Horizon Europe Work Programme

BIG LEAP

Next Generation of Battery Management Systems to increase Interoperability, bridge the Gap between 1st and SL-BESS, Extend Adaptability and emPower battery value chains

D1.1 - FL & SL-BESS requirements for interoperation

FL and SL-BESS´s requirements for enhanced integration and performance in an interoperability battery framework.

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

Executive summary

The document is the first deliverable from Work Package 1. It documents battery system applications for first life; maritime, mobility and stationary usage. The document maps the battery system from the first life applications, in terms of usage, cell type, safety and certification requirements, battery management system interface, etc. Further, the report defines the second life use cases and defines requirements to fulfil the demonstration activities later in the project. At last, the document reports the technologically agnostic stationary use case requirements to ensure the scalability of the battery management technology being developed in the project.

Acronyms and abbreviations

BESS	Battery Energy Storage System
BIG LEAP	Next Generation of Battery Management Systems to increase Interoperability, bridge the Gap between 1st and SL-BESS, Extend Adaptability and Empower battery value chains.
DEMO	Demonstrator
EMS	Energy Management System
EMC	Electromagnetic compatibility
EOL	End of Life
ESS	Energy Storage System
EV	Electric Vehicles
FLB	First Life Battery
HW	Hardware
KW	Kilowatts

KPIs	Key Performance Indicators
KWH	Kilowatt - hours
MS	Milestone
PV	Photovoltaic
RUL	Remaining Useful Life
RMP	Risk Management Plan
ROL	Result Ownership List
SLB	Second Life Battery
SOX	State of X
SW	Software
WP	Work Package
R&D	Research and Development
NA	Not available
EFC	Equivalent Full Cycle
KWP	Peak Kilowatts

Introduction

The BIG LEAP project focuses on developing solutions for battery management systems for the second life battery systems. The technology breakthroughs will be made in its BMS, as a new three-layer architecture will be designed to ensure interoperability, safety, and reliability. It will be complemented with an adaptable ESS design to ensure BMS integration and expand the SLB's potential applications.

The methodology for the development of these innovations includes the collection of EV, maritime E-Vessel, and ESS batteries that will be dismantled, and the data collected will serve as the basis for the BMS architecture development. It will contain adaptable SoX algorithms for accurate battery measurement, a DT for real-time monitoring, and a standardization roadmap.

The new BMS will be integrated into the batteries, alongside the ESS and will be tested in three demo sites. Two physical demos will be in Paris and Prague, and a virtual demo will be in Morocco.

A part of WP1 of the project aims to define the comprehensive requirements for each use case on FL and SL-BESS applications, including SoX parameters for SL applications, the duty cycle, the expected RUL, and the validation framework.

This report documents the work performed in tasks 1.1 of WP1. The document maps battery system configurations from FL-BESS based on cell chemistry, BMS, communication, interfaces, lifetime, and SOH at EOL. Its mapping process adheres to FLB regulations and safety standards for SLB applications. The document further defines suitable use cases for FLB applications in SL usage, analyzes battery systems for stationary storage, and characterizes applications based on power, energy, safety, and lifetime requirements.

This document forms the basis for the further tasks within the project.

1. Battery systems in FL applications

This section introduces battery systems for different first life applications; maritime, stationary and mobility applications.

1.1. Maritime battery systems

Maritime sector can be categorized into several segments depending on the vessel type, operational profile, range of distance etc. Table 1 lists the battery systems installation based on vessel type delivered by Corvus Energy till August 2023.

Table 1. Projects delivered by Corvus Energy in different maritime segments

Car & passenger ferries	Cruise & yachts	Offshore & subsea	Tugs/Workboat/ Fishing/Research	Merchant vessels	Port equipment/shore stations etc.
158	**42**	**142**	**152**	**78**	**186**

Each vessel type has its own requirements and challenges for battery systems installations. One battery system would not meet all the maritime requirements. Hence, different types of battery systems are needed to suit the different applications. Some applications may tolerate more weight than others, some vessels have more space than other types of vessels, and some applications need to charge faster, e.g., within few minutes, compared to other applications. Understanding the operation of the vessel and its load requirements during the lifetime is one of the keys to design and size an optimal battery system. Table 2 shows the benefits of installing and using battery ESS on board different types of maritime vessels. The table shows the benefits in terms of reduction in operation and maintenance costs, fuel savings and reduction in CO$_2$ and NO$_x$ emissions.

Table 2. Benefits of installing battery systems on board maritime vessels

	Fully Electric Car ferry	Hybrid Car ferry	Hybrid PSV	Fully electric Tug	Hybrid Fishing vessel	Hybrid Shuttle tanker
Operation and maintenance cost reductions	80 %	35-50 %	35-50 %	80 %	50-75 %	35-50 %
Fuel saving	100 %	15-40 %	15-20 %	100 %	20-25 %	20-25 %
CO$_2$ emission reductions	95 %	15-40 %	15-20 %	95 %	20-25 %	20-25 %

NOx emission reductions	95 %	30-60 %	30-40 %	95 %	30-40 %	30-40 %

1.2 Stationary applications

Stationary applications involve a vast number of applications across diverse sectors, from renewable energy integration to grid stabilization and beyond. The transition towards a sustainable and resilient energy future hinges upon the effective deployment of stationary battery storage solutions. With the rise of renewable energy sources like solar and wind power, the need for efficient energy storage has never been more pressing. Battery storage systems serve as the linchpin in this transition, bridging the gap between intermittent renewable generation and reliable power supply. Battery storage systems have emerged as a cornerstone technology in the energy sector, offering a versatile array of applications across various domains. Here are the main applications:

Residential energy storage: Homeowners can use batteries to store excess solar energy generated during the day for use at night, reducing reliance on the grid and potentially lowering electricity bills.

Grid stabilization and balancing: Batteries can store excess energy during times of low demand and release it during peak demand periods, helping to stabilize the grid.

Electrical vehicle charging infrastructure: Batteries can be used in charging stations to store energy and provide a more consistent power supply for electric vehicles, especially during times of high demand.

Peak shaving: Utilities use battery storage systems to smooth out peaks in electricity demand. During times of high demand, such as hot summer afternoons when air conditioners are running full blast, batteries can supply additional power to reduce strain on the grid. Large energy users, such as industrial facilities or commercial buildings, can use batteries to reduce peak demand charges by drawing power from the grid during off-peak hours and storing it for use during peak periods.

Microgrids: In remote areas or in places with unreliable grid infrastructure, batteries can serve as a key component in microgrids, providing backup power and smoothing out fluctuations in supply and demand.

Uninterruptible power supply (UPS): Batteries can provide backup power in critical facilities such as hospitals, data centers, and telecommunications facilities to ensure uninterrupted operation during power outages.

Frequency regulations: Batteries can respond rapidly to changes in grid frequency, helping to maintain the stability of the electrical grid by providing ancillary services.

Energy arbitrage: Energy companies can buy electricity when prices are low and sell it back to the grid when prices are high, effectively profiting from the price difference, using battery storage systems.

1.3 Mobility applications (Electric Vehicles)

Mobility applications primarily involve land-based vehicles such as automobiles and bicycles but also encompass a range of other aspects of transportation, including ships, airplanes, and trains. Battery systems have emerged and taken center stage as a revolutionary technology that transforms global mobility. From electric vehicles (EVs) to public transportation and beyond, battery systems are the driving force behind the shift towards cleaner and more efficient modes of transportation. Let us explore the battery systems in mobility applications and their transformative impact.

Battery-powered electric vehicles (EVs) offer significant benefits that are reshaping transportation. They contribute immensely to environmental conservation by reducing greenhouse gas emissions. EVs powered by battery systems play a crucial role in promoting cleaner air. With zero tailpipe emissions, they are combating climate change and offering a hopeful future of cleaner air.

Additionally, battery powered EVs provide a more cost-effective and sustainable mode of transportation with reduced fuel consumption and maintenance requirements compared to traditional internal combustion engine vehicles. This translates into lower operating costs for consumers. Moreover, EVs promote energy independence by leveraging electricity from diverse sources, including renewable energy. This reduces reliance on fossil fuels, enhancing energy security and sustainability for individuals and communities.

By electrifying the road with advanced battery technology, we can enhance efficiency and performance in mobility applications, enabling sustainable transportation while presenting challenges and opportunities for the future of mobility. As battery systems lead to a paradigm shift in mobility applications, there are promising developments in transportation solutions for cleaner, more efficient, and sustainable transportation. While social demands for sustainability continue to increase, technology also tries to meet these demands. Battery-powered mobility has revolutionized transportation, guiding in a new era of transportation innovation and environmental management.

2. Design basis of battery system: Maritime

There are several factors to consider when designing a battery system for a maritime application. The following are some of the important considerations.

2.1. Space and weight

Each project can be different for maritime battery system as vessel type, operating conditions etc. vary from vessel to vessel. For fast ferry application, weight and volume are to be balanced where for a large cargo vessel, these factors can be relaxed, and cost could be the priority factor.

2.2. Safety

Safety of battery systems for maritime applications is very critical. It is essential to have thermal propagation protection, preferably at the cell level. Protection against ground fault, over and under voltages, high current, high temperature, communication failure etc. are to be included and operational. All the class societies (for example, DNV, Lloyds Register, Bureau Veritas, ABS, RINA, etc.) require the safety requirements in place before a battery system can be installed on a maritime vessel.

2.3. Lifetime

The design lifetime of a maritime battery energy storage system is usually maximum 10 years. For a given operational profile, the performance of the battery system is simulated to make sure that operational criteria are met at the end of life; the cell voltage, cell temperature, C-rate, Depth of Discharge (DoD) and State of Health (SoH) are maintained within the limits.

2.4. Charge criteria

For some applications, the charging criteria can be a key factor for sizing the battery system. The time available for charging and the corresponding charge C-rate are the important considerations.

2.5. Short circuit current

Quantification of short circuit current for a given system configuration is necessary. This information is used to have proper short circuit protections in the overall system.

2.6. Type of operation

For fully electric vessels with battery energy storage systems as the main source of energy source, there are additional considerations one needs to account for. For example, there should always be enough energy available to safely return to a port. To meet the criteria, missing a charge at a port, severe weather conditions etc. are to be considered while sizing the battery system.

Another example is the Dynamic Positioning (DP) operation for offshore vessels. If the battery system is designed to support the DP operation, it has serious implications in the designing and sizing phase of the battery system.

2.7. Product certification

A maritime battery system must have certifications before it can be installed on a maritime vessel. In addition, the battery product must be approved from a class society depending on the classification of the vessel.

2.8. Battery room requirements

The battery room must meet certain requirements to have the battery system installed:

- Battery room temperature should be maintained within the specified range, usually 15-20°C.
- The battery system shall be installed in a salt free environment with humidity less than 60% and free from significant dust.
- General safety and risk analysis in case of ground fault, fire, and thermal run-away scenarios.

3. Design basis of battery system: Stationary

Designing a battery system for stationary applications involves considering various criteria to ensure optimal performance, safety, and reliability. The key factors typically considered will be explored in detail in the following paragraphs.

3.1. Space and weight

Battery height-to-base ratio should be within a safe range to prevent tipping or instability. Batteries weight should be distributed evenly especially at the base. Batteries are preferred to have lower center of mass to increase stability. Attention should be given to placement of heavy components, mounting hardware, and structural reinforcements to maintain stability. Clear guidance and recommendations for installing the battery system safely should be provided. This includes specifying minimum clearance distances from walls, ceilings, and other obstacles to ensure ventilation and accessibility for maintenance. If needed safety features such as secure anchoring mechanisms, impacts resistant enclosures, and built in sensors for detecting and mitigating potential dangers should be applied.

Battery system components should be manageable during installation, maintenance, or relocation. This might involve using smaller battery modules or packs that can be easily maneuvered without specialized equipment. Minimum clearance requirements should be specified around the battery system to allow for safe operation, airflow, and access for maintenance purposes.

3.2. Safety

Safety is crucial when designing and operating battery storage systems to mitigate risks and ensure the protection of people, property, and the environment. A thermal management system, such as active cooling or heating, to regulate battery temperature and prevent overheating or thermal runaway should be applied. It is also important to provide adequate ventilation to disperse gases and heat generated by the battery system, minimizing the risk of accumulation and potential hazards such as gas buildup or thermal stress. Electrical isolation implementation is crucial to prevent electrical shock hazards and safe operation during maintenance, servicing, or fault conditions. Emergency shutdown procedures should be taken into account to quickly de-energize the battery system in the event of an emergency or abnormal operation, ensuring rapid response and minimizing risks to personnel and property.

Battery storage system must have all required labeling to inform about hazardous areas, equipment, and materials to inform about potential risks and operating procedures. Also, there should be mechanisms that monitor battery performance, environmental conditions, and safety parameters.

Consider installing alarms, notifications systems to alert of potential hazards, abnormalities, or critical events. Lastly, it is important to ensure compliance with relevant industry standards, codes and regulations governing battery storage system, such as UN38.3, IEC62619 etc. to meet safety requirements and regulatory obligations.

3.3. Lifetime

The lifetime of a battery system refers to its operational lifespan or the duration it can reliably provide energy storage and discharge functions before its performance degrades to a point where it needs replacement or significant maintenance. Battery lifespan largely depends on its charge-discharge cycles or, in other words, cycle life. During cycle life, batteries are charged and discharged up to a specific level, both overcharging and deep charging can accelerate degradation. Managing DoD (Depth of discharge) within recommended limits can extend the battery lifespan and implementing SoC (State of charge) management strategies can help optimize battery lifespan. Another important aspect is cell chemistry; for stationary applications mostly, LFP cells are used, which is one of the safest lithium-ion alternatives in the market, providing lower degradation rates and improved charge and discharge efficiency. Though, even when not in use, batteries degrade over time due to chemical reactions within cells. This is known as calendar aging. Battery chemistries have different rates of calendar aging, and factors such as storage temperature and state of charge during storage can affect calendar life. Overall, to increase battery lifetime, a proper battery management system (BMS) must be chosen. Also, manufacturers' specifications and warranties have to be taken into account.

3.4. Charge Criteria

Proper charging is essential for maintaining battery health, optimizing performance, and ensuring safety. The most important parameters in charging are voltage and charge rate. For stationary applications, it is important to evaluate the batteries' safety and efficiency before choosing operating battery voltage. For residential applications, safety is more important; meanwhile for industrial applications-efficiency is important. Charge rate, often expressed as the C-rate, refers to the ratio of charging current to the battery's capacity. For example, a 1C charge rate means charging the battery at a current (in A) equivalent to its capacity (in Ah), while a 0.5C means charging at half the capacity.

Maintaining an appropriate charge rate helps optimize battery performance and longevity. Proper charge termination is essential to prevent overcharging and minimize the risk of damage to the battery. Charging should be automatically terminated when the battery reaches full capacity or when other specified conditions are met, such as reaching a target voltage or current threshold.

3.5. Short circuit current

Short-circuit current refers to the maximum current that a battery can deliver when a direct electrical connection (short circuit) is made between its positive and negative terminals. To prevent such cases, the battery must be designed in a way that these contacts cannot connect directly. It can be done by implementing protective measures such as internal fuse, circuit braker, or current limiting device. These safety mechanisms help safeguard the battery and connected equipment from damage and mitigate safety risks.

3.6. Type of operation

Different types of operations can have distinct requirements and considerations. Here are examples:

- For continuous cycling, the battery regularly cycles between charging and discharging to meet ongoing energy demands. Continuous cycling is common in applications such as grid stabilization, renewable energy integration, and load shifting, where the battery serves as a primary or supplementary energy source to balance supply and demand.

- Batteries in standby backup mode remain charged and ready to provide backup power in the event of a grid outage or other emergencies. This mode of operation is prevalent in critical facilities such as hospitals, data centers, and telecommunications networks, where uninterrupted power supply is essential for maintaining operations.

- Peak shaving involves using batteries to reduce peak demand charges by discharging stored energy during periods of high electricity demand. By reducing the peak load on the grid, peak shaving helps lower electricity costs for consumers and utilities and alleviates strain on the electrical infrastructure.

- Energy arbitrage involves buying electricity from the grid when prices are low and storing it in batteries for later use or resale when prices are high.

- In residential settings, batteries are increasingly used for energy management purposes, such as storing excess solar energy for nighttime use, optimizing self-consumption of renewable energy, and reducing reliance on the grid.

3.7. Product certification

Certification provides assurance to consumers, businesses, and regulatory authorities that the product has undergone rigorous testing and meets defined criteria for safety, performance, quality, and environmental impact. For stationary uses, main certificates include IEC62619 (Safety requirements for lithium cells and batteries for use in industrial applications) and UN38.3 (Transportation test). Certified battery storage systems are typically labeled or marked with certification marks, logos, or identifiers to indicate compliance with relevant standards and regulations. These markings provide visual confirmation of the product's certification status and help facilitate regulatory compliance and product acceptance.

3.8. Battery room requirements

Battery rooms must have adequate ventilation to dissipate heat and maintain ambient temperatures within specified limits (0 °C to 35 °C) to optimize battery performance, lifespan, and safety. Humidity should not exceed 80 %. Fire suppression systems are also crucial to have in case of battery failure. Proper battery grounding, electrical systems and components within the battery room must comply with relevant electrical codes and requirements. Battery room should be easily accessible for industrial cases only for required personnel while restricting access to random people.

4. Mobility

Battery integration in mobility revolutionizes the automotive industry, propelled by advancements in energy density, power density, and packaging and integration. High energy density batteries extend driving ranges, while high power density batteries provide the rapid acceleration essential for automotive applications. Proper packaging and integration ensure optimal use of space and structural integrity, thereby enhancing vehicle performance and safety. Innovative solutions, such as modular battery packs and flexible form factors, are being developed to facilitate vehicle integration.

Thermal management and safety features are fundamental to maintaining battery performance, longevity, and safety. Additionally, liquid cooling is crucial for regulating temperatures to prevent degradation and safety hazards. Concurrently, battery management systems are responsible for monitoring and managing battery health. These systems incorporate features such as overcharge protection and thermal cutoffs to prolong the lifecycle.

Adherence to binding regulatory standards and testing protocols is imperative to guarantee the safe operation of batteries in mobility applications. Scalability, modularity, and lifecycle considerations are vital for accommodating diverse vehicle platforms and ensuring sustainability. Modular battery designs provide flexibility for various applications, from small urban electric vehicles to large commercial trucks. Thus, they facilitate more manageable maintenance and replacement. Sustainable practices in production, optimal usage, and end-of-life management, including repurposing batteries for secondary applications and recycling materials, are crucial for minimizing environmental impact. These efforts ensure that battery technology supports the future of sustainable transportation.

5. Mapping of FL battery system

In this section, the first life battery systems are mapped and categorized based on different factors and usage conditions.

5.1. Cell type

There are different Lithium-ion based battery systems and these systems can be categorized based on the type of active Li-ion used in the cell. Some of the commonly used cell chemistries are LCO (Lithium Cobalt Oxide), Lithium Manganese Oxide (LMO), Lithium Nickel Manganese Cobalt Oxide (NMC), Lithium Iron Phosphate (LFP), Lithium Nickel Cobalt Aluminum Oxide (NCA) and Lithium Titanate (LTO). Similarly, the systems can be categorized based on the geometry of the cell used in the battery system. Lithium-ion cells are available in different formats: cylindrical, pouch and prismatic. Table 3 lists the maps the battery systems from the project partners based on cell type.

Table 3. Battery systems mapping based on cell type

Application	**Maritime**	**Maritime**	**Maritime**	**Stationary**	**EV**	**EV**
Product name	Orca Energy	Blue Whale	Dolphin	NOVA	Long Range Battery Pack	xStorage second life
Cell chemistry	NMC	LFP	NMC	LFP	NMC	LMO
Cell geometry	Pouch	Prismatic	Cylindrical	Prismatic	Pouch	Pouch

5.2. Performance specification

Table 4 lists the specifications of battery modules from different market segments.

Table 4. Module performance specifications

Application	**Maritime**	**Maritime**	**Maritime**	**Stationary**	**EV**	**EV**
Product name	Orca Energy	Blue Whale	Dolphin	NOVA	Long Range Battery Pack	xStorage second life
Modular (Module/Pack) level	Module	Module	Module	Module	Pack	Module
Modular Ah capacity	128	560	190	100	219Ah Pack Capacity	66.2
Continuous charge C-rate	up to 2 C	0.7 C	0.5 C	1 C	1.8 C	1 C
Continuous discharge C-rate	up to 2 C	0.7 C	0.5 C	1 C	3 C	1 C
Normal design lifetime	10 years	10 years	10 years	10 years or 6000 cycles	8 years	TBD
Lowest SOH EOL (%)	~70 %	~60 %	~50 %	~70 %	~80 %	~65 %
Modular level voltage (V)	44.1 (nominal)	79.2 (nominal)	50 (nominal)	51.2 (nominal)	43.8 (nominal)	7.6 (nominal)
Modular kWh capacity	5.6	44.35	8.2	5.12	9.6	0.503
Minimum Module Voltage (V)	36	60	30	43.2	26.4	TBD
Maximum Module Voltage (V)	50.4	87.6	50	58.4	50.4	TBD
Mechanical integration (rack or rack-less)	Rack	Rack-less	Rack-less	Rack-less	Rack	Rack-less
Module BMS	Yes	Yes	Yes	Yes	Pack Level	No
Module physical dimensions (L x W x H) mm	420 x 164 x 600	1165 x 904 x 241	660 x 488 x 100	511.1 x 200.4 x 228.1	NA	NA
Module weight (kg)	58	350	45.5	38.2	NA	NA

5.3. Certifications

It is necessary to have certifications for battery systems for installing them in different applications. Depending on the application, the requirements for certifications vary. Table 5 lists the different types of certifications for different battery systems.

Table 5. Battery system certifications

Application	Maritime	Maritime	Maritime	Stationary	EV	EV
Product name	Orca Energy	Blue Whale	Dolphin	NOVA	Long Range Battery Pack	xStorage second life
Class compliance	DNV, Lloyds Register, Bureau Veritas, ABS, RINA	DNV, Lloyds Register, Bureau Veritas, ABS	DNV GL, Lloyds Register, Bureau Veritas* (*Project Approval)	NA	TBD	NA
Type approval	DNV, Bureau Veritas, ABS, RINA	Pending	Pending	NA	TBD	NA
Ingress protection	IP44	IP44	IP44	IP22	IP67/IP69K	NA
Cooling type	Forced air	Forced air	Forced air	Natural	Liquid cooling system	Passive
Vibration and shock	UNT38.3, DNV 2.4, IEC 60068-2-6	UNT38.3, DNVGL-CG-0339, IEC 60068-2-6	UNT38.3, DNV 2.4	UN38.3	UN38.3	UN 38.3
EMC	IEC 61000-4, IEC 60945-9, CISPR16-2-1	IEC 61000-4, CISPR16-2-1	DNV-CG-0339	IEC 62619	EMC /EMI is validated on pack level	Class B (EN 61000-6-3:2007; EN 61000-6-1:2007)

5.4. Safety

Battery systems need to be operated within the operational limits as specified by the system providers. Any violation of operational limits may result into unsafe operation and can risk serious incidents. Table 6 lists different safety features included in the first life battery systems from different market segments.

Table 6: Battery systems safety features

Application	Maritime	Maritime	Maritime	Stationary	EV
Product name	Orca Energy	Blue Whale	Dolphin	NOVA	Long Range Battery Pack
Thermal Runaway anti-propagation	Passive cell-level thermal runaway isolation with exhaust gas system	Passive cell-level thermal runaway isolation with exhaust gas system	Passive cell-level thermal runaway isolation	Passive cell-level thermal runaway isolation	Cell-level, module level and pack level thermal runaway isolation
Fire suppression recommended	Per SOLAS, class and Corvus recommendation	Per SOLAS, class and Corvus recommendation	Per SOLAS, class and Corvus recommendation	NA	TBD
Disconnect circuit	Hardware-based fail-safe for over-temperature and over-voltage	Hardware-based fail-safe for over-temperature and over-voltage	Hardware-based fail-safe for over-temperature and over-voltage	Hardware-based fail-safe for over-temperature and over-voltage, cell wire break	Hardware-based fail-safe for over-temperature and over-voltage
Short Circuit protection	Fuses included on pack level	Fuses included on the module and string level	Fuses included on cell level	Fuses included on module level	TP fuses included on pack level
Emergency stop circuit	Hard-wired	Hard-wired	Hard-wired	N/A (module level)	Hard-wired
Ground fault detection	Integrated	Integrated	Integrated	No (module level)	Integrated
Disconnect Switchgear Rating	Full load	Full load	Full load	N/A (module level)	TBD

6. System requirements of second life applications

With regard to the system requirements for the Second Life application, Octave has identified the minimum State of Health (SOH) requirement for the batteries received from their first life application. Considering the nonlinear behavior of Lithium-ion Batteries (LIBs) at lower SOH levels and the potential hazards and risks associated with using batteries with low SOH, Octave proposed setting the minimum acceptable SOH for batteries transitioning from their first to second life applications. Additionally, in order to successfully demonstrate the results of the BIG LEAP project, Octave proposed having battery cabinets with higher capacity. Octave also requested detailed information about the battery modules provided from the first life application, which are critical for system integration in the second life application. This information has been collected in an Excel file initiated by the WP leader and shared with the battery providers.

6.1. Thermal and cooling requirements

This section presents the thermal and cooling specifications pertinent to the DEMO use cases. Determining the most appropriate thermal management system requires careful consideration of various factors. Initially, specifying particular requirements such as ambient temperature, type of cooling system, and coolant type is imperative, given their significant impact on the Battery Management System (BMS) performance. Several key requirements must be considered:

1. Ambient Temperature: The surrounding environment's temperature significantly impacts battery performance. Keeping batteries within their specified temperature range is critical to prevent overheating and ensure optimal operation.

2. Type of Cooling System: Selecting the appropriate cooling approach is essential. Cooling systems not only need to maintain the desired battery operating temperature but also reduce the risk of thermal runaway. Most battery thermal management systems fall into three primary types:

    - Air-based systems, which are further divided into forced convection and natural convection airflow. Natural convection systems use no extra energy to circulate air, while forced convection systems use external energy to enhance airflow. These systems differ in airflow direction, speed, and battery arrangement.

    - Liquid-based systems, which can vary depending on whether the battery directly contacts the cooling fluid.

- Phase Change Material (PCM)-based systems, which use latent heat to absorb or release thermal energy and are suitable for both heating and cooling purposes. It includes systems based on solid-liquid phase change and liquid-vapor phase change. In the second systems heat pipes can be used to transport heat from the battery to a condenser using a heat transfer fluid. Alternatively, batteries can be submerged in a stationary liquid heat transfer fluid. The first method is referred as a heat pipe-based system, while the second is known as evaporative pool boiling-based system.

These cooling methods can generally be categorized into passive and active approaches. Passive cooling uses ambient temperatures to cool the battery, while active cooling involves an external energy source. Active cooling can be further classified into direct and indirect methods based on how the cooling medium interacts with the battery. Figure 1 shows the primary categories of cooling systems.

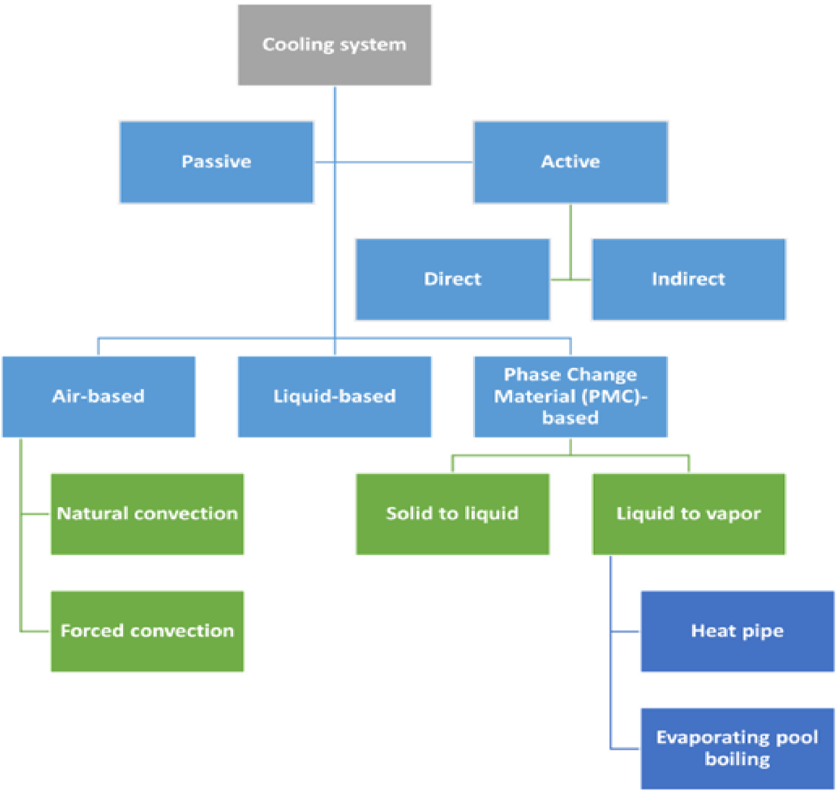

Figure 1. Primary categories of cooling systems

- **Type of Coolant:** In liquid cooling systems, selecting the right coolant is essential. In direct contact systems, a dielectric heat transfer fluid such as mineral oil is commonly employed to prevent short circuits while effectively dissipating heat from the battery. Indirect contact cooling systems utilize a range of heat transfer fluids, including water, ethylene glycol-water mixtures, deionized water with sodium polyacrylate, mineral oil, Al_2O_3-water nanofluid, liquid metal, and the refrigerant R-134a.

- **Coolant Flow Rate:** In a battery cooling system, it directly affects the system's ability to remove heat generated by the batteries. A higher flow rate increases the rate at which heat is carried away from the batteries, improving cooling efficiency and maintaining optimal operating temperatures. Conversely, a lower flow rate may result in insufficient cooling and lead to overheating, reducing battery performance and lifespan.

- **Heat Transfer Coefficient:** It quantifies the rate of heat transfer per unit area per unit temperature difference between the two materials. It depends on various factors, including the properties of the materials involved (such as thermal conductivity), the geometry and surface conditions of the surfaces in contact, the fluid properties (if applicable), and the flow conditions (if there is fluid flow involved). A higher heat transfer coefficient is desirable as it allows for more efficient cooling and better temperature control.

- **Thermal Cooling power:** It's the capability of the cooling system to absorb and carry away the heat generated by the batteries. This capability is typically measured in watts (W) or kilowatts (kW) and depends on factors such as the heat generation rate of the batteries, the efficiency of the cooling system, and the thermal properties of the cooling medium (air, liquid, etc.).

- **Insulation:** It is vital for regulating temperature, enhancing safety, and optimizing performance. It minimizes heat transfer between batteries and their surroundings, stabilizing internal temperatures and preventing thermal runaway events. By reducing heat loss or gain, insulation improves energy efficiency and protects batteries from extreme conditions. Insulation materials, such as thermal barriers and encapsulation coatings, are chosen based on their thermal properties and compatibility with the battery chemistry.

By addressing these thermal and cooling requirements comprehensively, battery systems can operate safely, reliably, and efficiently across various applications and environmental conditions.

6.2. Use-case requirements to ensure the up-scalability of BIG LEAP technology

The use of second life batteries paired with interoperable battery management systems in stationary applications for the Indian context offers the following use cases:

1. **Grid Stabilization and Peak Shaving**: Second life batteries strategically store excess energy during off-peak hours and discharge it during peak demand, stabilizing the grid and reducing strain on power infrastructure.
2. **Renewable Energy Integration**: These batteries store surplus renewable energy and release it when demand exceeds supply, facilitating the integration of solar and wind power into the grid.
3. **Urban and Rural Microgrid Support**: In remote areas, microgrids powered by renewables and second life batteries provide backup power during outages, enhancing reliability and energy autonomy.
4. **Electric Vehicle Charging Infrastructure**: Repurposed batteries in EV charging stations store renewable energy or off-peak electricity, easing grid load during peak charging times.
5. **Voltage and Frequency Regulation**: Second life batteries equipped with interoperable management systems stabilize grid operations by responding rapidly to voltage and frequency fluctuations.
6. **Energy Access and Rural Electrification**: Decentralized systems with second life batteries provide reliable power to rural areas lacking grid access, ensuring uninterrupted electricity supply.
7. **Energy Storage for Industrial and Commercial Use**: Industries and businesses benefit from peak shaving, load shifting, and backup power, reducing reliance on the grid and lowering energy costs.

Second life batteries paired with interoperable management systems are predominantly beneficial for low voltage applications, where they contribute to grid reliability, renewable integration, extended energy access, and enhanced efficiency. However, for larger Battery Energy Storage Systems (BESS), new batteries are often preferred due to regulatory business.

Parameters while considering Second Life Batteries for Stationary Applications are given in Table 7**.**

Table 7. Key considerations for SL energy storage system deployment in stationary application

Parameters	***Description***	***Considerations for Indian Context***

Operating Temperature Range	The range of temperatures within which the batteries can operate efficiently.	-20°C to 50°C for most applications, with additional cooling or heating systems in extreme climates such as desert or high-altitude regions.
Weather Resistance	Ability of batteries to withstand moisture, humidity, and environmental exposure.	Sealed enclosures with IP65 or higher rating to protect against rain, humidity, and dust ingress. Corrosion-resistant materials for longevity in coastal areas.
Load Profiles	Variability in energy demand patterns across different regions and sectors.	High peak demand in urban areas vs. more stable but lower overall energy consumption in rural areas. Off-grid areas may have continuous but lower energy demands.
Grid Stability and Voltage Fluctuations	Response to voltage fluctuations and grid instability.	Rapid response to grid disturbances. Seamless transition during blackouts. Voltage regulation to stabilize the grid.
Battery Chemistry and Lifespan	Lifespan and performance characteristics of different battery chemistries.	Consideration of battery chemistry (e.g., lithium-ion, lead-acid) based on lifespan, energy density, and temperature sensitivity. Refurbishment processes to extend battery lifespan.
Regulatory and Policy Environment	Impact of regulatory frameworks and policies on energy storage deployment.	Compliance with safety standards and environmental regulations. Access to incentives and subsidies for energy storage and renewable energy projects.

6.3. Standardization framework relevant for the project

The following list represents the commonly used elements in a standardized framework:

- Battery Specifications and Performance Standards
- Safety Standards and Regulations

- Installation and Commissioning Guidelines
- Monitoring and Control Protocols
- Maintenance and Service Procedures
- Environmental and Sustainability Standards
- Interoperability and Compatibility
- Certification and Compliance

Applicable standards are as follows:

- ISO 26262: This standard deals with the functional safety of electrical and electronic systems within road vehicles. Given the focus on BMS for electric vehicles in the project, this standard is critical for ensuring that the developed systems are safe from a functional perspective.
- UL1973: This standard applies to batteries for use in stationary applications and light electric rail applications. It may not directly apply to the primary focus of the BIG LEAP project unless part of the project involves these specific applications. However, it provides a framework for safety and reliability that could be adapted.
- UL2271: Pertains to batteries in light electric vehicle applications. This is highly relevant for the project as it focuses on batteries in EVs, ensuring the safety and reliability of battery packs and cells used in such applications.
- UL2580: Focuses on batteries for use in EVs. This standard is directly applicable to the project’s goals, ensuring that batteries meet safety criteria for EV use.
- UL9540: This is a safety standard for energy storage systems. For energy storage systems connected to a utility grid, the UL 9540 standard extends to the equipment used to make that connection.
- IEC 62619: Safety requirements for secondary lithium cells and batteries for use in industrial applications.
- The ECE R100 Rev3 / UNR100: This certification is one of the main European requirements for type approval of electric road vehicles. To guarantee the safety of lithium batteries, abusive and safety tests are necessary to reproduce the constraints of vehicle use: vibrations, impact, thermal constraints or even fire.

Evaluation of gaps and limitations:

- Coverage Gaps: While these standards cover many safety aspects of battery use in vehicles and stationary applications, there may be gaps in addressing the unique challenges posed by second life batteries, such as aging effects, degradation behaviors, and varied histories of the cells.

- Adaptation to SLBs: The standards focus on new batteries. There may be a need for additional guidelines or modifications to these standards to adequately address the reconfiguration and repurposing involved with SLBs, which could vary significantly in terms of their initial manufacturing and usage conditions.
- Interoperability Issues: None of these standards directly address interoperability between different types, brands and chemistries of batteries or between first life and second life batteries, which is a key focus of the project.

Evaluation of the opportunities:

- Standard Development: There is an opportunity within the project to contribute to the development of new standards or the adaptation of existing ones to better suit the needs of SLB technologies and interoperability.
- Enhancing Safety and Efficiency: By aligning the project outputs with these established standards, the project can enhance the safety, efficiency, and market acceptance of the developed technologies.
- Innovation in Testing and Compliance: The project can innovate in how compliance with these standards is tested, especially in a landscape where SLBs present new challenges that are not fully covered by existing regulations.

6.4. SL use-cases: Front of the meter use-cases

Two kinds of front-of-the-meter use-cases are considered according to their cycles duration: (i) low-frequency use-cases with slow charges and discharges (**PV smoothing, arbitration**), and (ii) high-frequency use-cases with swift charges and **discharges (frequency regulation**).

Their main KPIs are summarized in Table 8 and each use-case is further described and illustrated in a later paragraph.

Table 8. Main KPIs for front-of-the-meter use cases

		Use-cases		
		Grid-scale PV smoothing	Arbitration	Frequency regulation
KPIs	max C-rate / mean C-rate	0.5 / 0.25	0.8[1] / 0.3	0.8[1] / 0.3
	Average SoC (%)	30	50	45
	DoD range (pts SoC)	75	95	15 - 60
	FEC per year	260	365	365

In some renewable energy projects, the off-taker (whether it is a local utility or the grid operator) can require the site to deliver a constant power over time. Due to the intermittency of the solar resource, a co-located storage system can help smoothen the power output of the overall hybrid PV + storage site. **A PV smoothing use-case** is thus characterized by a phase of fluctuating power flow from the battery during the daytime period as a way to offset the varying PV production, as shown in Figure 2.

In the proposed use case, the PV smoothing phase is also used to charge the battery and a constant power discharge phase is included in the evening.

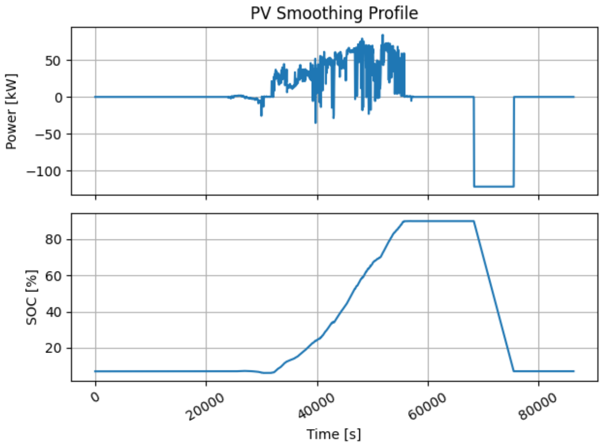

Figure 2. Grid-scale PV smoothing profile

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[1] This maximum C-rate is defined by the capabilities of Demo 1 but in a real use-cases the C-rate can be higher.

The arbitration use-case typically refers to the applications where blocks of energy are traded on the market both as a producer (discharge) and consumer (charge). The exact profile is dependent on the market the FL or SL battery is operating in. In this example, as shown in , the SL-BESS performs several phases of charge and discharge at a constant power with the objective of discharging during the morning and evening consumption peaks that usually come with the highest market prices. The duration of these steps is a multiple of 30 min or 1 h to represent blocks of energy as they would be traded on the market.

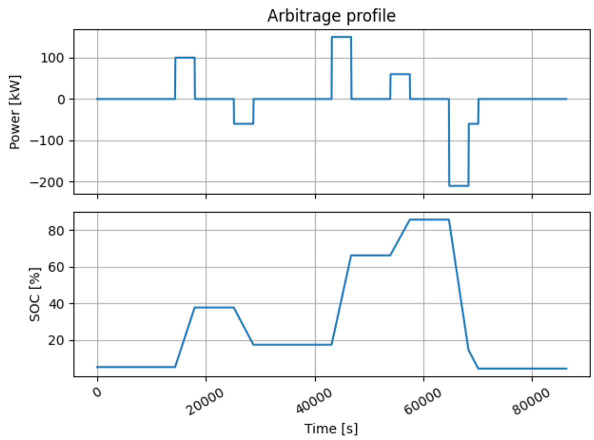

Figure 3. Arbitration profile

The frequency regulation use case consists of using battery storage systems to maintain the grid frequency at its target value - 50 Hz in Europe. When demand exceeds supply, the grid frequency drops and in response, the battery discharges power into the grid, helping to increase the frequency. Conversely, when supply exceeds demand, the grid frequency rises and the battery absorbs excess power from the grid, reducing the frequency. Therefore, the battery power profile on a given day, as shown in Figure 4, has many sharp fluctuations corresponding to these short charge and discharge cycles, while the battery SOC oscillates around a mean value of ~45 %.

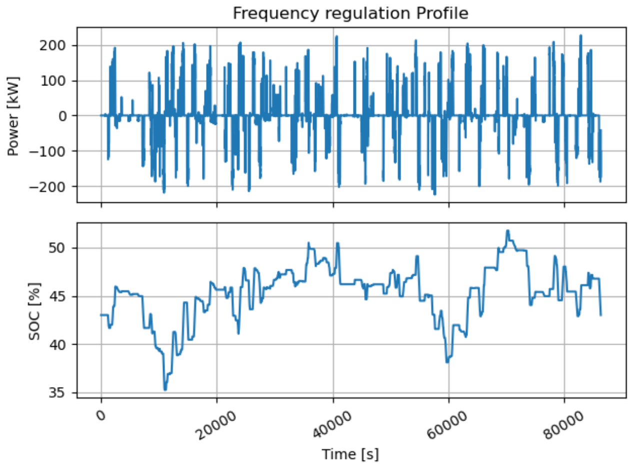

Figure 4. Frequency regulation profile

6.5. Behind the meter use-cases

Eaton has currently completed the first round of investigation and analysis on the possible use-case scenarios to be tested in the BIG LEAP second life demonstrator behind the meter. Recently, in the Czech Republic Electric power retailers started to offer electricity tariffs with prices derived from the spot electricity price (Electricity Spot Market), this is giving more flexibility and dynamism in the usage of a big energy storage system whose purpose is to support a building during its peak of load and to store electricity when there is a local generation surplus and cheap electricity tariff. An example is presented in Figure 5, where it shows electricity consumption and electricity price of the Eaton European Innovation Center (EEIC) building, where the demonstrator is supposed to take place. The green line indicates the electricity price and the blue area the energy consumption (from the grid) during the day.

The electricity price evolution is derived by the official Czech energy trade market; the energy consumption is measured by the main electricity meter of the building, and it is visible how the load rises during the working hours, and it is also quite aligned with the electricity price (depending on the usual forecast of load in the country).

This leads to the formulation of the main use-case for the BESS in Eaton facility as load shifting strategy. Charging the battery during off-peak period of night and discharging it during peak period during the day would increase the economic and the sustainability revenues of the building and the demonstrator. The planned storage capacity of 500 kWh does not cover the consumption of the building for a day and is not sufficient to fully cover daily energy increase, thus full capacity of the battery will be used according to priority settings and a proper planned control logic. The planned inverter power of 250 kW gives the battery charging/discharging rate maximum of 0.5 C (considering its capacity), however, such big power can exceed the consumption facility and will not bring benefits but needs to be limited on the contrary. The current analysis of the consumption profile leads us to the conclusion that a discharge power of 70 kW (0.14 C) and charge power of 50 kW (0.1 C) will be favorable for running tests of the battery, however, this needs to be still evaluated during the next period of the project and more realistic data will be produced in time closer to the demo.

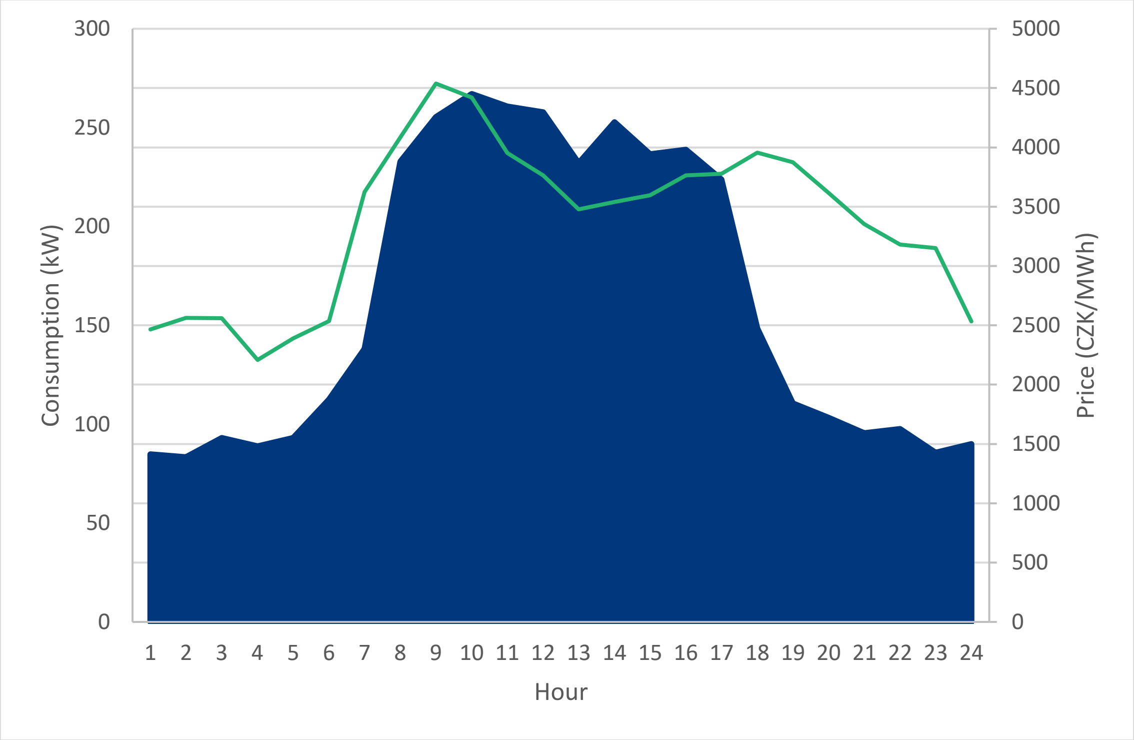

Figure 5. Example of day power profile of Eaton building and electricity spot price evolution

There are also alternative and potential use-cases that can be tested. Amongst the preferences we have: peak shaving testing, to keep consumption under reserved power capacity fixed in the energy contract. Current data does not show such behavior, however, the capacity of the innovation and microgrid laboratory in Eaton makes such scenarios possible to test. Currently, we consider this scenario as potential, and we will address it as soon as more data is provided by the building management and measured during additional tests.

Table 9 summarizes the utilization of 500kWh battery operation in the potential scenarios for the Eaton second life BESS behind the meter demonstrator.

Table 9. Summary of the 500kWh battery operation at Eaton

Indicator	Value
Charging/discharging cycles frequency	1 day
Battery capacity utilization per average cycle	100 %
Average charging power	50 kW (0.14 C)
Average discharging power	70 kW (0.1 C)
Occasional charging/discharging peak power	250 kW (0.5 C)

This analysis was done with a certain level of approximation for the estimation of demands to the battery system, according to real data measured and obtained by our building but also according to some assumption of behavior and technical specifications of the BESS. The real operation of the battery will be ruled by the Energy Management System (EMS) system and specific daily profiles can differ from day to day.

7. Demonstration requirements

This section documents the requirements of the demonstrations that are planned to be performed in the project period. Project partners EDF and Eaton are going to perform the demos using the battery systems from the first life applications.

7.1. Demonstration at EDF

The demonstration is set to unfold at the EDF R&D's Power Networks Lab located in Les Renardières, France, as part of Work Package 7. The prototype will be manufactured in Work Package 6 using second life batteries. Its maximum energy and power will be **300 kWh and 250 kW**, respectively.

The primary objective of this demonstration is to demonstrate the performances of the newly developed solution in front-of-the-meter use cases. To ensure a realistic evaluation, the prototype will undergo testing in a laboratory simulating an actual grid. Figure **6** and Figure **7** show the test bench and testing container. The test bench can simulate DC current of up to 800 A, and voltage of up to 1000 VDC, while maintaining total power below 320 kW, which is well fitted for the 250 kW prototype.

Figure 6: Test Bench

Figure 7: Testing container

Physical, electrical, thermal, and communication requirements for integration of the prototype in the laboratory are detailed hereafter.

First, the second life batteries used to manufacture the prototype will have a state of health (SoH) of more than 80 % of their initial capacity.

In terms of dimensions, the prototype's height, width, and length should all be less than 2 meters. The design should be compatible with the use of a forklift and/or lifting ring to ensure smooth integration into the lab and easier handling. A horizontal design is preferred over a vertical one. The prototype could consist of several branches interconnected while each adheres to the specified dimensions.

Regarding **electrical connectors**, threaded fittings are favored.

Electrically speaking, the testing bench limits the voltage, current and power of the prototype to less than 1000 V_{DC}, 800 A, and 320 kW. If the BMS needs external power - i.e., is not powered directly by the prototype, its voltage should be either 12 or 24 V_{DC}.

Communication between the battery prototype and testing bench will use a Bus CAN protocol at 500 kb/s. Bidirectional communication is essential between these two components.

Thermally, the maximum thermal cooling power should be less than 10 kW with water cooling being employed as the type of coolant; however, a thermal exchanger can also be used if another cooling liquid is needed. Easy-to-plug connectors (such as Stäubli connectors) are preferred. Air cooling can also be considered.

Easily available consumables should be used for ensuring easy procurement in case repairs are needed. Furthermore, the design should ensure easy access to the consumables and modules.

7.2. Demonstration at Eaton

The project BIG LEAP aims at demonstrating different use-case scenarios where the technologies developed by the cooperation of partners are being integrated and tested. The Eaton demo addresses the physical demonstration of an interoperable battery system with a second life batteries use-case to be installed in a behind the meter demonstrator in Prague, Czech Republic.

This demonstrator consists of a high capacity and high power Battery Energy Storage System that will be developed, integrated, installed and interfaced to the main AC grid connection of the Eaton European Innovation Center (EEIC), the building of the Eaton office, to provide with peak shaving capability and local grid support and mitigate the high load demand of the building.

The objectives of the Eaton demo, which will be finalized in WP7, are to prove the interoperability, modularity and scalability of the second life BESS and BMS, building a containerized solution for Energy Storage up to 250 kW peak power and rated capacity 500 kWh in a behind the meter layout.

The behind-the-meter configuration will let Eaton focus in BIG LEAP on testing the BESS in power exchange with the EEIC building to store electricity during the low-consumption period and discharge it to the building grid during the peak price/demand periods enhancing the self-consumption capability and the electricity cost minimization of the building.

Figure 8 shows the geographical location where Eaton is targeting to build the demonstrator. The EEIC office is located in a town called Roztoky, belonging to the municipality of Prague, Czech Republic, therefore it will be referred usually as Prague demonstrator or Czech demonstrator.

At the time of writing this deliverable, Eaton is discussing internal requirements for the installation of this powerful demonstrator near the Eaton office and focusing on the safety and compliance matters related to locating the cabinet/container outdoors, connected to the electrical grid of the building.

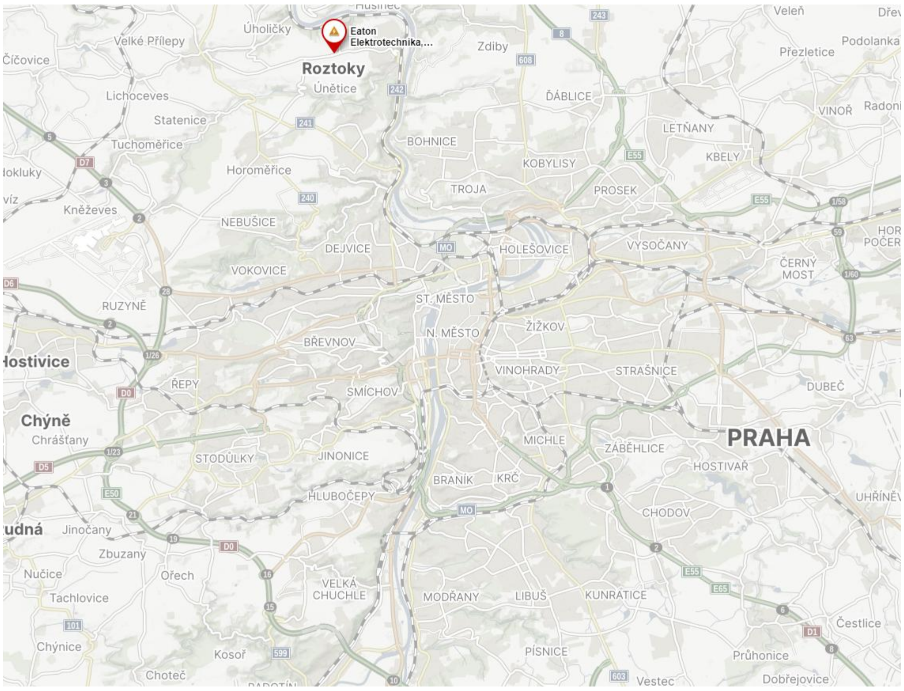

Figure 8 Location of the Eaton physical demonstrator in Czech Republic

7.2.2. Infrastructure for the demonstrator

As mentioned, the demonstration is targeted to take place at EATON premises in the EEIC office in Prague, Czech Republic. In Figure 9, it is illustrated as a simplified single line diagram of the second life demonstration led by Eaton in Prague. The EEIC building is supplied from a separate transformer that powers the AC network via the main breaker and energy meter. The AC connection feeds two main distribution subnetworks: one dedicated to the laboratories and one to the offices in the building. The containerized solution of the battery demonstrator will be connected to the AC connection, thus it will be able to store electricity during the day (via either the PV system on the rooftop of the building or via charging the battery from the grid) and to discharge when it is needed (peak of load, high cost of electricity) or during tests. The EEIC building shows on average a power consumption (during the working day) between 100 - 200 kW, which can be highly variable depending on the season (heating, cooling), day of the week (more or less presence of employees in the building) and tests running (several laboratories are part of the building). Currently, the PV system on the rooftop of the building has a peak power of 17 kWp, which is planned to be extended to double the capacity, and the LV microgrid laboratory includes multiple power sources, power converters, electronics loads (up to 30 kW each) as well as another battery storage system (Eaton xStorage, 50 kWh, 40 kW, first life).

The aim is to integrate the second life ESS developed in BIG LEAP for the Prague demonstrator and test the BMS developed by project partners within the above-described Eaton facility in Czech Republic.

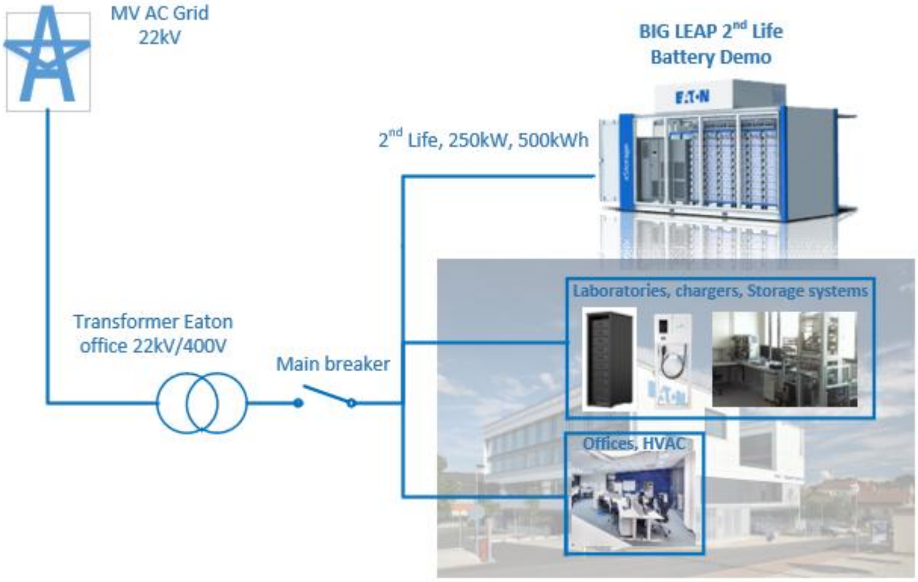

Figure 9. EATON second life Battery Energy Storage Demonstrator in BIG LEAP

Technical specifications of the demo and main requirements for the demo connection to the local facility.

The second life BESS demonstrator needs to comply with multiple requirements derived by different factors, which are below listed and described according to a high-level analysis that will be evolving during the project:

- **Environmental requirements:** The container will be placed outdoors because of environmental and safety regulations, subject to seasonal temperature variations ranging from -20°C to + 38°C. Given these conditions, it’s crucial to provide with temperature monitor and control within the container. The possibility of connecting/extending the container HVAC to the overall building ventilation is under investigation, but until confirmation, it will be considered a design with a standalone air conditioning system.
- **Location and Size:** Despite several restrictions due to proximity to other technologies/demonstrators nearby the EEIC office, an ideal placement of the final installation has been identified and agreed upon with facility management.

  However, before finalizing, Eaton is seeking for approval from the fire department and city office to ensure compliance with safety regulations and land property.
- **Connection:** The electrical connection is considered, as mentioned in the introduction paragraph, behind the meter, which let Eaton focus on the building support use case as well as helps with overcoming possible complications due to the local regulation and distribution system operator (DSO). However, considering unfavorable grid feeding conditions, it’s essential to monitor consumption of the building and to maximize the control of the BESS. The battery control system should prevent exceeding the consumption profile. Although there’s a substantial reserve capacity (with reference to a 350 kW Genset in the building), additional installation preparations are necessary.
- **Containerized solution:** The goal is to have a containerized battery storage system to achieve modularity and flexibility in the energy storage solution and meet the desired power and capacity requirements. The size of containers is typically between 5-10 m length and 2.5-5 m of depth to facilitate transport and scalability, the container selected by Eaton is expected to fall within this range as mentioned above. The container is expected to measure at least 2.5 m x 3 m x 6.5 m. Essential components of this system include battery modules divided in racks, power converter unit/ inverter, power distribution unit and control/monitor system.

One very critical requirement is the adherence to safety standard with considerations for fire suppression systems, alarms, emergency shutdowns as well as safety monitor system; the goal of these components is to prevent and manage the risks associated to the battery operation. Thermal management is also critical, with presence of suitable HVAC system to keep optimal operating temperatures. Real time data on measurement and energy performance will be also considered for this demo in order to monitor the status of the battery operation connected to the building grid. Also, the Battery Protection unit (BPU) ensures the safe operation of battery modules as well as the electrical connection and supply.

- **Back Energy Feeding and Consumption Exceeding:** Back energy feeding and exceeding consumption energy are possible. However, updating the contract for higher back feeding power capacity is required. While this can help in testing battery utilization scenarios, the current electricity purchasing price may not justify this approach for Eaton facility. More investigation will be carried out on this topic and approach.
- **Communication:** The facility operates an Energy Management System (EMS) and a control system for the microgrid laboratory and EV charging stations that are being installed. Core communication protocols include Modbus TCP (or RTU) and OCPP for the chargers (not applicable in general for the BESS demonstrator).

  The choice of communication protocol is one of the most important criteria to satisfy the project interoperability (of battery and BMS, therefore it is important that alignment with project partners will follow this pattern of matching Modbus protocol for exchange of information.

Table 10 summarizes the main technical specification so far agreed for the BESS of the second life behind the meter demonstrator lead by Eaton.

Table 10. Main tech specifications of the EATON 2nd life BESS demonstrator

Technical specification of BESS	Max or rated value
Max Voltage on battery side [V]	800 V DC
Rated voltage on grid side [V]	400 V AC, 3ph
Max Current on the battery [A]	310 A
Max Power [kW]	250 kW
Max Energy Capacity [kWh]	500 kWh
Battery Chemistry	Second life application, cell chemistry TBD

7.3. Virtual Demonstration at Masen

Masen's R&D Platform is growing at a rapid rate, with each year incorporating various state-of-the-art photovoltaic and battery energy system technologies. Figure 10 and Figure 11 show an overview platform in Ouarzazate, Morocco. The platform consists of a renewable energy demonstration site connected to the national grid and contains different projects with different partners, namely:

- 1 MWp CPV plant a Vanadium Redox Flow Battery (125 kW), and a real load of 300 kVA.
- Jica project with 10 kW PV and 20 kW CPV.
- Azelio project with 200 kW PV.
- Super-PV project with 20 kW consisting of different PV technologies (monofacial and bifacial).
- Hydro PV project with 15 kW.
- DSM Project with 30 kW.

Figure 10. Map showing the platform in Ouarzazate, Morocco

Figure 11. Platform in Ouarzazate, Morocco

7.3.1. Purpose of the R&D Platform

With such a site, rich in solar irradiation resources, Masen R&D's is an ideal location for developing, testing and validation of upcoming innovative technologies. In addition to the technologies currently installed, a future 200 kW (200 kW/400 kWh) Capacity Multi-Microgrid System with different battery, PV, and coupling techniques will be installed which will enable Masen to embark on a new challenge in the development of Digital twin technologies as in the case of the current project.

This is illustrated in Figure 12.

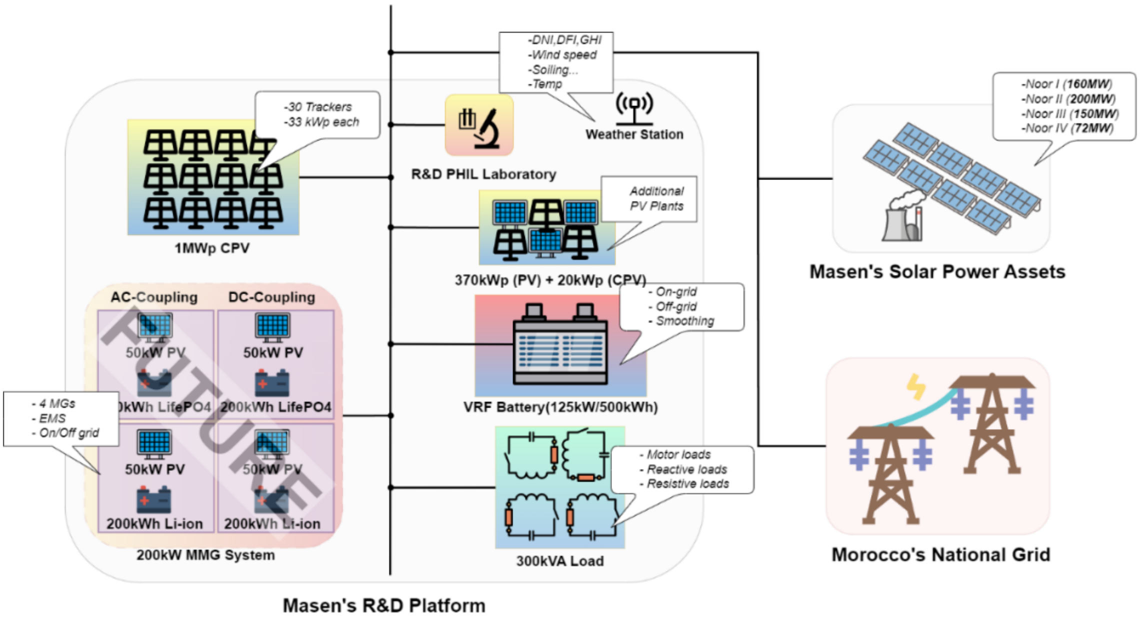

Figure 12. Masen's R&D platform

7.3.2. Virtual use-case demonstration

The demo consists of virtual testing of an SL-BESS powered by a PV plant generating up to 64 kW, simulating a total ESS of 64 kWh with a total power load capacity of up to 100 kW. The total energy of the ESS will be simulated to demonstrate the system behavior under various sets of conditions and climate network services.

The demonstration will take place inside Masen's R&D Power-Hardware-In-The-Loop Laboratory in a simulated environment, taking into account the Digital twin framework capabilities that will be developed in the project.

7.3.3. Requirements

This use-case is virtual, meaning that most physical requirements, such as weight, electrical connectors, etc. won't be taken into consideration. In the case they are needed for modeling purposes, they will be arbitrary.

Additionally, an EMS system will be used during the demonstration phase. MODBUS TCP Communication between the tested BMS and the EMS will be conducted in order to simulate as precisely as possible communication delays between the BMS and the EMS.

Most of the data collected from the EMS and the BMS will be exported in an adequate format (CSV for example) for conducting further analyses.

The Electrical requirements are given in Table 11. Electrical requirements.

Table 11. Electrical requirements

Max Voltage (V)	Max Current (A)	Max Power (kW)	BMS external power
600-1200(DC)	50 - 100(DC)	64kW	None

These values have been chosen in order to stay in coherence with existing BESS Simulator equipment available in the R&D PHIL Laboratory. Thus enabling further comparisons and validation with the obtained results.

Finally, the main use case scenarios for this demonstration will be to test Peak shaving, Load shifting, Power smoothing and Power stabilization capabilities of the developed BMS algorithms. These tests will be conducted using real profile data extracted from the weather stations in the R&D platform.

7.3.4. Implementation plan

Firstly, accurate representations of FL/SL batteries will be developed using the digital twin framework. These representations will be used to validate the BMS algorithms developed in the project.

Validation of the BMS algorithms will be conducted in an entirely simulated environment at first before implementing it into hardware-based real-time simulation using a Battery Cell Emulator (BCE).

Figure 13. PHIL laboratory at Masen

Multiple SoX algorithm functionalities will be validated and demonstrated in the R&D PHIL Laboratory, shown in Figure 13 and Figure 14.

Figure 14. PHIL laboratory building at Masen

A Virtual environment containing a model for the equipment in the laboratory will be utilized to demonstrate the BESS's capabilities for the following demonstration applications:

- **Peak shaving / Load shifting:** Peak shaving and load shifting are energy management techniques aimed at optimizing electricity usage. Peak shaving reduces high-demand periods by implementing efficiency measures, while load shifting redistributes consumption from peak to off-peak hours, improving grid stability and efficiency.

- **Wind/PV Power Smoothing:** Power smoothing involves techniques that stabilize the fluctuating output of wind and solar energy. This is achieved through the BESS ensuring a more reliable and consistent power supply despite variations in weather conditions.

- **Power Stabilization (sudden loss/increase of load):** Power stabilization addresses sudden changes in load, whether it's a rapid increase or decrease in demand.

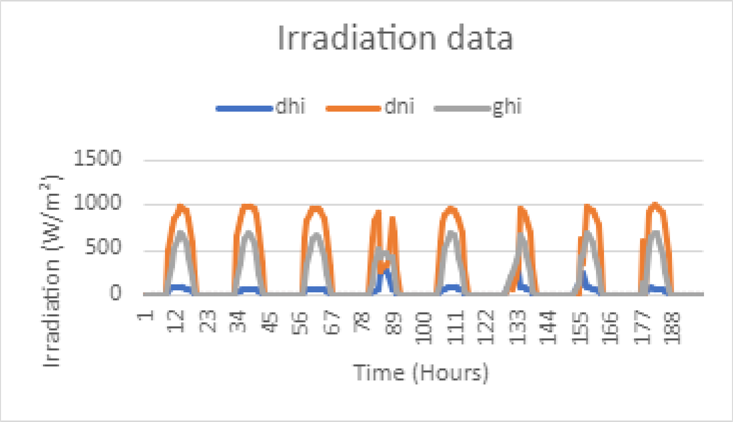

Figure 15: Irradiation data sample

A comparison between real power-hardware-in-the-loop equipment will be conducted for validation. Essentially, the same weather as shown in Figure 15 and Figure 16 and the load profile shown Figure 17 will be used for the virtual environment and the PHIL environment. The weather station collects wind speed and solar irradiation data. The latter is collected in three key measurements:

- **GHI** (Global Horizontal Irradiance): Total solar radiation received by a horizontal surface, including both direct sunlight and diffuse sky radiation.
- **DNI** (Direct Normal Irradiance): Solar radiation received per unit area by a surface perpendicular to the sun's rays, excluding diffuse sunlight.
- **DHI** (Diffuse Horizontal Irradiance): Solar radiation received by a horizontal surface from the sky, excluding direct sunlight.

$$\text{GHI} = \text{DNI} \times cos(\theta) + \text{DHI}$$

With θ is the solar zenith angle: the angle between the vertical direction and the line to the sun.

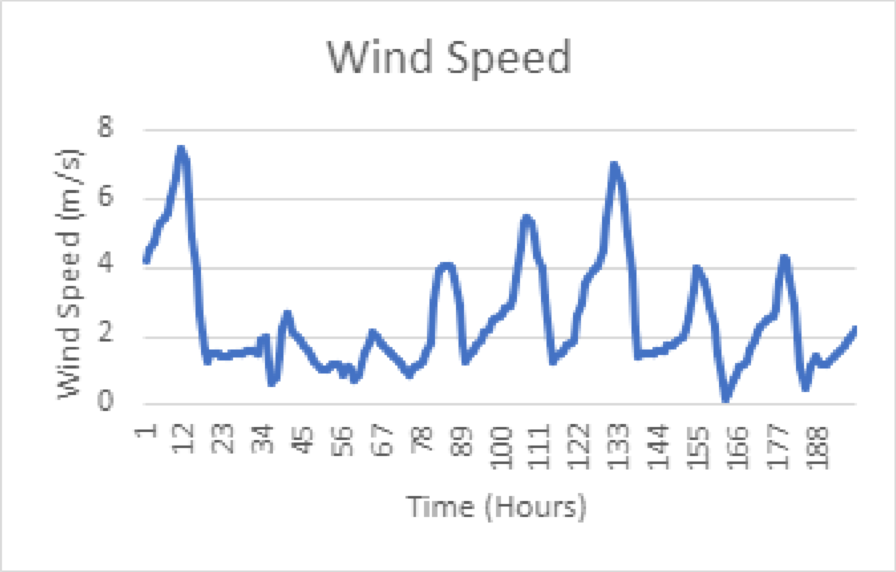

Figure 16. Wind speed data sample

One future destination for the application of technologies developed in this project is aimed at resolving electricity issues in rural areas. One of the main provinces that were severely damaged by Morocco's Marrakesh–Safi earthquake on 2023-September-08 include: Al-Haouz, Taroudant and Marrakech. One typical 24-hour load profile will be used for this use case demo, as shown in Figure 18.

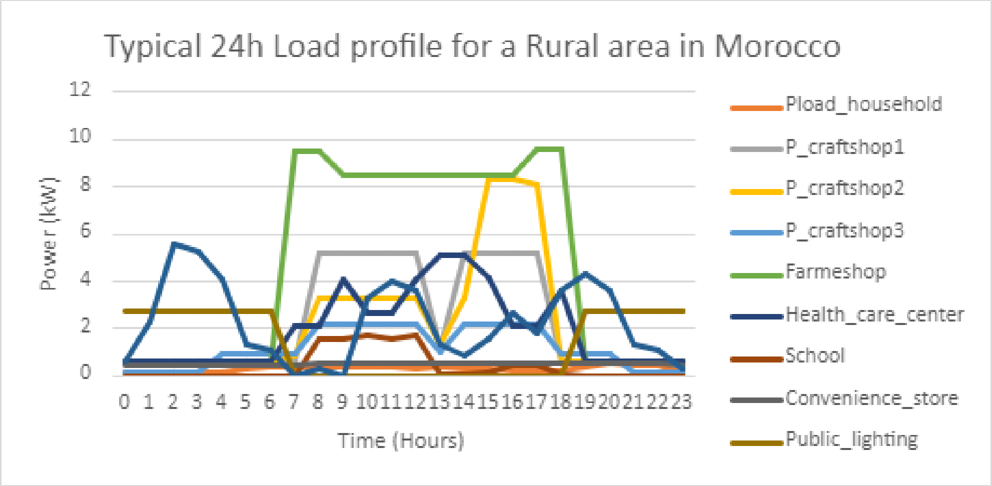

Figure 17. Typical load profiles in rural areas of Morocco

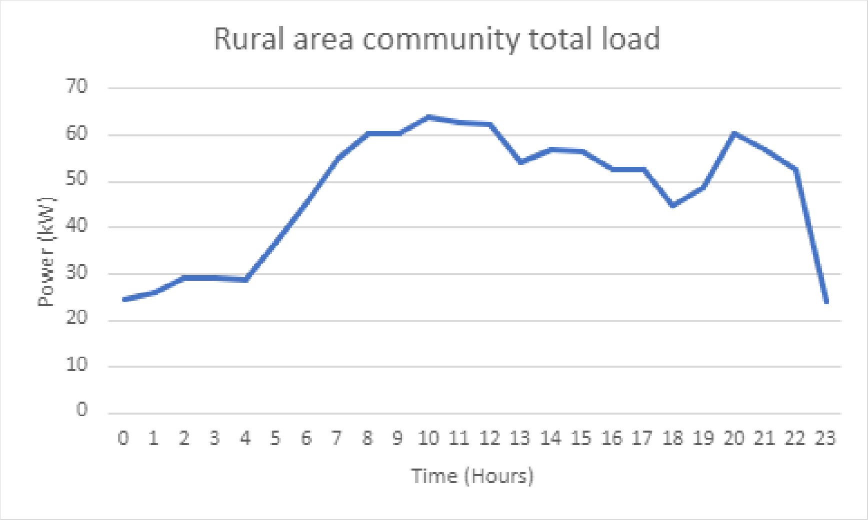

Figure 18. Typical 24-hour load profile

The total load profile is then constructed from the sum of the individual power requirements which gives out a profile that roughly peaks at 64 kW.

8. Conclusion

The document establishes a comprehensive set of requirements for battery management systems in second life battery systems. These requirements are informed by a detailed analysis of first life battery systems across various applications. The document thoroughly discusses the specifications of different battery systems, including those used in maritime, stationary, and mobility applications, and highlights their cell chemistry, performance, BMS, communication, safety, lifetime including SOH and EOL, and certification aspects.

Furthermore, the document identifies and defines the use cases for second life battery systems, such as grid stabilization and renewable energy integration, and sets forth the technical, environmental, and communication requirements for the planned demonstrations in France, the Czech Republic, and Morocco. It also provides a standardization framework and evaluates the gaps and opportunities in existing standards and regulations, particularly in relation to the challenges presented by second life batteries and interoperability.

Nevertheless, this document serves as a foundational step towards enhancing the integration and performance of second life battery energy storage systems (SL-BESS) within an interoperable battery framework, paving the way for a more sustainable and efficient use of battery technology in various sectors.

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