 should issue a preliminary datasheet on the cells.
1st life	Cell	LC-BAT-5-2019 call	**Sensors**	**Operating Conditions**	Increased tolerance of a wider range of temperature conditions?		Baseline=?
Manufacturing	Cell	LC-BAT-5-2019 call	**Manufacturing & equipment**	**Additional**	Manage thinner material layers to increase density and reduce cost		Baseline=? BG: maybe close this requirement? It's unspecific an our manufacturing/tech concepts don't really focus on this (tbc)
Manufacturing	Cell	LC-BAT-5-2019 call	**Manufacturing & equipment**	**Additional**	Increase quality and its control to increase density and reduce cost		Baseline=?
Manufacturing	Cell / Module / Battery Pack	LC-BAT-5-2019 call	**Manufacturing & equipment**	**Cost [€]**	Enhance throughput to reduce cost		Baseline=? Maybe we have nothing to say on this point, in which case the requirement should be marked 'INACTIVE' in the status column (K)
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Battery Performance**	**Data**	State of Health (SOH) - 2nd life BoL	70% to 80% of total usable capacity at C/2.	
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Battery Performance**	**Energy [kWh]**	Achieve a resting self-discharge rate of only about/not more than 5% over a 24-hour period		Evaluate after complete charge followed by 24h rest time
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Battery Performance**	**Additional**	Internal resistance depending on SOC (0-100) and SOH (80% to 50%)	during continuous charge & discharge at C/2	Need to specify max value / In order to evaluate max current, availbale SOC window and associated round trip efficiency
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Battery Performance**	**Life Expectation**	Cycle life	Ensure 250 full equivalent cycles per year between 10-40°C	Evaluate for one representative sunny day usage i.e. complete charge 5.5h / rest 7h / complete discharge 3.3h / rest 9h
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Battery Performance**	**Voltage [V]**	Information required: Open circuit voltage (OCV) depending on SOC (0-100) and SOH (80% to 50%)		Need to specify desired values / Each 10% of SOC at least In order to evaluate max current, availbale SOC window and associated round trip efficiency
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Battery Performance**	**Power [kW]**	Information required: Maximum continuous ~~and short term~~ power depending on SOC (0-100) and temperature (10-40°C)		In order to evaluate availbale SOC window and associated round trip efficiency
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural**	Information required: Integrity of casing: swelling and internal gas generation	Visual inspection	Ask for mechanical structural engineer if structure will support swelling at end of 2nd life (swelling level to be defined)

Lifecycle stage	System level	Host Application/Battery Type/So	Topic	Subtopic	Requirements	Desired Values	Note
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Additional Information**	**Life Expectation**	Information required: First life aging model of cell and historical data of 1st life analysis to determine the state of ageing (cell internal state)	SOH and R evolution during 1rst life with informations of applied current profile, Charge throughput, Cell temperature, SOC window. At research level, during ageing tests	BG: ageing models - discuss with CEA (cf. T7.5) and ABEE (cf. T4.7) what modeling exactly is planned. For historic data: we need to ensure that sufficient data logging takes place during testing. FHG will provide an interface from the BMS through which recorded data can be exported/saved to external storage. This will likely be for module/pack level. For loose cell testing where no BMS in play, we need a different solution?
2nd life	Battery Pack	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural: Disassembly**	No glued surface or welded surface. No requirements for the use of an angle grinder to remove the protective casing (safety issue when you don't know how close inside are the modules/cells and you risk touching them with the grinder. (SNAM) Same size screws for all of the screws (SNAM) No metallic inserts into plastics (SNAM)		This is a requirement given from a 2nd life perspective, but actually applies to (or needs to be considered at) time of manufacturing. See R_IDs 282, 291,290, 292
2nd life	Module	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural: Disassembly**	Be careful of the layout of the power cables, when for example connectors are between two modules, the dismantling is done in a 2-step way, which is prone to short-circuits and thus electrical arcs. (SNAM) (cf. figure here: https://threebelieve.emdesk.com/#!/documents/direct/d908)		This is a requirement given from a 2nd life perspective, but actually applies to (or needs to be considered at) time of manufacturing. See R_Ids 287, 294
2nd life	Cell	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural: Disassembly**	No thermal paste to be used as a junction with the cooling system, because when removed (with force) the isolating film of the cells tears apart. (SNAM)		This is a requirement given from a 2nd life perspective, but actually applies to (or needs to be considered at time of manufacturing. Deprecated: see R_ID 294
2nd life	Battery Pack	Circular economy (3beLiEVe T1.2)	**BMS**	**Structural: Reassembly**	Any exchange of BMS necessary? The BMS has to be re-programmed or substituted if necessary (MIT) for 2nd life: o Imax, Vmax, Vmin o Continuous available power charge and discharge o Charge protocol o CAN protocol Self-diagnosis of the electronic parts.		Duplicate of R_ID309? That requirement seems more accurately defined, hence this one is deprecated.
2nd life	Battery Pack	Circular economy (3beLiEVe T1.2)	**BMS**	**Structural: Reassembly**	BMS to identify each module and access archived data from 1st life		Which data, exactly, should be archived?
2nd life	Cell	Circular economy (3beLiEVe T1.2)	**Battery Performance**		Standard SOC windows deduced by : - Pmax cha & dch =f(SOC,T, SOH, R) - Ageing recommandations - Warranty conditions Can we increase them by sensors/better algorithms?		Can be replaced by R_ID 307 ?
2nd life	Battery Pack	Circular economy (3beLiEVe T1.2)	**BMS**	**Data**	data acquisition on pack level? Yes in order to have substituted if necessary (MIT) from real usage + SOH/R evolution to realize predictive maintenance	prediction about impending cell sudden death	
2nd life	Module	Circular economy (3beLiEVe T1.2)	**BMS**	**Data**	data acquisition on modul level?		As it stands, this is a question. What specific data should be acquired on module level? Maybe this requirement should be set to DEPRECATED, since it is not very specific? Cf. also R_ID 316 and R_ID 317.
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**BMS**	**Data**	data acquisition on cell level?		Determine where cell-level data should be stored: in the module? At pack level? Or in the cloud altogether?
2nd life	Cell	Circular economy (3beLiEVe T1.2)	**Battery Performance**	**Data**	At end of life: detectability of fully discharged cell? SOH?	1- target 50% SOH 2- internal resistance increase 4- safety aspect : swelling, CID disrupt, thermal runaway	see also R_ID 255
Recycling	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Battery Performance**	**Data**	only final status of cells required:	SOC, SOH, short circuit, shocked ...	cf. R_ID 297. Duplication? SOC and SOH are final values; history might be needed for short circuit, shock...tbd. Clarify. Question of SOH-computation algorithm. Basic SOC and SOH functionality already included in BMS. Better models must be implemented using sensor information (additional parameters we can monitor).
Recycling	Battery Pack	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural: Disassembly**	No glued surface or welded surface. No requirements for the use of an angle grinder to remove the protective casing (safety issue when you don't know how close inside are the modules/cells and you risk touching them with the grinder. (SNAM) Same size screws for all of the screws (SNAM) No metallic inserts into plastics (SNAM)		Deprecated; has been broken down into multiple requirements, see R_Ids: 282, 283, 284, 290, 292.

Lifecycle stage	System level	Host Application/Battery Type/So	Topic	Subtopic	Requirements	Desired Values	Note
Recycling	Module	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural: Disassembly**	Be careful of the layout of the power cables, when for example connectors are between two modules, the dismantling is done in a 2-step way, which is prone to short-circuits and thus electrical arcs. (SNAM) (cf. figure here: https://threebelieve.emdesk.com/#!/documents/direct/d908)		Deprecated; superceded by R_ID 286
Recycling	Cell	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural: Disassembly**	No thermal paste to be used as a junction with the cooling system, because when removed (with force) the isolating film of the cells tears apart. (SNAM)		Deprecated; superceded by R_ID 287
Recycling	Module	Circular economy (3beLiEVe T1.2)	**Environmental**	**Materials recovery**	limit the plastic usage in modules to improve recycling efficiency and limit harmful emissions which have to be treated (€€) (SNAM) High-energy density cells and thermal treatment can be a very powerful combination (SNAM) Graphite and Silicon pose problems in hydrometallurgy (SNAM)		Deprecated; superceded by R_IDs 288, 299
1st life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Additional Information**		Standard SOC windows Can we increase them by sensors/better algorithms? Reducing usage which occurs specific degradation (Rapid and low temperature charge, deep discharge, high temperature storage, ...)		Is this a requirement? The first part sounds more like a research question. The part about reducing usage which degrades the battery is contrary to some of the 1st life requirements from OEM side
1st life	Battery Pack	Circular economy (3beLiEVe T1.2)	**BMS**	**Data**	data acquisition on pack level	Tmin/Tmax/SOC distribution (hot/cold climate), kWh throughput or kAh throughput, Charge number (normal & rapid) Deep discharge	Define the cycling stress factor, i.e. Temperature (°C), Depth of Discharge (DOD, %), Middle State-of-Charge (Mid-SOC, %). Related to R_ID 280, 281?
1st life	Module	Circular economy (3beLiEVe T1.2)	**BMS**	**Data**	data acquisition on module level	Tmin/Tmax/SOC distribution	
1st life	cell	Circular economy (3beLiEVe T1.2)	**BMS**	**Data**	data acquisition on cell level	Tmin/Tmax/SOC distribution	
Recycling	Battery Pack	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural: Disassembly**	No glued surface or welded surface.		efficiency in dismantling
Recycling	Battery Pack	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural: Disassembly**	Same size screws for all of the screws		efficiency in dismantling
Recycling	Battery Pack	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural: Disassembly**	No requirements for the use of an angle grinder to remove the protective casing		safety issue when you don't know how close inside are the modules/cells and you risk touching them with the grinder.
Recycling	Battery Pack	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural: Disassembly**	No metallic inserts into plastics		can create unwanted sparks/arcs (operator safety)
Recycling	Module	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural: Disassembly**	thought-out cable layout		Be careful of the layout of the power cables, when for example connectors are between two modules, the dismantling is done in a 2-step way, which is prone to short-circuits and thus electrical arcs. (cf. figure here: https://threebelieve.emdesk.com/#!/documents/direct/d908)
Recycling	Cell	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural: Disassembly**	No thermal paste to be used as a junction with the cooling system		when removed (with force) the isolating film of the cells tears apart.
Recycling	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Environmental**	**Recycling Efficiency**	limit plastic usage in casing and component protection		to improve recycling efficiency and limit harmful emissions which have to be treated (€€)
2nd life	Battery Pack	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural: Disassembly**	No glued surface or welded surface.		efficiency in dismantling. Deprecated, because duplicate of R_ID 282.
2nd life	Battery Pack	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural: Disassembly**	Same size screws for all of the screws		efficiency in dismantling. Deprecated, because duplicate of R_ID 283.
2nd life	Battery Pack	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural: Disassembly**	No requirements for the use of an angle grinder to remove the protective casing		safety issue when you don't know how close inside are the modules/cells and you risk touching them with the grinder. Deprecated, because duplicate of R_ID 284.
2nd life	Battery Pack	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural: Disassembly**	No metallic inserts into plastics		can create unwanted sparks/arcs (operator safety). Deprecated, because duplicate of R_ID 285.
2nd life	Module	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural: Disassembly**	thought-out cable layout		Be careful of the layout of the power cables, when for example connectors are between two modules, the dismantling is done in a 2-step way, which is prone to short-circuits and thus electrical arcs. Deprecated, because duplicate of R_ID 287.
2nd life	Cell	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Structural: Disassembly**	No thermal paste to be used as a junction with the cooling system		when removed (with force) the isolating film of the cells tears apart. Deprecated, because duplicate of R_ID 287.
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Environmental**	**Recycling Efficiency**	limit plastic usage in casing and component protection		to improve recycling efficiency and limit harmful emissions which have to be treated (€€) . Deprecated, because duplicate of R_ID 288.
Recycling	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Battery Performance**	**Data**	status of the battery	SoH, temperature, aging profile	
Recycling	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Battery Performance**	**Data**	status of the battery	SoH, temperature	Pls clarify: do you mean: last known status, or do you need historical evolution of this status?

Lifecycle stage	System level	Host Application/Battery Type/So	Topic	Subtopic	Requirements	Desired Values	Note
2nd life	Battery Pack	Circular economy (3beLiEVe T1.2)	**BMS**	**Structural: Reassembly**	BMS Validation for 2nd-life		Check if the BMS is capable of supporting the 2nd life of the battery after its first life (c-rates, default, v-rates, CAN communication)
Recycling	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Environmental**	**Materials recovery**	Reduce graphite and silicon usage		hydrometallurgical treatment is troublesome
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Battery Performance**	**Round trip efficiency**	Energy Efficiency [%]	0,9	Evaluate for one representative sunny day usage i.e. rest 9h / complete charge 5.5h / rest 7h / complete discharge 3.3h at pack level with BMS & without converter
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Battery Performance**	**Energy [kWh]**	Usable Energy at Beginning of Life (Battery System)	500 kWh	
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Battery Performance**	**Energy [kWh]**	Usable Energy at End of Life (Battery System)	500 kWh	
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Battery Performance**	**Power [kW]**	Continuous Charge - BoL	500 kW	
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Battery Performance**	**Power [kW]**	Continuous Charge - EoL	500 kW	
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Battery Performance**	**Power [kW]**	Continuous Discharge - BoL	500 kW	
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Battery Performance**	**Power [kW]**	Continuous Discharge - EoL	500 kW	
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Additional Information**	**Life Expectation**	Information required: 2nd life aging model of cell, state of ageing (cell internal state) at beginning of 2nd life and usage profile	Specify optimal BESS sizing and SOC window to minimize LCOE	
2nd life	Cell / Module / Battery Pack	Circular economy (3beLiEVe T1.2)	**Battery Performance**	**Life Expectation**	Lifetime	25 years	Battery replacement will be considered
2nd life	Battery Pack	Circular economy (3beLiEVe T1.2)	**BMS**	**Communication**	Reuse same BMS for 2nd life: o Imax, Vmax, Vmin o ensure that indication of charge and discharge power is for continuous power demand o CAN protocol o Self-diagnosis of the electronic parts.		Same as R_ID 266? Please clarify: does the requirement mean that the BMS should pass to the EMS information about the maximum/minimum I and V it can provide? When this requirement clarified, "Owner" should be assigned to WP4 / FHG.
Manufacturing	Cell	Advanced manufacturing (3beLiEV	**Manufacturing & equipment**	**Image sample acquisition**	Foil Inspection - acquisition speed	max 2 m/s	
Manufacturing	Cell	Advanced manufacturing (3beLiEV	**Manufacturing & equipment**	**Image sample acquisition**	Foil Inspection - acquisition resolution	10-50 um/px	
Manufacturing	Module		**Connectors**		Define requirements for connectors - inter module(s)		The module hosts ~~four~~ eight cells and three sensors boards (NXP, INSPLORION, SENSICHIPS). Each board has specific connectors for measurements, communication and I2C.
Manufacturing	Module		**Additional Information**		Define communication (hardware and software) inter module		Locally (inside the module), the three sensors boards (NXP, INSPLORION, SENSICHIPS) communicate using I2C communication bus. Eventually, I2C SENSICHIPS sensors should be isoltated. Communication protocol is fixed, determined by SENSIPLUS had-wired firmware. INSPLORION communication protocol is still open.
1st life	Cell		**Battery Performance**	**Power [kW]**	Express individual requirements for cell voltage, power, current		
Manufacturing	Cell		**Connectors**		Define cell tab placement: on opposite ends or same side?	tbd	Decision should be made after considering analysis of WP4, WP3/WP6. Has an impact on sensor placement, wiring.
1st life	Cell	Other	**Battery Performance**	**Data**	Evolution of performance characteristics is needed	Capacity, resistance, voltage profile on charge and discharge at slow C-rate (C/10 and/or C/25) -> to be performed at each check-up or as much as possible	To clarify: can you confirm that what is needed is the "data history" (evolution) of the indicated performance characteristics over time?
1st life	Cell	Other	**Battery Performance**	**Data**	Ageing history	Start and end date; cumulative charge quantity for cycling, of ageing phase; ageing conditions per phase (calendar/cycling, SOC, T, C-rate,…)	
1st life	Cell	Other	**Battery Performance**	**Data**	Knowledge about fresh & aged electrode behaviour	Electrode voltage profile on charge and discharge at slow Crate (C/10 and/or C/25) and, eventually, GITT.	BG: presumably one of the final or near final electrodes. TBD whether this should be provided out of WP2 or WP3 (probably the latter…)
1st life	Cell	Other	**Testing**	**Data**	Link WP3 cell testing results to quality inspection images from VAC inline foil inspection.		BG: We want to ensure that we can correlate testing (cycling, post-mortem) results from cells with the quality images of the electrode foils. Assumption: foils for "final" cells from WP3 will be imaged on AIT Pilot Coating Line.

Lifecycle stage	System level	Host Application/Battery Type/So	Topic	Subtopic	Requirements	Desired Values	Note
Manufacturing	Cell	Other			Need to define formation protocols		From WP2, WP3 and WP6 - assuming there is an iterative fine-tuning as the cells progress along the WPs
Manufacturing	Module				Need to define the pressure that should be applied to the cells for optimum operation		
Recycling	Battery Pack	Circular economy (3beLiEVe T1.2)	**Mechanical**	**Recycling Efficiency**	Battery pack liquid coolant: ensure the choice of coolant is accorded with recycling partner SNAM and vehicle OEMs (CRF, VOLVO)		SNAM comment: "...and if we are to be using antifreeze as a coolant, this pose additional problems of removing it, storing it and getting it taken care of safely for the operators. We actually have already seen a battery using antifreeze as coolant, and the solution, if not technically demanding was adding additional costs to the total (vacuum pump, IBC for storing, getting it removed safely from our premises, additional individual equipment, etc.).