European Commission

ROADMAP ON STATIONARY APPLICATIONS FOR BATTERIES

Prepared by Working Group 6

#BatteriesEurope

Energy

Disclaimer

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List of Acronomys

BOS	Balance of System
BES	Battery Energy Storage
BESS	Battery Energy Storage Systems
BEV	Battery Electrified Vehicle
BM	Battery Management
BMS	Battery Management System (at cell and system level)
BoL	Beginning-of-life
DoD	Depth of Discharge
DC	Direct Current
EMS	Energy Management System
EoL	End-of-life
EV	Electric Vehicle
FEC	Full Equivalent Cycle
FL-BESS	First-Life Battery Energy Storage
Li ion	Lithium ion
HESS	Hybrid Energy Storage System
MTBF	Mean Time Between Failures
RES	Renewable Energy Sources
RTE	Round trip efficiency
SDR	Self-discharge rate
SL-BESS	Second-Life Battery Energy Storage

List of Acronomys

SoC	State-of-Charge
SoE	State-of-Energy
SoF	State-of-Function
SoH	State-of-Health
SoL	State-of-Life
SoP	State-of-Power
SoS	State-of-Safety
TR	Thermal Runaway

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Executive Summary

The EU roadmap towards a climate neutral economy set the energy system at the core of the transition. To achieve the ambitious targets a massive shift from fossil fuels to renewable energy is expected to occur by 2030, with RES (mostly from wind and solar) reaching a penetration of at least 40% in end use and a 65% share in the electricity mix. Such a massive penetration of RES sets important challenges to the power system that can be effectively addressed by integrating storage technologies. Batteries are a versatile and viable technology that can play a major role in the electrification pathway, but massive technology improvements are necessary to support a large-scale deployment of batteries in stationary applications and build a competitive European battery industry.

The R&I priorities for BESS targeting 2030 are structured around six Strategic Topics (ST):

ST1 Components and technologies for performance and cost-effectiveness: To ensure competitiveness of stationary BESS, the main challenges to address are related to the decrease the cost to a half of the current cost (at present is between 300 and 400 €/kWh); the increase the overall performance at the system level; extension of calendar and cycle life; reduction of the size and physical footprint of stationary batteries. To achieve these objectives, suggested approaches are: Development of current and new chemistries; Further modularity of the whole system and sub-systems to reduce costs of manufacturing and installation; Use-case oriented BESS design; Optimized Battery Energy Storage Systems considering both the battery and conversion system; Smart BMS/EMS (ST3).

ST2 Technologies, methodologies, tools to enhance safety: Higher level of safety in BESS applications is a prerequisite for faster market adoption and social acceptance. The definition of a required safety level is complex due to several aspects: large variety of differing applications; large range of utility scale and energy content; range of different technologies; location (in private homes, densely populated urban areas or remote areas). A science-based safety validation technique for the entire BESS system must be developed, covering the broad range of different battery technologies as well as the magnitudes of energy range. Priority R&I challenges to address in the short-to-medium term are related to:

- Monitoring and maintenance tools to secure longer (re)use of cells and batteries;

- Test protocols for BESS applications and system testing;
- Risk assessment and risk analysis tools;
- Modelling and simulation tools & prognosis;
- Development of criteria for 1st life batteries to be better applicable for 2nd life;
- Controlled and safe loading and unloading.

ST3 Interoperable advanced BMS: BMS plays an important role in ensuring a reliable, safe and efficient operation of BESS, since it handles controlling functions like cell balancing and thermal management, charging and discharging, and monitors important battery parameters influencing performance and aging of the battery such as state of charge (SOC) and state of health (SOH). However, current BMSs allow only limited access to internal information to third parties, and many BMS use proprietary software to determine battery parameters. Overcoming these limitations and developing advanced and interoperable BMS with enhanced diagnoses and prognoses functions is a key challenge for BESS.

In the short-to-medium term, R&I shall prioritize:

- Development of transparent and trustworthy methods for the diagnosis of battery parameters like SOC and SOH and the prediction of battery aging;
- Development of BMS hardware and advanced sensor technologies enabling BMS self-diagnosis, reduced self-consumption;
- Development of communication standards and interfaces to enable interoperability and access to BMS information.

ST4 Digitalisation, hybridisation and interoperability: Thanks to its flexibility, BESS already offers services to all power circles: local behind-the-meter; energy communities; DSO, TSO. A strong digitalization of BESS into the grid, and the synergistic use of different energy storage technologies operated as Hybrid Energy Storage Systems (HESS), will allow faster multiservice capability, accelerating the integration of energy storage in the new grid paradigm.

To achieve this vision of an integrated, flexible power system based on RES and BESS, it is necessary to accelerate digitalization and hybridization of BESS. Digitalization is expected to allow an increasing number of new BESS-based energy services to come to the market, helping the development of cost-effective BESS and HESS ecosystems, and an optimal management of storage resources at the grid level. To support this vision, an R&I agenda to 2030 shall prioritize:

- **Interoperability of BESS:** enabling a real interoperability between different types of assets and optimizing the allocation of storage assets along the grid to achieve multi-service flexibility. Main R&I topics are: standardization of communication protocols, a common battery real-time data platform and data nomenclature; scalable basic and advanced BESS control features,

- Digital Twins will make possible reliable simulation studies, and consequently facilitate the inclusion of storage in grid-planning processes and a wide use of BESS and HESS on grid use-cases. By 2030 research shall deliver 'plug and play' BESS models;
- Multi-service capability of BESS: Standardization of centralized and decentralized control architecture & features for grid connected applications, Multi-scale control features, Technical and market coupling between BESS, hybrid systems, EV, and other energy and flexibility assets.

ST5 Second life batteries for stationary applications: By 2030, many batteries will have completed their function in EV applications and will be available for recycling in the European Union. Although at the end of their first-life (FL) they no longer meet EV performance standards, EV batteries are still able to perform on less-demanding applications, such as stationary energy-storage. Second-life (SL) batteries can serve a wide range of applications both in domestic and industrial markets with storage needs from hundreds of Wh to MWh. To tap the potential of SL batteries for stationary applications, four main technical challenges appear to be significant to support the usage of SL-BESS before recycling:

- **EOL Diagnosis:** versatile and rapid diagnosis methods to assess the SoH of FL-BESS; methodologies and technologies for understanding & modelling SL-BESS behaviour and performance forecast;
- **Refurbishing & repurposing:** existing FL batteries are not eco-designed and significant difficulties can occur while disassembling, sorting/grading, storing, re-designing (ideally with eco-design), reassembling and repurposing. R&I priorities are related to: design of SL-BESS BMS to adapt to different EOL FL-BESS or EV battery inputs Thermal management for SL-BESS; Transposition of FL-BESS safety design to SL-BESS; Eco-design & LCA methodologies;
- **Sizing:** the sizing of SL-BESS should consider advanced diagnosis results from EOL diagnosis. It is essential to continue the efforts to observe, understand, identify and model physicochemical aging phenomena to better forecast SL-BESS lifetime and performances, addressing in particular the detection of 'sudden death' phenomena;
- **Management:** SL-BESS management coupled with the EOL diagnostic results, should be versatile suitable to

address diverse SL-BESS typologies. Research shall focus on SL-BESS indicators follow-up in stationary applications; Methodologies for predictive maintenance of SL-BESS in stationary applications; development of BMS and associated power electronics topologies that could deal with high variability of chemistries, compositions and SoH of SL-BEES.

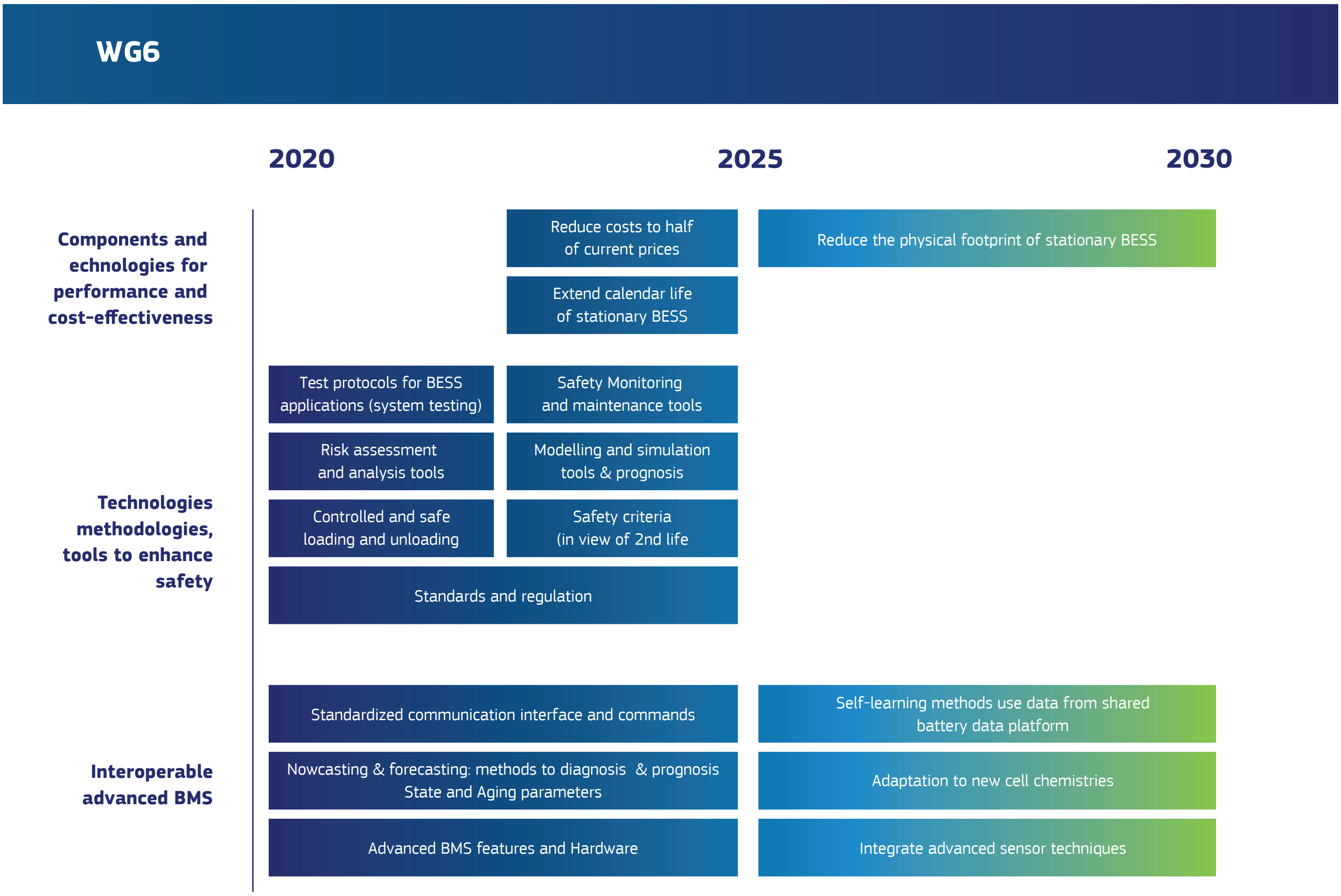
ST6 Medium-to-long term BESS: A higher penetration of RES in power generation as targeted in the new EU 2030 framework require a massive deployment of storage capacity and an increasing need for long-term / long duration energy storage[1].

The objective for Europe is to **develop a portfolio of technologies that are capable of cost-effectively serving the needs of medium-to-long storage in stationary grid- and utility-scale applications by 2030.** Batteries can be a suitable and competitive technology for **medium-to-long-term storage** and **medium-to-long-duration**, provided they meet functional and performance requirements. A R&I roadmap is proposed as following:

- **In the short term (2025):** Accelerate development of close-to-market batteries technologies, considering modularity and scalability aspects, increase of performance and cost parameters; foster pilot projects and demonstration to define the business case;
- **In the long term (2030):** Significant advancement (close-to-market) of promising technologies for long-term long-duration batteries to meet competitive cost and performance parameters and considering sustainability aspects.

[1] This broad topic is also present in the Working Group 1 (New and emerging technologies) roadmap. Working Group 1 considers low TRL at cell level and disruptive research towards new chemistries, and new cheaper materials to explore long term & long duration storage. Working Group 6 focuses on system level, current available chemistries aiming for high TRL, medium-to-long term & long duration storage.

Figure A: Graphical representation of strategic topics for stationary battery applications in the period 2020-2030+, developed by Batteries Europe WG6



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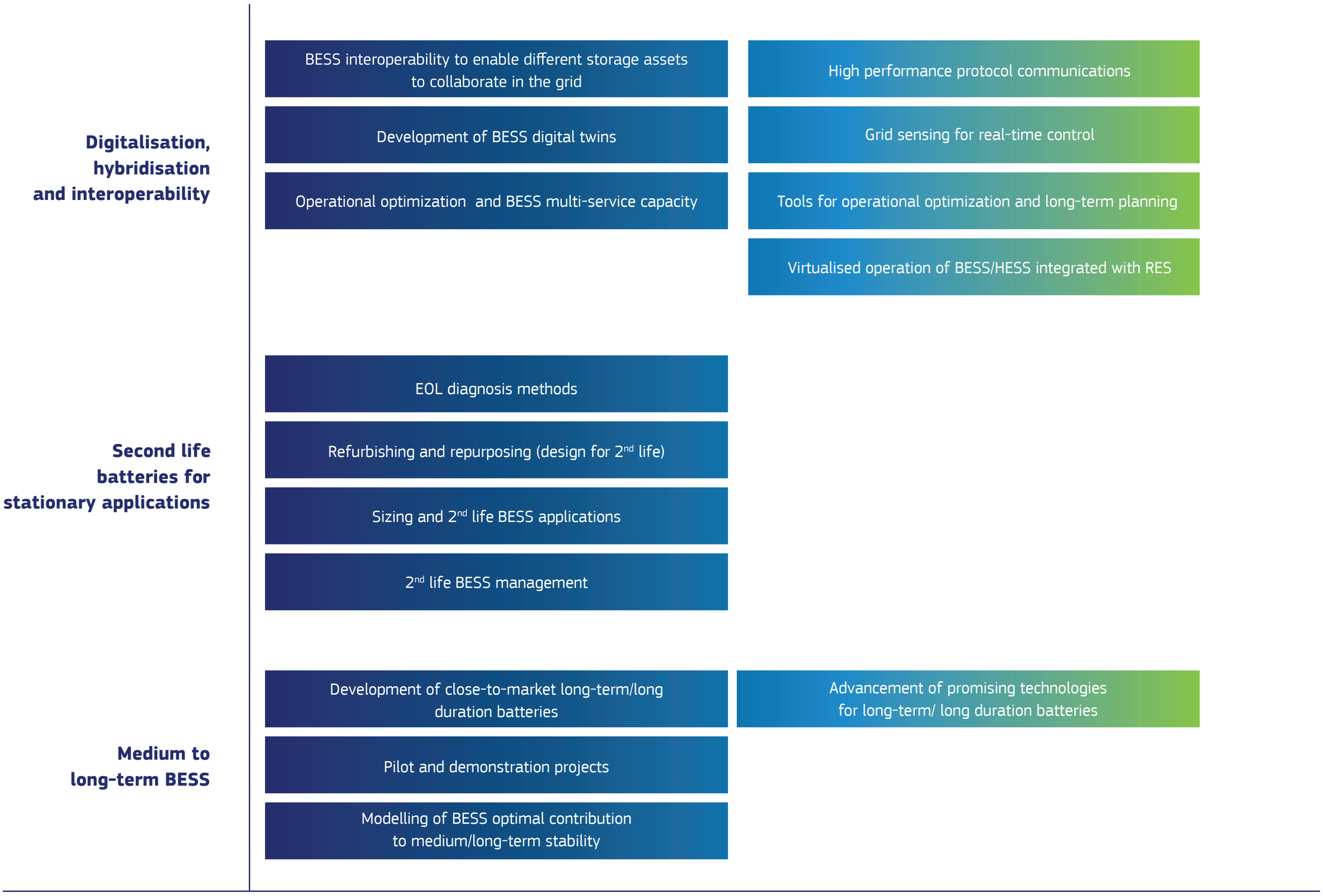


Figure A: Graphical representation of the Raw materials and recycling roadmap developed by the Batteries Europe WG6

Vision

The EU roadmap towards a climate-neutral economy by 2050 sets ambitious decarbonisation targets that shall be achieved by a massive deployment of renewable energy sources. As set in the EU Strategy for Energy System Integration[2], and in the "Fit for 55" package[3], the share of renewable energy should reach 40% by 2030 (up from initial target of 32%). This implies the share of renewable energy in the electricity mix of around 65% in 2030.

Such a massive penetration of variable renewable energy sources will present challenges for the management of the electricity system, which can be effectively addressed by integrating storage technologies. Battery storage of electricity can play an important role facilitating full decarbonisation of the energy system by 2050 as targeted by the European Green Deal[4]. In this scenario, it is envisioned that batteries will support the transition of the energy systems at many different levels: contributing to the security of supply, grid flexibility and energy sector integration; allowing increased shares of RES in power generation and fostering the transition to a more decentralised energy system relying on distributed generation.

In the medium to short term, stationary application for batteries will face a rapid up-take in different segments and use-cases. Due to their versatility, battery technology will undergo significant development and a rapid market uptake in the medium-term, thanks to the EV market, which will trigger relevant spill-over effects into the stationary energy storage market.

At grid and utility scale, the major contribution of battery technology is related to RES integration allowing the storage of surplus energy and providing services to the grid such as frequency and voltage control, peak shaving, congestion management and black start services. In commercial and industrial facilities, batteries will enable the maximum self-consumption of renewable energy, smooth integration with EV recharge systems into the grid, and provide ancillary services to the grid (including through demand response). Similarly, in the residential markets, home batteries will support the integration of RES and EV services at the building/district level at the demand side, while additionally providing balancing services to the grid. In niche applications, such as telecom or micro-grids, batteries are almost the only suitable storage solution. Finally, to some extent batteries - thanks to increased performance and lower CAPEX and OPEX - will compete with other storage technologies also in

[2] COM(2020) 299 final: Powering a climate-neutral economy: An EU Strategy for Energy System Integration
[3] COM(2021) 550 final: 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality
[4] COM(2019) 640 final: The European Green Deal

long-term and long-duration stationary applications, adding further flexibility to the system.

Digitalization will play a key role in BESS enabling a real integration of batteries as a flexible part of the grid. Digitisation of BESS systems, virtualisation of storage assets, hybridisation and the combined use of different BESS and storage technologies will lead to Hybrid Energy Storage Systems (HESS), allowing for multiservice capability of batteries in an integrated and flexible energy system.

Scope and Objectives

Within Batteries Europe ETIP, the WG6 focuses on batteries for stationary storage, from a battery system perspective and integration into the energy system. The scope of the WG and this roadmap is to identify and elaborate research priorities and technology needs for efficient stationary battery storage systems, from a joint perspective of research and industry.

To ensure usability and the further development of battery energy storage systems, there are some key challenges to be addressed, related to cost-competitiveness and performance, safety and sustainability. Indeed, due to the variety of BESS use-cases and applications, battery performances requirements vary considerably. Nevertheless, there are common challenges that are key to the advancement of BESS technologies in view of a larger integration in the reference market segments. The present roadmap focuses on six priority R&I challenges expressed as Strategic Topics (ST) to be addressed by 2030:

- **ST1** Components and technologies for performance and cost-effectiveness;
- **ST2** Technologies, methodologies, tools to enhance safety;
- **ST3** Interoperable advanced BMS;
- **ST4** Digitalisation, hybridisation and interoperability;
- **ST5** Second life batteries for stationary applications;
- **ST6** Medium-to-long term BESS.

The main objective is to set a common research agenda to support the development of a fully integrated, competitive and sustainable battery value chain in Europe, leveraging the potential of stationary applications.

Methodology

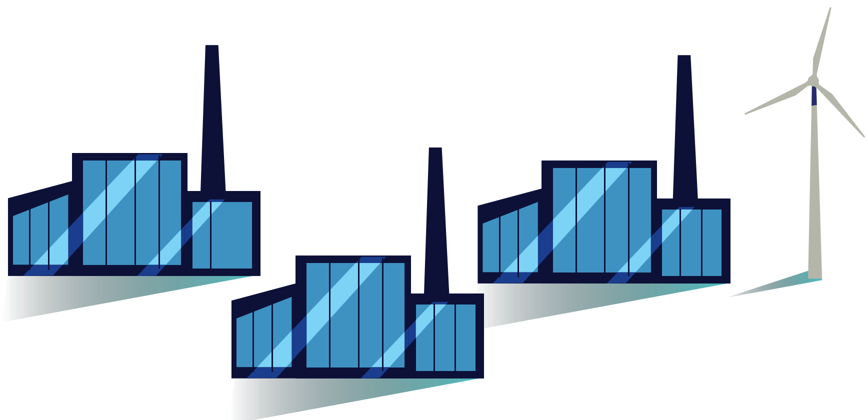
The Batteries Europe WG6 management team including Chair, co-Chairs and Sherpa have worked together to generate a sound structure and preliminary draft of the document. This Roadmap is the provisional end-point of a work started with the contribution to the Batteries Europe Strategic Research Agenda (released on December 2020), that focused the strategic areas to drive R&I on batteries in the next decade, and with an outlook to 2050. The present Roadmap, thus builds on and expands on the six key areas of the Batteries Europe SRA, identifying R&I needs with a major granularity, in order to represent a guideline for aligning public and private stakeholders R&I programmes on shared objectives.

The Strategic Topics were proposed for validation and adoption to the entire WG6 in the course of a dedicated web-meeting in November 2020. Following which, six dedicated Drafting Groups, based on voluntary commitment, were tasked with the elaboration of each section of the Roadmap through off-line and on-line work, and monthly review of the state-of-play.

In analysing the topic, the following synergies or interactions with other Batteries Europe WGs have been considered and common discussions taken place namely on Second life batteries: with WG2 Roadmap and Advanced BMS and Safety: with WG5 on mobile application,

A first iteration round of comments and feedback was organized after the release of the preliminary consolidated draft, collecting written feedback and further input from the entire WG6, and a final round for validation.

The document was finalised within a few on-line meetings and feedback given via a broad consultation of WG6 members, in addition to feedback from the Governing Board of the Batteries Europe in May 2021.



1. STRATEGIC TOPIC 1: COMPONENTS AND TECHNOLOGIES FOR IMPROVED PERFORMANCE AND COST EFFECTIVENESS

1.1 DESCRIPTION

To ensure competitiveness, the global cost of BESS must decrease to half of current costs. This can in effect be achieved by increasing the performance or doubling the lifespan of BESS compared to current values or a combination of these advancements. Reducing the size (physical footprint) of BESS is important in particular for large installations (energy and power density improvements), availability of the whole system (MTBF[5] increase) and roundtrip efficiency are currently at good levels, but improvements in these areas will be welcome.

1.2 STATE OF THE ART

Battery technology has been demonstrated, to varying degrees, to serve all five power circles: local (behind-the-meter), community, DSO (Distribution System Operator), TSO (Transmission System Operator) and pan-European. Battery stationary storage deployment benefits from a non-linear growth rate, especially in countries where legal provisions are favourable, the electrical grid is weak or climatic conditions lead to significant periods of over-supply of sun or wind energy. At the same time, cost of BESS is still an issue for Europe-wide deployment.

Today the key driver for the battery system cost are battery cells, currently between 100 to 200 €/kWh, depending on the technology, and will decrease to less than 100€/kWh by 2030. The battery pack is currently below 250 €/kWh, and the whole system is between 300 and 400 €/kWh, depending on BESS configuration. In the near future up to 2025 the expected reduction in cell costs will be the main driver for stationary energy storage system cost reduction. In the medium to long-term the cost share of the electronic and hardware components will become more significant and further cost reduction strategies need to be identified.

Batteries lifespan is highly dependent on the application. Some batteries will

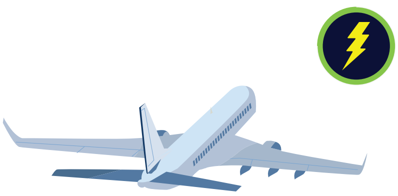
[5] Mean time between failures.

last for just a few (3-4 years) years under given use-cases (e.g. high numbers of cycles and/or deep cycles as is the case in frequency regulation), while in low-exigence use-cases (e.g. voltage regulation, back-up or PV-coupled home batteries), batteries can have lifetimes of up to 15 to 20 years. The factors that limit the life of batteries are complex (Electrolyte oxidation, surface rock-salt layer (RSL) growth, etc.). Theoretical studies and internal simulation of battery behavior are needed to explain fundamental concepts leading to longer BESS lifetime.

Batteries marketed for domestic use (i.e. in residential buildings) of +/- 10 kWh are twice as expensive per kWh than batteries for industrial use. Nevertheless, already today, it often makes sense to buy them, especially in the southern EU regions with sufficiently high irradiation factors and difference in electricity price and feed-in price of +/-0.15 EUR kWh the pay-back time of the battery is less than 10 years.

1.3 WHAT IS NEEDED FOR EUROPE TO BE COMPETITIVE?

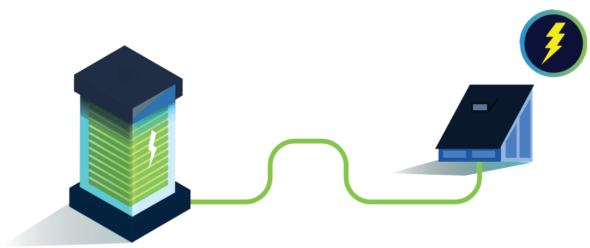
- **Reducing BESS-cost to half current prices.** Generally, for grid applications, current costs of BESS limit its use to fast-response services except in areas where traditional solutions (notably pumped hydro) are not optimal. Reducing prices would make batteries competitive in all grid markets. The use of batteries for residential application requires extreme reduction of prices;
- **Extending calendar life of BESS.** Traditional grid solutions have a calendar life of 30 to 40 years. Batteries should approach these durations to be considered solutions for grid reinforcement use-case. Alternatively, the cost should be so low that the use of two consecutive BESS solutions could be economically feasible. Telecom industry needs long life batteries for back-up application in remote locations;
- **Increasing energy density to reduce the physical footprint of BESS.** Grid use-cases need from tens to one hundred MWh, while renewable energy sources (RES) installations need hundreds of MWh of storage. This requires large sites, logistics and costs. Batteries for remote location use-cases (Telecom, etc) need long duration service. High energy density allows many hours of service when electricity service is not



available. The RES sector is starting to ask for use-cases above 5 hours. For other applications (hospitals, data centers, etc.) diesel generators are still the classical back-up solution which has unlimited service duration, even though it brings air and noise pollution plus CO2 emissions. To be competitive, batteries must provide cover for considerable durations and should have a service life of many years to make possible the amortization of investment.

1.4 RESEARCH NEEDS AND RESOURCES REQUIRED

- **Development of current and new chemistries along with modelling of internal degradation processes** as described in the Batteries Europe Roadmaps on New and Emerging technologies prepared by WG1 and Advanced Materials of WG3;
- **Further modularity** of the whole system and sub-systems to reduce costs of manufacturing and installation, e.g. wiring, cooling and overall system design optimization;
- **Use-case oriented BESS design:** e.g. a battery with **low degradation rates** over extended durations, even if it is valid only for a low number of cycles (new chemistries, new materials). Such batteries would address the needs of back-up use-cases, which require an important investment for occasional use of the BESS;
- **Optimised Battery Energy Storage Systems** as a whole both at battery and at conversion system: e.g. Selection of the optimal battery voltage output can result in lower costs, less materials required (e.g. copper) and energy losses; modularity of power converters, etc.;
- **Smart BMS/EMS algorithms** to preserve the lifespan of cells. Surveillance system of main parameters and uses, as well as automatic recovery procedures for abnormal situations (e.g.: low voltage in some cells), and intelligent operation strategies can influence and reduce the cost of the system (eg. lower DoD of the cells, less over-dimension of safety hardware). More details can be found at "Strategic Topic 3: BMS interoperability".



2. STRATEGIC TOPIC 2: TECHNOLOGIES, METHODOLOGIES & TOOLS TO ENHANCE SAFETY

2.1 DESCRIPTION

Safety of the stationary storages systems is a key parameter to the success of increasing demand for energy storage and for social acceptance. The definition of required safety level is complex due to several aspects:

- Large variety of differing applications: e.g. energy storage, backup power, frequency regulation or grid stabilization;
- Large range of utility scale and energy content: smaller kW/kWh systems mainly deployed for domestic storage applications and larger MW/MWh (today up to 300 MW) systems for commercial grid level services;
- Range of different technologies: e.g. Li ion batteries, redox flow batteries, hybrid flow batteries)[6], and other secondary batteries (lead-acid, sodium nickel chloride, sodium sulfur technologies, etc);
- Location: in private homes, in densely populated urban areas or in remote areas.

This complexity obliges specific requirements to define the safety for each individual type of application, while at the same time a general approach to safety is necessary to be adopted in standardization and regulations to provide legal certainty.

2.2 STATE OF THE ART

For stationary BESS applications, safety - not only of the cell or battery itself - is an issue of concern, but also the application component parts and the whole construction needs to be included in the safety concept. **As a BESS consists of the battery system itself and further components such as the cooling devices, power electronics and energy management, it is crucial to consider functional safety – the safe and reliable interplay between all system** components. In principle, safety should be considered at every step of the value chain including design, manufacturing, controls, communication installation, operation, maintenance, reuse, dis-assembly and recycling as well as testing of the BESS.

[6] Hybrid flow batteries are similar in design to Redox- flow batteries, but one or more electro-active component is deposited as a solid within the system. Hybrid flow batteries therefore have one battery electrode and one fuel cell electrode. The term hybrid refers to this mix of fuel cell and battery characteristics.

Identification of hazards

For each technology, the specific hazards need to be identified. Common causes of battery failure include mechanical damage, overcharge, overheating, short circuit, internal cell failure and manufacturing deficiencies. Besides electrical and physical hazards (fire, heat) also health and environmental hazards need to be considered, e.g. toxic gases, spilling or environmental impact of water runoff after extinguishing a battery fire. A specifically dangerous failure reaction of lithium-ion batteries is thermal runaway (TR), an exothermal reaction resulting in degassing, fire or even explosion of battery cells. In such cases it is critical to avoid battery pack level propagation in which one cell affect the safety of the other cells inside a module / system.

Safety testing

There are few test methodologies developed focusing exclusively on stationary storage batteries. Most extensive tests focusing on safety have been developed for Electric Vehicle (EV) battery technologies. There are the following main categories of tests: Environmental tests (atmosphere, pressure, temperature cycling), electrical tests (overcharge, short circuit, deep-charge), mechanical tests (impact, drop, vibration); thermal tests (fire, heating) and specific tests (insulation resistance, projectile) as well as propagation tests.

Safety measures

To increase safety of BESS a variety of safety measures have been developed and can be introduced at different levels. Table 2 in the Appendix displays state of the art safety measures with a focus on the currently most common Li-ion technology. However, many tools are generally applicable also for other BESS techniques. Research on safety aspects is needed at battery level, starting with cell and BMS eg, balancing cells, to enhance intrinsic safety. Safety measures also need to be developed at system level (i.e. gas and thermal management) because it remains important to mitigate effects of hazard events.

In this respect, redox flow batteries lack the inherent safety limitations of Li-ion batteries. However, the stability, toxicity, eco-friendliness, sustainability and safety of the employed active materials and cell components need to be considered. Additionally, non-corrosive, milder pH and aqueous supporting electrolytes would help to avoid spillage associated risks, limit exposure in maintenance operations and improve the overall safety of the batteries.

Safety Standards and regulation

To date there are very few relevant legal regulations internationally and only a few standards exist. Some examples are: IEC 62619; IEC 61427; VDE AR 2510-50, IEC 62620. UL 1973, UL 9540A, NFPA 855.

2.3 WHAT IS NEEDED FOR EUROPE TO BE COMPETITIVE?

Higher level of safety in BESS applications is a prerequisite for faster market adoption. A science-based safety validation technique for the entire BESS system (including batteries, power electronics, controls, housing / construction, installation, operation, monitoring, warning and mitigation measures, interplay between components) must be developed, covering the broad range of different battery technologies as well as the magnitudes of energy range. For this validation, substantial work, experiments and modeling are needed. Based on the results, standards and regulation can be enhanced. It is a challenge from a sustainability and economical perspective to open the field of BESS for 2nd life applications, unless their state of health (SoH) and also the safety (SoS) can be properly assessed.

To ensure a major up-take of batteries in large stationary applications, but also to enhance trust and acceptability by consumers, priority challenges are identified as follows:

Risk assessment: In order to define the safety level of the BESS plant, all hazards need to be identified. As numerous parameters contribute, a risk assessment will be quite complex. Respective tools must be developed and improved. A common database of incidents, which may include analysis and interpretation of the causes of the faults, would represent an important reference and support for risk assessment through real-life data.

Improvement of safety measures: increasing safety by existing or new safety measures (see also Table 1 in the Appendix) is a priority. Cost efficiency is the main factor, e.g. spatial separation is an effective way to impede propagation in case of Li-ion batteries, larger BESS installations are often leading to high costs. Next battery generations[7] or intrinsically safe cells / batteries are an important challenge in this respect. Data collection using smart functionalities (smart shut-off, smart derating, smart BMS with sensors, smart cooling system) also involving AI (artificial intelligence) will be important in future systems.

Diagnose and Monitoring: diagnose and monitoring of the state of safety (SoS) of a cell / battery, using all data available in a "big data" approach, are key to improve safety, in particular for 2nd life cells and batteries.

Safety tests on batteries according to standardized test procedures: Size and cost of grid-scale storage system often prohibit testing full-scale systems. Standardized test procedures, physical test installations and sufficient

[7] See Appendix.

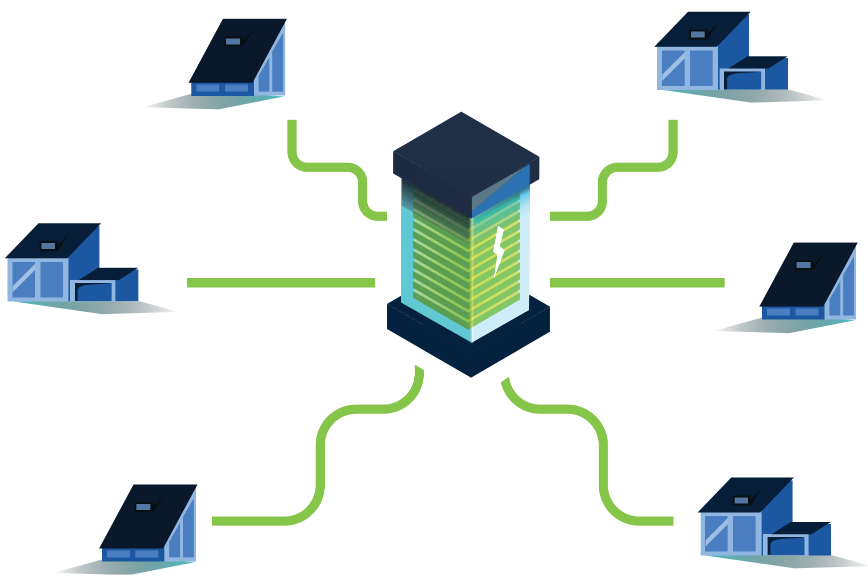
availability of testing facilities are needed to be fast to market.

Modelling and scaling challenges: Due to their size and energy content, BESS often cannot be tested on the large scale. Therefore, modelling and simulation, as well as appropriate extrapolation of results achieved at a smaller scale to expected outcomes at a larger scale are important. Modelling and simulation shall involve multi-physics approaches (electro-chemical, electric, thermal, mechanical), also enabling risk assessment and testing.

Standards and Regulations: A current concern of BESS operators are undefined legal requirements. Custom-made safety concepts involve high costs and are a time killing factor in the building permission and construction process. Standardized definition of safety levels and requirements will provide legal certainty to the operator of BESS and fair competition in the market.

The European Committees for standardization and the proposal for Batteries Regulation COM/2020/798 final[8] are the right framework to define minimum safety requirements for BESS. Classification of batteries according to the degree of hazards (as it is currently discussed in the UN subcommittee on transport of dangerous goods) will facilitate comparison of the different measures required.

Considerable research and innovation effort is needed to support standardization activities.



[8] Article 12 and Annex V (https://ec.europa.eu/environment/topics/waste-and-recycling/batteries-and-accumulators_en)

2.4 RESEARCH NEEDS AND RESOURCES REQUIRED

In terms of R&I key challenges are:

Table A: Safety in BESS: key challenges and objectives

Key Challenge	Starting point	Objectives
Standard safety solutions	Very few standards available, the contents are insufficient	Accelerating time to market Reducing costs caused by custom made solutions increasing safety of the application
Diagnose and Monitoring	Information on the SoS of cells is barely accessible (parameters not defined)	Definition of SoS and identification of suitable parameters and test methods Big data approach by combining all available data and information on the cell / battery status
Modelling, upscaling and simulation	Not available for the whole system as input data is missing	Generate input data and models Support testing by multi-physics modelling

To address these challenges, extensive research, modeling and validation are required:

Table B: R&I needs to improve safety in BESS

Key Topics	R&I identifies axes	Budget req.	Time frame
Monitoring and maintenance tools to secure longer (re)use of cells and batteries	• Identification of parameters for analysis and monitoring the SoS of cell and battery (SoS / SoH) potentially differentiate between 1st and 2nd life cells • Definition of parameters and tools for BESS plants • Big data approach	40M€	Short and medium term
Test protocols applicable for BESS applications – System testing	Facilitate development of test procedures for BESS plants focusing on: • Utility scale, private houses, commercial / industrial, district storage, buffer storage for EV (fast) charging • Battery Technology (including solid state, redox flow, sodium batteries, existing and new generation) • Fail Safeness of the safety devices (e.g. BMS) used in the BESS plant • BMS on both cell and battery levels	30M€	Short term
Standards & Regulation Delivering legal certainty Facilitates planning process	• Contribute to development of standards for stationary BESS • Identifying minimum safety requirements respecting market requirements	10M€	Short term
Risk assessment and risk analysis tools	• Identification of possible hazards of the BESS plant system • modelling of scenarios • modelling of effects and rating of efficiency of the integrated safety devices • models shall respond to and mitigate all of the observed hazardous events • protocols / equipment to be applied to the scenarios identified	20M€	Short term
Modelling and simulation tools & Prognosis	• Input data • Reference data • Multi-physics approach • up- and down-scaling • substituting/complementing tests that are not possible on the original large scale	30M€	Short and medium term
Development of criteria for 1st life batteries to be better applicable for 2nd life	• Identification and development of safety related design	20 M€	Medium term
Controlled and safe loading and unloading	• Safe fast-charging for stationary applications, high current solutions, private houses / grid applications	20M€	Short term

3. STRATEGIC TOPIC 3: INTEROPERABLE ADVANCED BMS

3.1 DESCRIPTION

Battery energy storage systems (BESS) are increasingly integrated into a wide range of applications. While battery technologies are evolving quickly, it is equally important to improve the associated battery management system (BMS) to ensure the reliable, safe and efficient operation of BESS. The BMS consists of software and hardware, which control charging and discharging and diagnose (now-casting) and prognose (fore-casting) important battery parameters, such as state of charge (SOC) and state of health (SOH). Furthermore, it handles controlling functions like cell balancing and controlling efficiently thermal management for safe and reliable operation.

In the course of its life, the battery ages depending on the load in its application and the environment. With the aging of cells, safety limits such as the charge limit must be strictly controlled. The variety and specificities of applications and the different optimization algorithms used by different energy management systems (EMS), call for open and interoperable BMS. It is necessary to be able to communicate with a third-party BMS via standardized interfaces and to access detailed data of the state of the battery system. Battery management systems must offer the possibility to be operated individually and, if necessary, to be integrated into an already existing system.

In this way, advanced and interoperable BMSs enable optimal use and second use of battery modules in terms of system costs, environmental impact and safety.

3.2 STATE OF THE ART

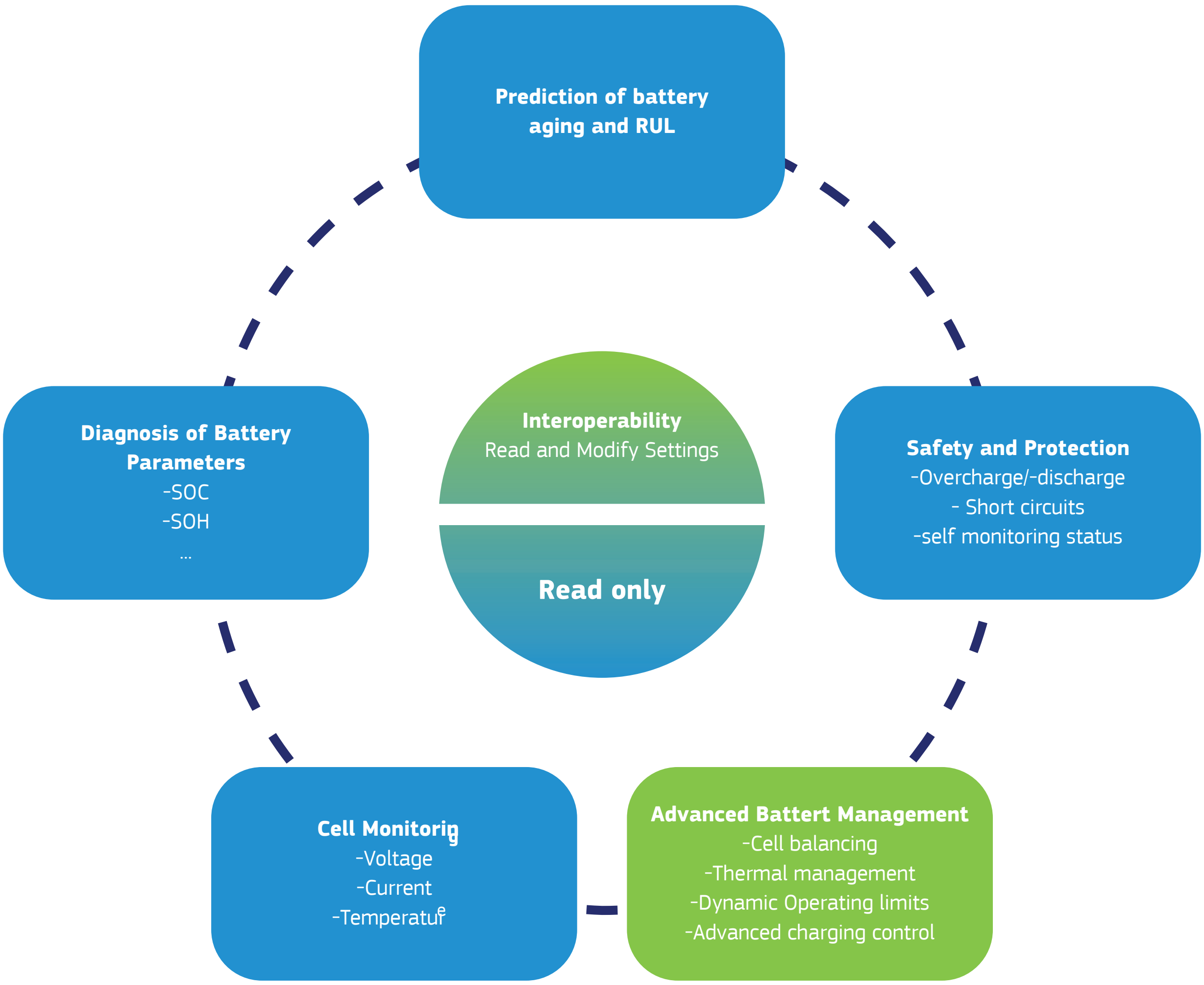
The battery management systems currently allow only limited access to internal BMS information to third parties. Furthermore, many BMS manufacturers use their own proprietary software to determine battery parameters. The definition and algorithms to estimate these parameters are still a matter of ongoing research development by the scientific community. Methods for diagnosing the various battery states or forecasting battery aging as well as the remaining useful lifetime of a storage device are rarely disclosed.

Similarly, there is little transparency about the associated error intervals. A uniform terminology and standardized communication interfaces are not available. These circumstances significantly complicate the use and integration of third party BMS.

3.3 WHAT IS NEEDED FOR EUROPE TO BE COMPETITIVE?

The key challenges arise from the most important functions of the BMS as illustrated in Figure 1. The first challenge is the definition of transparent and trustworthy methods for the diagnosis of battery parameters like SOC and SOH and the prediction of battery aging. For the use of third-party BMS the verification of already existing tools is also important. Here, a consideration of the linked accuracy and error ranges is very relevant. In addition, the suitability of different methods for various applications and battery chemistries (Li-Ion, lead-acid, redox flow...) needs to be considered.

Figure B: Future Key features of the BMS



Second, the further development of BMS **hardware** is needed. Challenges here are to extend hardware lifetime in terms of battery lifetime, reduce costs, enable BMS self-diagnosis, reduce self-consumption and specify needs for advanced sensor techniques. Improved hardware and software further enable the use of **advanced battery management** to increase lifetime, safety and reliability of BESS. This includes methods such as dynamically adaptable battery operating limits, advanced charging and control strategies, optimized thermal management and advanced cell balancing.

Finally, a communication standard to enable **interoperability** must be introduced. In large stationary BESS many battery packs with individual BMSs will be combined. In order to simplify the use of third-party BMS, commands for controlling balancing, temperature regulation or switching-off unused functions must be defined. Communication with the BMS should take place over a standardized interface. For this, also standardized communication commands, data formats, data structure and a standardized definition of important battery states must be provided.

This could also support the creation of an **open and transparent EU battery performance** database facilitating further research and development and investments in battery market.

Furthermore, it must be possible to collect and extract aging relevant battery information such as the number of cycles or extreme operating conditions, especially for stationary BESS. This can enable scalability and therefore be open market opportunities for second use applications. Furthermore, it serves as a basis for adaptability of battery packs to various applications and enables the communication with an external EMS which will optimize battery operation. The differences between EMS and BMS are defined in Table 2 in the Appendix.

3.4 RESEARCH NEEDS AND RESOURCES REQUIRED

Main R&I challenges identified are:

- Enabling Interoperability;
- State of battery health, safety, etc. diagnosis (nowcasting);
- Accessing RUL - remaining useful life and battery aging prognosis (forecasting);
- Creating Advanced Battery Management systems;
- Developing Advanced BMS Hardware.

The Table C below summarizes the R&I needs to support BESS further advancement:

Table C: R&I needs to achieve open and interoperable BMS for stationary storage

Key challenge	R&I topics	Objectives	Time frame	Resources required
Interoperable BMS	**Short to medium term** • Contribute to definition of standardized communication interface and communication commands • Enable extracting important battery life information	• Supports the transfer of batteries to second use application • Market opening for second use application • Allows for easier system integration, hybridization and scalability • Allows exchange of BESS subsystems	5 yrs → 2025	50M€
State diagnosis (nowcasting)	**Short to medium term** • Identify trustworthy methods for diagnosis of all relevant states (battery chemistry and application dependent on EMS and BMS level) • Specify required Accuracy and Error ranges • Develop self-learning methods **Long term:** • Adaptation efforts to new cell chemistries • Self-learning methods use data from shared battery data platform	• Extend battery life and ensure safe and reliable operation	3 yrs → 2025 + Long term tasks → 2030	25M€ +Long Term 2M€ / cell chemistry 30M€
RUL and battery aging prognosis (forecasting)	**Short to medium term** • Trustable, basic methods to prognose RUL and battery aging (battery technology/chemistry and application dependent on BMS and EMS level) • Application-specific Accuracy and Error ranges **Long term** • self-learning methods use data from shared battery data platform	• Ensure safe and reliable operation and extend battery life	5 yrs → 2025	10M€ Long Term + 1M€ /cell chemistry
Advanced Battery Management	**Short to medium term** • Improved battery management methods (e.g. reliable management of special situations, dynamically adjustable battery operating limits...) • Develop Charging (not only CCCV) and operating control strategies (cell chemistry dependent) • Enabling of optimized BMS maintenance (data-driven diagnostics, firmware replacements) **Long term:** • Adaptation efforts to new cell chemistries	• Decrease Levelized Cost of Storage (LCOS) • Ensure safe and reliable operation and extend battery life	3-5 yrs → 2025 + Long term task → 2030	50M€ 25M€ +Long Term 2M€ / cell chemistry
Advanced BMS Hardware	**Short to medium term** • Extend BMS Hardware lifetime in the scale of battery lifetime • Develop advanced BMS self-diagnosis capability • Cost reduction of BMS hardware • Energy efficient hardware • Hardware which enables advanced management methods (e.g. improved cell balancing) • Specification of sensor needs **Long term** • Integrate Advanced Sensor techniques (e.g.: in vivo sensors)	• BMS Cost reduction • Ensure safe and reliable operation and extend battery life	5 years → 2025 - 2030	30M€

4. STRATEGIC TOPIC 4: DIGITALIZATION, HYBRIDISATION AND INTEROPERABILITY

4.1 DESCRIPTION

With energy generation becoming decentralized and ICT (Information and Communications Technologies) increasingly present in the energy domain, the integration of renewable energy sources (RES) and promotion of energy efficiency should benefit from stationary use of Battery Energy Storage Systems (BESS, both stationary and EVs'). **BESS should, with its flexibility and thanks to integration of the ICT, be able to serve to all five power circles simultaneously:** local (behind-the-meter), community, DSO (Distribution System Operator), TSO (Transmission System Operator) and pan-European.

A strong digitalization of BESS systems into the grid along with the combined use of different energy storage technologies defined as Hybrid Energy Storage Systems (HESS), will allow faster multiservice capability. There are well-known synergies between batteries and other types of energy storage: including pumped hydro, super-capacitors, thermal storage, and hydrogen, etc. As Europe is strong in a number of storage technologies, hybridisation allows the best offering of services on the market.

The BESS' multiservice capability provides the ability to stack different grid services at the same time and is completely linked with the interoperability feature being both key topics to accelerate the integration of energy storage in the new grid paradigm. Digital twins will be a powerful tool for analysing and emulating new grid functionalities thanks to the energy storage.

Interoperability defined as the synergies between systems, sharing information for providing services between them. **Aligning that interoperability with appropriate standards, business models, and technical solutions** needs to be a part of BESS and HESS development to achieve multi-service flexibility. Interoperability would create devices with true Plug-and-Play capabilities for the Internet of Things (IoT) and seamlessly connect batteries from all EU manufacturers for the provision of innovative services, and thus scaling.

4.2 STATE OF THE ART

Digitalization is the key part of the real integration of the energy storage as a flexible part of the grid. Currently the integration of stationary energy storage systems is carried out on a plant basis, integrating its services directly to the grid or plant operator. Virtual power plants based on distributed energy storage are the first stage in the digitalisation of these assets. An additional step would involve the real time data integration in order to inter-operate them in a distributed way, improving their capabilities and the optimum operation.

Hybridisation of different battery chemistries or types of energy storage systems, working as a whole, looking for synergies between technologies in order to provide a multi-service solution, avoiding any possible chemistry oversizing or over stressing, is a trend that has technically demonstrated its benefits in some pilots in Europe, both with DC and AC coupling. The next step is to enable the distributed and de-localized hybridisation, by means of in-depth digitalisation of the systems, enabling a real interoperability between different types of assets and optimising the spread of those assets along the grid. The generation of the virtual equivalent of such hybrid systems is the first necessary step.

A given component or system's (i.e. BESS) degree of interoperability can be assessed using a 3-level scale. Establishing an assessment scale will provide market actors with a common language for understanding a BESS unit's level of interoperability, whilst also setting industry goals for interoperability. This, in turn, will act as an enabler for future advanced technologies and services, such as digital twins and multi-services.

Interoperability studies and initiatives have already been demonstrated in other areas of the smart energy sector: smart meters. CEN-CENELEC has worked with other institutions and established a Smart Meters Coordination Groups to identify a common set of interoperability standards for communication protocols. The same standards are used throughout Europe and beyond. This can serve as an example for other applications, such as the interoperability layers defined in European Smart Grids Task Force Expert Group 1 'Interoperability & Access to Data[9].

Interoperability can be assessed on a three-level scale and it can be used for most or all use cases and serve as qualitative KPIs:

1. **Level one (low), functional:** Basic standards of exchanging data between BESS and interfacing systems. BESS solutions do not have

[9] https://esmig.eu/sites/default/files/interoperability_and_access_to_data_-_eg1_work.pdf

the ability to interpret the data they receive.

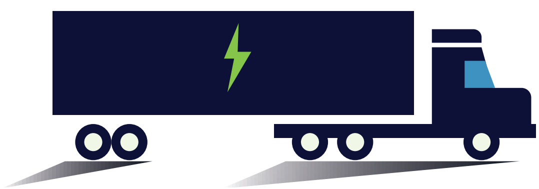
2. **Level two (intermediate), structural:** Data can be interpreted. A structure is created that ensures BESS and interfacing systems data meanings remain constant.
3. **Level three (high), semantic:** Disparate solutions can exchange information. BESS systems will be able to exchange, interpret, and use data[10].

4.3 WHAT IS NEEDED FOR EUROPE TO BE COMPETITIVE?

Interoperability, Digital Twins and Multi-Services are key enablers for improving the usability and competitiveness of battery-based and hybrid energy storage systems (BESS and HESS). Interoperability will enable cost reduction and a more efficient use of systems enabling machine-to-machine collaboration. Digital Twins will make possible reliable simulation studies, and consequently facilitate the inclusion of storage in grid-planning processes and a wide use of BESS and HESS on grid use-cases. Digital twins will enable an improved knowledge of the performance of the energy storage system during its life-time (developing online digital diagnosis tools) as well as a digital image (passport) providing essential information for second-life purposes. Energy storage still needs cost reductions and improvements in calendar life to compete with other alternatives. A Multi-Service approach can be the way to rapidly increase BESS market uptake. Without it, implementation costs will be higher, time to market will be longer, and system benefits for European electricity and battery industries will be delayed.

4.4 RESEARCH NEEDS AND RESOURCES REQUIRED

Digitalization of BESS is expected to allow an increasing number of new BESS-based energy services to come to the market, helping the development of cost-effective and sustainable BESS and HESS ecosystems, and an optimal management of storage resources at the grid level. Main R&I challenges are defined as follows in Table D:



[10] https://www.cencenelec.eu/standards/Topics/SmartMetering/Pages/default.aspx

Short to medium term 2020–2030

Table D: R&I agenda for digitalization, hybridisation and interoperability in BESS

Topic	Key Challenges
BESS Interoperability (at the system level)	**Standardization of communication protocols** • Research should contribute to alignment of existing standards should be used where possible, rather than creating new ones.
	Universal data dictionary/nomenclature • Common battery real-time data platform
	Electric Vehicle as an "Energy Storage Asset"
	Scalable BESS basic/advanced control features standardization
	Hybrid energy storage technologies/chemistries systems collaborating along the grid, both distributed and centralized
Digital twins	**Creation of plug and play BESS models embedding:** • Multi scalable modelling levels (scale to be adapted to study type) • Global/Customizable and scalable BESS architecture (user defined parameters) • Sizing capabilities • Ageing simulation capabilities • Battery basic and advanced control features at BESS level • Battery basic and advanced control features at point of connection level (centralized or decentralized operating control) • Communication protocols and capabilities
	Deep learning process based on battery past operation for battery management optimization • Predictive ageing feature • Preventive maintenance advisor
	Grid modeling and operation oriented • Grid studies: to be used for new infrastructure impact analysis • Grid operation: to be used for operation optimization scenario
	Updated model parameters for state characterization and second-life use definition (traceability)
Multi-services	**Standardization of centralized and decentralized control architecture & features for grid connected applications**
	Multi-scale control feature (residential/commercial, off-grid/isolated area/grid connected)
	Technical and market coupling between BESS, hybrid systems, EV, and other energy and flexibility assets.
Operational optimization	**Integration of battery degradation stress factors and the cost of degradation into the operational optimization and long-term planning tools**

Table D: R&I agenda for digitalization, hybridisation and interoperability in BESS

Key challenge	Research needs	Resources required
Interoperability	Support to development of standard protocols Universal data dictionary Scalable control features	65M€
Digital Twins	Plug&play BESS models Deep learning process Grid modelling Digital passport with dynamic data	60M€
Multiservices	Standardized control architecture Multi-scale control feature Technical and market coupling	50M€
Operational Optimization	Integration of BESS degradation into optimization& planning tools	40M€

Long-term up to 2050

To achieve the objective of a high number of BESS/HESS integrated on a real time basis with energy sources and the grid, working as a decentralized primary plant, in the long-term, R&I priorities are:

- Development of high performance and standardized protocol communications ; Standardized data model; Real-time shared services (splitting and stacking);
- Deep knowledge of the chemistries' behavior and degradation models (system-based models) vs the services (model matrix) for the multi-services real time control and digital twin;
- Real time control being able to emulate the behavior of generators;
- Grid sensing for detecting lack of inertia, disturbances, load and production forecasting;
- Tools for operational optimization and long-term planning that include battery degradation stress factor models;
- Standardized data model for modeling, communication and real-time control (like IEC 61850);
- Standardized virtualization layers scheme (BESS <-> HESS <-> RES+HESS/HESS <-> Distributed systems);

In the longer term the digitalization process in BESS application sector, will deliver significant results:

- Fully modellized sources and grid;
- Full link with digital twin(s) for

forecasting, optimal operation and preventive maintenance, improving safety and reliability;

- Online diagnosis during ESS life cycle, digital passport and battery state characterization for second-life purposes, adjusting model parameters during their life-time;
- Interoperability necessary to enable grid integration of BESS and use of different BESS in demand response aggregation programs for distribution (and even transmission level), in Virtual Power Plants, for offering ancillary services, etc.;
- Deep system model protocols regardless of the chemistry/vendor/technology;
- Advanced operational optimization tools enable longer lifetime, higher benefits, and lower actual LCoES and environmental impacts;
- Virtualized operation of BESS/HESS integrated with RES and linked with multiservice capability.

5. STRATEGIC TOPIC 5: SECOND-LIFE STATIONARY APPLICATIONS

5.1 DESCRIPTION

EV sales hit historic highs with 1,045,000 cars sold in EU in 2020 representing 10.5% of the market share (an increase from 3% market share in 2019)[11]. The number of EVs on the road doubled to more than two million in the EU in course of 2020.

With the dynamism of the EV market, about 450 new electric-vehicle models will be launched through 2022. By 2030, many batteries will have completed their function in EV applications as lifetimes are about 8-10 years according to OEMs warranty policies and about 1 000 000 EV batteries will be available for recycling (in the European Union). When batteries retire from EV applications, they often still have 70-80% of their initial capacity left. Although, there is value to recover materials from the battery cell, not exploiting the residual capacity would be a waste of energy and resources. As a result, the growth of the electric vehicle industry presents an opportunity for repurposing batteries (mainly LIBs) for secondary applications such as for electricity grid storage services. Thus, those batteries are becoming part of the circular economy keeping their value in the loop. New LIBs cost approximately 150 to 250 US$/kWh while second-life EV LIBs range from 44 to 180 US$/kWh[12].

[11] Transport and Environment, CO2 targets propel Europe to 1st place in e-mobility race, 2021.

[12] Eliott et al, Degradation of electric vehicle lithium-ion batteries in electricity grid services, Journal of Energy Storage, Volume 32, December 2020, 101873

There is clearly a potential for a second battery life, at least in the short term (7 to 8 years), which is dependent on the technical and economic aspects of recycling, new energy storage needs, the competition from new batteries (as new battery costs are decreasing). Although repurposing EV batteries in stationary applications seems to offer obvious environmental and economic opportunities, whether end-of-life (EOL) EV batteries should be recycled or repurposed is still debated in the community. Major challenges/barriers for repurposing remain.

5.2 STATE OF THE ART

The question of using second-life (SL) batteries must be addressed under three complementary aspects: economical, technical, and environmental.

Economic viability of SL-BESS

Considering the large volumes of used EV batteries which will become available in the coming years the potential for second-life battery energy storage system (SL-BESS) market is huge[13]. SL-BESS are mainly envisaged for stationary storage and can target a wide range of applications both in domestic and industrial markets with storage needs from hundreds of Wh to MWh. Many different players can engage in this market: vehicle makers, battery manufacturers, energy companies, but also dedicated SL companies that are starting to emerge.

With suggested SL-BESS market prices ranging from 35 to 150 €/kWh, there are several applications in which integrating SL batteries is likely to be economically viable, but the uncertainties of the stationary storage market are very large[14] and the profitability of SL-BESS remains often controversial. In addition, the market conditions are very different from one country to another. In this context, minimising refurbishment and Balance of System (BOS) costs, accurately predicting SL-BESS lifetime, and optimising its sizing may also contribute to maximise the profits of SL-BESS and bring clearer advantages over first-life battery energy storage system (FL-BESS). Other parameters such as the recycling cost or the price of new batteries will also impact the SL-BESS business cases.

The analysis of SL-BESS ageing performance was identified as a key point to their economic viability[15]. Important experimental and modelling efforts have been deployed to deal with this complex issue, aiming at predicting the capacity loss and impedance

[13] "Développement d'une filière intégrée de recyclage des batteries lithium", French National Industrial Council, 02/2020

[14] E. Martinez-Laserna et al, "Battery second life: Hype, hope or reality? A critical review of the state of the art", Renewable and Sustainable Energy Reviews 93 (2018) 701–718, doi: 10.1016/j.rser.2018.04.035

[15] E. Hossain et al, "A Comprehensive Review on Second-Life Batteries: Current State, Manufacturing Considerations, Applications, Impacts, Barriers & Potential Solutions, Business Strategies, and Policies," IEEE Access, vol. 7, pp. 73215-73252, 2019, doi: 10.1109/ACCESS.2019.2917859.

increase, but also understanding nonlinear behaviours such as the so-called "ageing knee" (rapid change in the ageing slope) and "sudden death" of batteries.

The economic analysis of the SL-BESS use strategies from the societal point of view is needed. Two main approaches of the economic assessment of SL-BESS may be performed. The first one consists in comparing the economic performance of two possible actor's choices: (i) investing in SL-BESS and (ii) investing in new BESS. This type of assessment reveal mostly the economic efficiency of private business strategies in the SL-BESS use. The second approach consist in comparing total costs and benefits of two BESS use strategies: (i) "Only First Life use and Recycling", and (ii)" First life use and Second Life use and Recycling". The latest assessment is based on the cost-benefit analysis (CBA) methodology and allows to assess the economic performance of the SL-BESS from the societal point of view.

Technical methodology and choices for SL-BESS conception

Although the 80% remaining capacity and power is widely used as a definition of FL-BESS EOL, it remains rather theoretical and in practice, the battery will be replaced when it becomes unable to fulfil the user's needs. Managing this diversity of SL-BESS initial condition, as well as the heterogeneity of cells ageing within a battery pack, is another key point for the technical an economic assessment of SL-BESS. This justifies the importance of developing robust FL-BESS assessment and refurbishment methods[6].

Depending on the specifications of the targeted application, the battery packs may be used entirely, or partly dismantled and reconditioned. Different diagnosis and test approaches have been proposed but are often project-specific since the FL-BESS design is generally specific and proprietary[7], in terms of cells arrangement, thermal and electrical management etc.

Little information can be found on safety aspects of SL-BESS6, and the evolution upon ageing of battery behaviour in abuse conditions depends especially on the cells' chemistry. The usual sampling methods for quality control are not applicable for SL-BESS since each system is virtually unique due to its first life use conditions.

International standards specific to SL-BESS are in development, while the UL 1974 standard[16] in the USA gives the general methodology for enabling repurposing batteries in second-life but remains very general concerning evaluation methods of EOL FL-BESS as well as specific safety aspects.

Specific regulations are also needed, to address in particular the transfer of responsibility to the new "battery

[16] UL 1974, 1st Edition, October 25, 2018 - UL Standard for Safety Evaluation for Repurposing Batteries.

producer", and SL-BESS warranty. The recent proposal for EU Batteries Regulation[17] provides the sound framework for re-use of batteries. R&I should support its implementation.

Environmental impact of using SL-BESS

Most studies (mainly life cycle assessment (LCA)) do converge towards a positive environmental impact of repurposing batteries and delaying recycling[5], especially concerning CO2 emissions, water consumption, energy demand, and use of fossil resources. Nevertheless, the environmental effectiveness of SL-BESS implementation strongly relies on their expected lifetime and ageing behaviour, and it is preferable to avoid extensive battery refurbishment (which would also impact the economic viability of the project)[6].

Recent demonstrators of SL-BESS applications

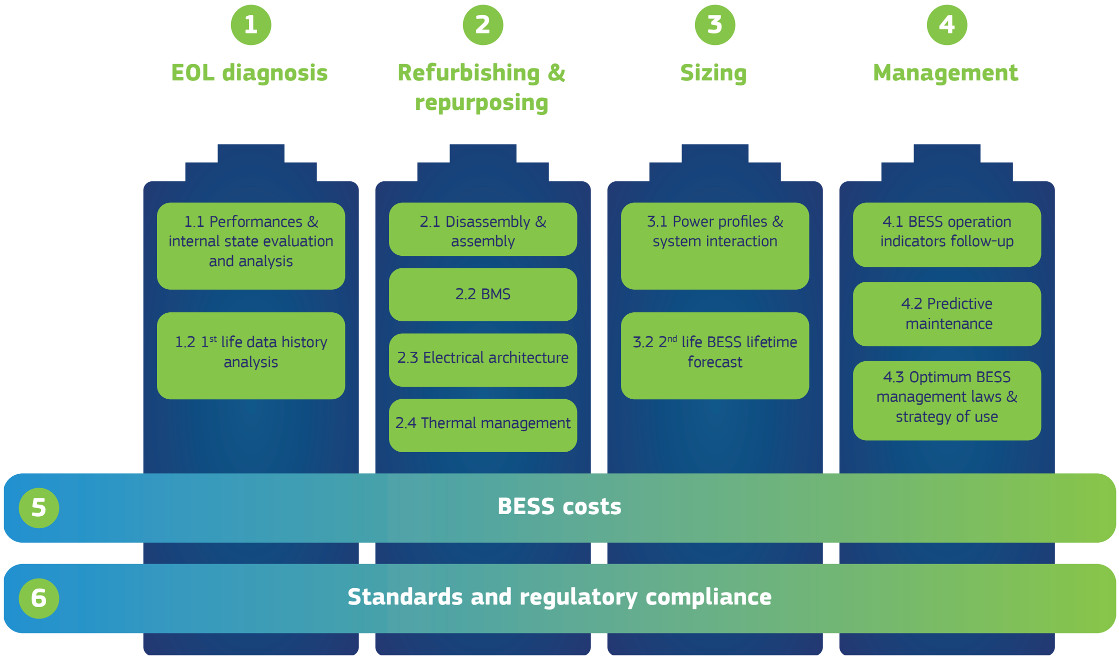
In the recent years, several demonstration projects have been deployed, especially by automotive OEMs, in order to prove the technical viability of SL-BESS use6. Many R&D projects are being conducted addressing the technical, economic and environmental viability of SL-BESS use. Some automotive OEMs have also already started commercialising products with second-life batteries, but the maturity of SL-BESS remains rather low.

5.3 WHAT IS NEEDED FOR EUROPE TO BE COMPETITIVE?

While SL-BESS potential exists (at least short term 7 to 8 years), they are competing with FL-BESS and V2G development. To move on to the next step, several key challenges have been identified in order to ease and generalise the usage of SL-BESS before recycling. Four main technical challenges appear to be significant: EOL diagnosis, Refurbishing & repurposing, Sizing and Management. Figure C aims to summarize and organize the key challenges of SL-BESS.

[17] See Batteries Regulation (with Annexes). Notably Article 14, 59 and Annex VII.

Figure C: SL-BESS Key Challenges for stationary application



1. EOL Diagnosis

Firstly, reliable First Life-BESS End of Life (EOL) diagnosis reflecting material internal FL-BESS state is essential. Currently, battery state indicators based on BESS electrical monitoring are too limited and do not allow a reliable SL-BESS performance forecast. In addition, FL-BESS usage history is rarely taken into account in the EOL diagnosis, even though it is necessary to forecast SL-BESS future performance behaviour and may help to define EOL criteria. The "battery passport" envisaged in the proposal for Battery Regulation[18] appears to guide FL-BESS new developments to improve the availability of such data. This should be accompanied by R&I to support accuracy of data.

2. Refurbishing & repurposing

As a second key challenge, refurbishing and repurposing is directly linked to FL-BESS design choices. Extracted from EV, FL-BESS will keep a variable percentage of the first life design (electrical, electronical, software, thermal, electrochemical, etc.) that may or may not be adapted to the SL-BESS regarding second-life usage expectations. As the major part of existing FL-BESS is not to date eco-designed, significant difficulties can occur while disassembling, sorting/grading, storing, re-designing (ideally with eco-design), reassembling and repurposing a maximum of FL-BESS parts to reduce SL-BESS costs while guaranteeing a safe usage. This key challenge and respective solutions haves also been identified in WG2 (Raw

[18] https://ec.europa.eu/commission/presscorner/detail/en/QANDA_20_2311

Materials and Recycling Roadmap)[19]. Please refer to WG2 document for complementary information.

3. Sizing

As a third key challenge, the sizing of SL-BESS should ideally consider advanced diagnosis results from EOL diagnosis. To achieve this it is essential to continue the current efforts in place to observe, understand, identify and model physicochemical aging phenomena to better forecast SL-BESS lifetime and performances. One particular difficulty and research interest exists regarding sudden death phenomena. This is a discontinuity on BESS SOH trend that can be seen on several BESS technologies for SOH below 80% and that may be affected by and affect SL-BESS sizing and usage.

4. Management

SL-BESS management should be, also coupled with the EOL diagnostic results, versatile enough to address diverse SL-BESS typologies. Considering the high variability of chemistries, compositions and SoH of the available SL-BESS, to add a further element of flexibility, the development of BMS and associated power electronics topologies that could deal with such differences need to be investigated.

SL-BESS should benefit from FL-BESS BMS and indicators (SOC, SOH, SOF, SOS, etc.) and from open BMS data communication to facilitate operation and monitoring. It should also be able to identify a lack of reliability of these systems (if repurposed), initially designed for higher SOH levels. An accurate SL-BESS operation follow-up coupled with specific established management methodologies and strategies of use will help to implement predictive maintenance and facilitate safe and cost-effective operation.

Cross-cutting challenges

Finally, and as transversal key challenge, SL-BESS cost (challenge #5) is strongly linked to all previous quoted challenges. All efforts on the technical challenges (#1 to #4) will reduce SL-BESS costs and support competitiveness. In addition, the definition of specific SL-BESS standards (#6) is essential in order to define an adapted regulatory framework and support the development of these systems in a safe and durable way, adapted to their new usage.

There are also legal barriers that need to be tackled. For instance, transferability of the EPR (Extended Producer Responsibility) according to the OEMs policies is essential to ensure a stable legal framework of the SL business as well as the management of EV lithium-ion batteries "End of Waste" status. The proposal for a Battery Regulation (COM/2020/798 final) offers a well-defined framework to this extent.

[19] https://ec.europa.eu/energy/sites/default/files/documents/raw_materials_and_recycling_roadmap_2.pdf

5.4 RESEARCH NEEDS AND RESOURCES REQUIRED

The following R&I activities are proposed:

Table F: Proposed R&I activities.

R&I challenge	Research needs	Budget required	Timeframe
EOL Diagnosis	• Development of versatile and rapid diagnosis methods to provide reliable FL-BESS state of health indicator, representative of BESS physicochemical state (R&I) • FL-BESS historic duty on SL-BESS behaviour understanding & modelling (R&I)	40M€	Short term (0 to 5 years)
Refurbishing & repurposing	• Design of SL-BESS BMS to adapt to different EOL FL-BESS or EV battery inputs • Thermal management for SL-BESS (R&I) • Transposition of FL-BESS safety design to SL-BESS (R&I, Coordination and Support Action (CSA)) Eco-design methodology definition & LCA (FL-BESS onto SL-BESS and third-life or recycling, R&I, CSA)	40M€	Short term (0 to 5 years)
Sizing and SL-BESS applications	• SL-BESS aging modelling and physicochemical understanding & identification (R&I) • Specific challenge on sudden death (or change of aging mechanism/trend: "aging knee") detection, identification, understanding & modelling (R&I, CSA) • SL-BESS aging heterogeneity understanding and modelling (R&I) • Development of SL-BESS sizing methodologies to minimize aging & maximize benefits focusing on the expected grid support services application (R&I, CSA) • Aging of safety devices (CID, PTC, venting valves, etc.) of SL-BESS (R&I, CSA)	20M€	Short term (0 to 5 years)
SL-BESS management	• SL-BESS indicators (SOC, SOH, SOF, ...) reliability (R&I, CSA) • SL-BESS indicators follow-up in stationary applications & Methodologies for predictive maintenance of SL-BESS in stationary applications (R&I, CSA) • Cloud / deported / universal / open-source BMS for SL-BESS (R&I, CSA) • Specific SL-BESS strategy of use, management & control laws definition & implementation (R&I, CSA) • Development of BMS and associated power electronics topologies that could deal with the expected high variability of chemistries, compositions and SoH of the future available SL-BEES (R&I)	20M€	Short term (0 to 5 years):
Cross-cutting: Costs	• Further reduce costs to be competitive with stationary FL-BESS • Modularity and design-to-reuse (R&I, CSA) • Automated processes for logistics: from EOL FL-BESS to SL-BESS (CSA)	20M€	Short term (0 to 5 years):
Cross-cutting: Standards and economic assessment	• Definition of equivalence between battery automotive standards and battery stationary standards to avoid extra cost for companies designing SL-BESS • The developments of standards for SoH and safety assessment of batteries at the end of first life applications should be addressed (R&I, CSA) • Development of methodology and elaboration of scenarios & assumptions for the societal cost-benefit analysis of SL-BESS use strategies	10M€	Short term (0 to 5 years):
Other Applications	• Development of a complete value chain dedicated to second-life applications (CSA) • Identify other business case than grid support to absorb future large upcoming end of life EV or BESS volumes (CSA)	5M€	Medium term (5 to 10 years):

6. STRATEGIC TOPIC 6: MEDIUM-TO-LONG TERM BESS

6.1 DESCRIPTION

This section focuses on batteries suitable for medium to long storage period (up to months) and long discharge times (days) at full power. Here we refer to all battery technologies enabling **medium-to-long-term storage** (storage of electricity that can be used up to several months after charge) and **medium-to-long-duration** (over 12 hours of storage at nominal power).

In this framework, ES systems (ESSs) are called to provide both fast services (i.e. power quality services) and slow services (i.e. energy management services). The latter will extend to both medium and long storage periods: weekly and/or monthly storage periods and seasonal or multi-month storage periods. Correspondingly, discharge times can range from several hours in the first case, and several days in the second case. In this framework, a parameter that may play an important role is the power to energy ratio of the storage and its capability to change and be modified in order to adapt it to evolving requirements and application.

6.2 STATE OF THE ART

Conventional stationary storage technologies

Today, conventional generation assets combined with PHES (Pumped Hydro Energy Storage), where they are available, and/or gas turbine generators provide grid flexibility. Rarely, CAES (Compressed Air Energy Storage) needing large caves, is also used. Table G reports some parameters, which can constitute benchmarks. PHES (and CAES) feature free power/energy (E/P) ratio, allowing for unbound discharge time.

Table G: (SDR = self-discharge rate; RTE = round trip efficiency)

Technology	Power	Energy	E/P	SDR	RTE	Cycle life
PHES	10^3 MW	10^4 MWh	free	≈0 %/month	70-85%	20x10^3
CAES	10^2 MW	10^3 MWh	free	≈0 %/month	60-75%	30x10^3

Innovative stationary storage technologies (other than batteries)

P2G (power to Gas) and P2H (Power to Hydrogen) are presently investigated technologies for medium-to-long-term storage, widely supported in specific EU funding programs (FCH-JU, EIC). These unbounded Energy/Power technologies are increasingly important in electric mobility and combined heat generation (CHP), but their low round-trip-efficiency suggests a lower profitability in stationary storage, considering that "challenges around cost and performance remain, and considerable improvements are still required for hydrogen to become truly competitive"[20].

Batteries / close-to-market technologies (high TRL)

Battery energy storage (BES) systems are based on different technologies/ chemistries and all together operate stationary services from frequency regulation to energy balancing. They don't pose geomorphologic constraints and are widely scalable from residential to DSO and TSO system sizes. Thus, they have also the potential to provide medium-to-long-term storage. However, some technology-dependent issues need to be solved, notably SDR (self-discharge rate, for some types of batteries), safety (for some types), volumetric energy density (for some types). Already industrialized technologies (high TRL) are:

- Li-ion batteries, in several different Li-chemistries, present Round trip efficiency (RTE)≈75-90%, SDR=2-3%/month, limited shelf life;
- Sodium based batteries, NaX (X = S; X-NiCl2) eg sodium sulfur (NaS) and Sodium-Nickel-Chloride (Na-NiCl2) present RTE≈80%, high SDR, good shelf life;
- Flow Batteries, including all-vanadium (VRFB), zinc-bromine (ZBFB), all-iron (IRFB), hydrogen-bromine (HBFB)[21]. Among them VRFBs are by far the most successful at present. Depending on the chemistry, they present RTE=70-80%, SDR≈0 (when stopped), very long shelf life.

Other batteries / non-industrialized technologies (low TRL)

- Lead-acid are not listed above for long-term storage due to SDR=4–6%/month and short shelf life under deep cycling;
- Ni-MH are not considered for long-term storage either due to SDR above 15%/month;
- Beyond-lithium solutions are potentially viable, but they still suffer a number of major issues and are still at an experimental stage (low TRL) – real potentials for long-term storage are still unexplored;
- MAB – metal-air batteries (lithium, zinc, iron, etc.) use air at one electrode with a gain in capacity and energy densities, but have low

[20] I. Staffell, et al. The role of hydrogen and fuel cells in the global energy system, Energy & Environmental Science, 2019,12, 463-491.

[21] E. Sánchez-Díez, et al. Redox flow batteries: status and perspective towards sustainable stationary energy storage, J power Sources, 481 (2021) 228804.

power density, which make them interesting candidates for some applications but major issues still persist – real potentials for long-term storage are still unexplored;

- NIFB – Non-Industrialized Flow Batteries, not listed above, are mostly experimental or at pilot level (low or mid TRL); notably aqueous organic redox flow batteries (AORFBs) are at an early operational stage, while alternative aqueous inorganic redox chemistries such as polyoxometalates are still emergent – real potentials for long-term storage are still unexplored.

6.3 WHAT IS NEEDED FOR EUROPE TO BE COMPETITIVE?

Competitive targets in the global market for the years to come have been defined in the EU by the SET Plan, to drive the further development of batteries technologies. Also in the United States the DoE has recently released its first comprehensive energy storage strategy to accelerate innovation across a range of storage technologies, including medium-to-long-term energy storage1.

To be competitive, BESS for medium-to-long-term storage applications have to meet functional and performance requirements, according to the following key performance parameters:

- **Pertinent performance and cost KPIs:** low self-discharge rate (SDR); high round-trip efficiency (RTE); high cycle and calendar life; competitive levelized cost of storage (LCoS); specific costs of power components and energy components;
- **Pertinent structural/operating features: low intrinsic fire/explosion risk; low** intrinsic contamination risk; Modularity and scalability (at uncompromised risk level): rated power from residential level up to hundreds of MW; Remote control;
- **General structural/operating features:** Topology flexibility enabling future expansions of power and/or energy; Reduction of raw material and manufacturing costs; Components' recyclability for environmental sustainability; Potential technological break-throughs to achieve industrial implementation at high TLR; Availability of raw materials; Large-scale unconditioned geographical location; Easiness of deployment.

6.4 RESEARCH NEEDS AND RESOURCES REQUIRED

The objective for Europe is to develop a portfolio of technologies that are capable of cost-effectively serving the needs of medium-to-long storage in stationary grid- and utility-scale applications by 2030.

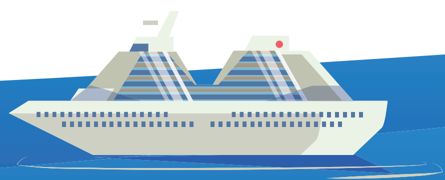
An ideal roadmap to accelerate R&I is proposed as following:

- **In the short term (2025):** Accelerate development of close-to-market batteries technologies, considering modularity and scalability aspects, increase of performance and cost parameters; foster pilot projects and demonstration to define the business case
- **In the long term (2030):** Significant advancement (close-to-market) of promising technologies for long-term long-duration batteries to meet competitive cost and performance parameters and considering sustainability aspects

Another key issues in the field of development of the medium- to long-term storage is the need to reinforce R&D&I, focused on specific medium- to long-term flexibility use cases provided with BESS-based solutions. In this regard, two complementary directions must be promoted:

- **Detailed analytic studies & modelling of the BESS optimal contribution to the medium- to long-term flexibility,** which the European electrical system will need in the future, especially due to the high penetration of intermittent renewable energy sources (RES), notably photovoltaic and wind;
- **Laboratory experimentations, demonstration and pilot projects to demonstrate technology, provide data for validation and standardization, and reduce technology risk,** providing a deep detailed view on technical and economic feasibility of relevant medium- to long-term use cases for the BESS.

A harmonized planning and coordination of these two activities, both at national and European levels, is greatly needed to allow the emergence of industrial, academic and institutional European stakeholders' commitment in this way.



7. PRIORITISATIONS & KEY RECOMMENDATIONS

Stationary battery storage is crucial for the next stage of energy transition, happening in this decade. BESS is:

- Highly valuable flexibility option;
- Highly modular --> usable in all applications: Behind-the-meter (residential, C&I), district storage, utility-scale, directly connected with huge PV and wind parks, buffer storage for charging stations for all kind of electromobility applications, stand-alone / off-grid systems, mini-grids, etc.

There are various technologies for fulfilling the requirements of all these applications but not one which fits best for all. R&D&I funding and support schemes have to be technology open. Evaluation has to consider technological, economic and environmental criteria on an equal foot.

To accelerate development and deployment of BESS solutions, an ideal roadmap is:

- In the short to mid temporal scale (2020-2030), the presently viable technologies produced by European players must be sustained in order to be optimized and to improve their competitiveness in the presently booming global market;
- In the mid-to long temporal scale (2031-2040), innovative chemistries may contribute to a widespread use of storage systems in utility scale applications, in the framework of a higher sustainability and of a real competitiveness at a global scale;
- European actions should be devoted at sustaining and promote all potentially competitive battery types which European manufactures are developing in the effort to be competitive in the global market in terms of CAPEX, OPEX and LCOS, on the basis of a real technology-neutral policy;
- It is important to promote alliances among battery manufacturers and users, in order to maximize the R&D effectiveness and competitiveness at EU Level.

Appendix

Table 1: Li-ion batteries Generations

Generation	1	2		3		4			5
		2a	2b	3a	3b	4a	4b	4c	
Type	Current	Current	State-of-The-Art	Advanced Lion HC	Advanced Lion HC	Solid State			Beyond Li-ion
Expected Commercialisation	Commercialised	Commercialised		2020	2025	>2025			
Cathode	NMC/NCA LFP LMO	NMC111	NMC424 NMC523	NMC622 NMC811	HE NMC Li-rich NMC HVS	NMC	NMC	HE NMC	
Anode	Modifed Gaphite $Li_4Ti_5O_{12}$	Modified Graphite	Modified Graphite	NMC910 Carbon (Graphite)+Si	Silicon/Carbon (C/Si)	Silicon/Carbon (C/Si)	Li metal		Li metal
Electrolyte	Organic LiPF6salts			(5-10%)	Organic+ Additives	Solid electrolyte -Polymer (+Additives) -Inogranic -Hybrid			
Separator	Porous Polymer Membranes								

Source: Nationale Plattform Elektromobilität, Marcel Meeus, JRC.

Table 2: Safety measures at different levels – focus on current Lithium-ion battery technology

	State of the art	Research level / prototypes
Safety measures at material level	• Safer materials (cathodes) • Adding flame retardants • Thick / stable separators	• Separators (e.g. ceramic, expanding materials / separators swelling after cycling)) • Cathode materials / anode materials • Electrolytes, e.g. solid-state electrolytes
Safety devices on cell level	• Short circuit protection • Over pressure protection (pressure relief), • Protection against overvoltage, undervoltage overcurrent • Shut off mechanisms (stopping cell TR)	• integration and use of sensors prohibiting chemical and electrochemical reactions directly at the cell level • self-healing functionalities to restore lost functionality within an operational cell • diagnosis parameters for SoH and SoS of the cell
Safety devices on battery level	• BMS(battery management systems) • BMS coupled with sensors • BTMS (thermal management systems) • Integrated cooling systems • Mitigation of propagation risks	• **enhanced BMS** = next generation / smart / intelligent BMS • diagnosis parameters for SoH and SoS of the battery • Research on mechanisms inside module / pack • Research on materials for **propagation mitigation**

Safety devices on application level	• design, size, location
	• design of housing (e.g. heat sinks, separations) to stop propagation of TR from one to another cell
	• passive safety device (CID, PTC, or self-healing separators)
	• shutdown devices
	• early fire detection and fire alarm systems
	• early detection of gases
	• sensor triggered warning system
	• diagnosis and surveillance: e.g. voltage measurement at cell level, current and redundant temperature measurement, gas pressure measurement,
	• sprinkler / fire extinguishing systems
	• Functional safety: reliable and safe interplay between battery storage components (DC battery with BMS, cooling, power electronics, EMS)
		• **next gen**eration and smart design /warning systems
		• diagnosis parameters for SoH (related to capacity fade and increase of inner resistance) and SoS of the battery
		  ◦ monitoring tools
		  ◦ combined with sensors
		  ◦ combined with reactive systems
		• Research on effects of cell aging on safety and reliability

Table 3: Difference between EMS and BMS

EMS	BMS

• Indicates charging and discharging strategy
• Has access to BMS information
• Organizes the interaction between application and battery
• Application specific state estimation (nowcasting)
• Estimation of application specific remaining useful life time (forecasting)
• Reliable communication with BMS and power electronics
	• Responsible for functioning and safety including functional safety of the system
	  • Permits charging /discharging
	  • Safety limits
	  • Balancing
	  • Collecting/Processing measurement data at specific system level (depending on system design)
	  • Thermal management control strategies
	• Reliable communication with peripherals (Energy- and Power management system and power electronics)
	• State estimation (nowcasting)
	• Final control decisions according to safety, reliability, performance restrictions
	• Estimation of remaining useful lifetime (forecasting) based on estimation of capacity fade and increase of inner resistance

Table 4: KPIs for stationary storage

Stationary								
Parameter	KPI	Operating conditions	Description	System/ Pack level	Unit	2015	2020	2030
PERFORMANCE								
Battery life time	Cycle life	(at 25° temperature)	Cycle life to 70% BOL and 100% DOD	Module level	n. of cycles	1,000-3,000	5,000	12,000
Battery life time	FEC - Full Equivalent Cycle	(at 25° temperature)	FEC - Life for stationary applications to 70% BOL and 100% DOD	Module level	n. of cycles	3,000-4,000	4,000-5,000	12,000
Battery life time	Calendar life	(at 25° temperature)	Calendar life considering 70% BOL	Module level	years	10	15	20
Charge/ discharge	Charging Rate time	(at 25° temperature)	Fast recharge time	Module level	min	30 (10 to 40 min)	22	12
Charge/ discharge	C-rate capability (relevant for power-oriented applications of BESS: grid stabilization etc.)	(at 25° temperature)	C (h-1) Power Rate/Specific Energy. Charge/ Discharge	Module level	h-1	1C/3C	4C/4C	up to 8C/8C
Charge/ discharge	Discharge duration (relevant for energy oriented applications/long-term storage systems)	(at 25° temperature)	Energy capacity / rated power	System Level	hours	1	4	>10
Charge/ discharge	Self discharge rate	(at 25° temperature)	% of SoC per month	System Level	% of SoC per month (%)	30%	2%	0.50%
Charge/ discharge	Roundtrip efficiency DC side	(at 25° temperature) (measured targeting a 1C charge / discharge)	(DC discharged energy/ DC charged energy) for a full cycle at system level	System Level	%	92%	95%	>97%
Charge/ discharge	Roundtrip efficiency AC/ DC side	(at 25° temperature) (measured targeting a 1C charge / discharge)	Efficiency of a complete charge/discharge cycle AC/DC/AC (calculated as AC conversion efficiency 98% each way, i.e. equal to 96% roundtrip)	System Level	%	88%	91%	>93%
Response	Response time	(at 25° temperature)	0-100% Power	System Level	0-100% Power (s/ms)	>1	200 ms	<100 ms
Energy density/ power	Gravimetric energy density	(related to 1C)		Module level	[Wh/kg]	85-135	235	>250
Energy density/ power	Volumetric energy density	(related to 1C)		Module level	[Wh/l]	95-220	500	>700 - 800
Energy density/ power	Gravimetric power density			Module level	[W/kg]	330-400	470	>700
Energy density/ power	Volumetric power density			Module level	[W/l]	350-550	1,000	>1,400
COST								
Cost	Battery cost		Battery modules cost for ESS application (including battery modules, racks e BMS)	Module level	Module level	180-285	150	75
Cost	LCoS	the KPI is dependent on use-case conditions	Cost for stationary applications (Net Present Value of the Total Cost of Ownership (Capex + Opex) / Net Present Value of the Discharged Energy, over the whole project lifetime)	System Level	System Level			
Cost	CAPEX		Capital cost of the whole system for stationary applications	System Level	System Level	600-800	450-350	

Additional Material

Table 2: Safety measures at different levels – focus on current Lithium-ion battery technology

Parameters	Li-ion	(NaX)	IFB (mainly VRFB)
Power range	some kW to 10 MW for C&I, up to several hundreds MW for large utility scale	**200kW to 50 MW**	some kW to 200 MW / 2 MW
Energy range	some kWh for residential, up to 50 MWh for C&I and to some GWh for large utility scale	**12 MWh to 400 MWh**	30 kWh to 800 MWh / 2 MWh
Cycle life	3000 to 10000	**4,500**	igent BMS diagnosis parameters for SoH and SoS of the battery
Shelf life	15-20 years	**15-20 years**	15,000–25,000
Efficiency	90-98%	70-80%	20-40 / 11-14 years
Energy density	110-220 Wh/kg	206 Wh/kg	70-84%
Temperature range	–20 – 60°C	250 – 350°C	15-25 Wh/l
Self-discharge rate	2–3%/month	high	0 – 50ºC
Reaction time	some millisec	Some millisec (if hot) / several hours (if cold)	< 0.1%/month
Pros	high efficiency high energy density high power density fast response time fair life cycle low CAPEX low LCOS possible	high capacity high efficiency high energy density high power density fast response time (hot) fair life cycle low CAPEX (NaS) possible	decoupled power and energy easy scaling-up to big plants, long energy storage time, low self-discharge fast response time intrinsically safe, no fire risk, low fault risk even in large plants, high reliability low LCOS possible
Cons	short discharge times, safety issues[22] fault risk increasing with plant size high cost of packaging and internal protection circuits (BMS)	weakness to humidity short discharge times high self-discharge (hot) high CAPEX (Na-NiCl2) critical issues related to safety, potential fires[23] fault risk increasing with plant size high cost of packaging and thermal control (BMS)	low energy density low power density some material/component costs to be reduced balance-of-plant technology to be improved/ optimized
Applications	utility grid-support applications (e.g. distributed energy storage systems), commercial end-user energy management, home back-up energy possible, frequency regulation, wind and photovoltaic smoothing, electric mobility	grid load stabilization, frequency regulation, wind and solar energy storage,	utility grid-support applications (e.g. distributed energy storage systems), commercial end-user energy management, home back-up systems possible, grid load stabilization, frequency regulation, wind and photovoltaic smoothing, utility grid-support, seasonal storage

22 Julian Spector, "APS Details Cause of Battery Fire and Explosion, Proposes Safety Fixes," GTM, July 27, 2020. Retrieved 2020-02-21. https://www.greentechmedia.com/articles/read/aps-battery-fire-explosion-safety-lithium-mcmicken-fluence

23 NAS Battery Fire Incident and Response. NGK Insulators, Ltd. On 2012-10-28. Retrieved 2020-02-21. https://web.archive.org/web/20121028121133/http:/www.ngk.co.jp/english/announce/index.html

Table 6: Extended list of topics contained in the graphical representation of strategic topics for stationary battery applications in the period 2020-2030+, developed by Batteries Europe WG6

<table>
<tr><th></th><th>Short term< 2025</th><th>Medium term 2025</th><th>Long term 2030</th></tr>
<tr><td>ST1 Components and technologies for performance and cost-effectiveness</td><td></td><td>Reduce cost to half current prices
• Further modularity of the whole system and sub-systems to reduce costs of manufacturing and installation
• Develop Optimised Battery Energy Storage Systems as a whole both at battery and at conversion system (selection of the optimal battery voltage output; modularity of power converters etc.)
• Use-case oriented BESS design

Extend calendar life of stationary BESS
• Smart BMS/EMS algorithms to preserve the lifespan of cells</td><td>Reduce the physical footprint of stationary BESS
• Increase energy density
• Development of current and new chemistries along with modelling of internal degradation processes (WG 1 and WG3)</td></tr>
<tr><td>ST2 Technologies, methodologies, tools to enhance safety</td><td>Test protocols for BESS applications (System testing)
• Development of test procedures for BESS focusing on different stationary applications (Utility scale, private houses, commercial / industrial, district storage, buffer storage for EV (fast) charging) and battery technologies
Risk assessment and risk analysis tools
• Identification of possible hazards of the BESS plant system, modelling of scenarios, modelling of effects and rating of efficiency of the integrated safety devices
Standards & Regulation delivering legal certainty and facilitating planning process
Controlled and safe loading and unloading
• Safe fast-charging for stationary applications, high current solutions, private houses / grid applications</td><td>Monitoring and maintenance tools to secure longer (re)use of cells and batteries
• Definition of parameters for analysis and tools for monitoring for BESS plants

Modelling and simulation tools & Prognosis
• substituting/complementing tests that are not possible on large scale; input and reference data
Development of safety criteria for 1st life batteries to be better applicable for 2nd life</td><td></td></tr>
<tr><td rowspan="9">ST3 Interoperable advanced BMS</td><td colspan="2">Interoperable BMS
• definition of standardized communication interface and communication commands
• Enable extracting important battery life information</td><td></td></tr>
<tr><td colspan="3">State diagnosis (nowcasting)</td></tr>
<tr><td colspan="2">• Identify trustworthy methods for diagnosis of all relevant states (battery chemistry and application dependent on EMS and BMS level)
• Specify required Accuracy and Error ranges
• Develop self-learning methods</td><td>• Adaptation efforts to new cell chemistries
• Self-learning methods use data from shared battery data platform</td></tr>
<tr><td colspan="3">RUL and battery aging prognosis (forecasting)</td></tr>
<tr><td colspan="2">• Trustable, basic methods to prognose RUL and battery aging (battery technology/chemistry and application dependent on BMS and EMS level)
• Application-specific Accuracy and Error ranges</td><td>• self-learning methods use data from shared battery data platform</td></tr>
<tr><td colspan="3">Advanced Battery Management</td></tr>
<tr><td colspan="2">• Improved battery management methods (e.g. reliable management of special situations, dynamically adjustable battery operating limits…)
• Develop Charging and operating control strategies (cell chemistry dependent)
• Optimized BMS maintenance (data-driven diagnostics, firmware replacements)</td><td>• Adaptation efforts to new cell chemistries</td></tr>
<tr><td colspan="3">Advanced BMS Hardware</td></tr>
<tr><td colspan="2">• Energy efficient hardware and cost reduction
• Hardware with advanced BMS self-diagnosis capability, enabling advanced management methods (e.g. improved cell balancing)</td><td>• Integrate Advanced Sensor techniques (e.g.: in vivo sensors)</td></tr>
</table>

Table continues on the next page

ST4 Digitalisation, hybridisation and interoperability	**BESS Interoperability (at the system level) to enable different storage asset to collaborate along the grid** • Standardization of communication protocols • Universal data dictionary/nomenclature • Common battery real-time data platform • Scalable BESS basic/advanced control features standardization	• Development of high performance and standardized protocol communications ; • Standardized data model for modeling, communication and real-time control
	Development of BESS Digital twins • Creation of plug and play BESS models embedding multiple features • Deep learning process based on battery past operation for battery management optimization with predictive ageing and preventive maintenance features • Grid modelling and operation oriented modelling • Digital passport with dynamic data	• Real time control being able to emulate the behavior of generators • Grid sensing for detecting lack of inertia, disturbances, load and production forecasting
	Enabling BESS multi-service capability • Standardization of centralized and decentralized control architecture & features for grid connected applications • Multi-scale control features • Technical and market coupling between BESS, hybrid systems, EV, and other energy and flexibility assets	• Virtualized operation of BESS/HESS integrated with RES and linked with multiservice capability • Standardized virtualization layers scheme
	Operational Optimization • Integration of BESS degradation into optimization & planning tools	• Tools for operational optimization and long-term planning that include battery degradation stress factor models
ST5 Second life batteries for stationary applications	**R&I topics**	
	EOL Diagnosis • Development of versatile and rapid diagnosis methods to provide reliable 1st life batteries state of health indicators **Refurbishing & repurposing** • Design of 2nd life BESS BMS to adapt to different EOL 1st life battery inputs • Thermal management for 2nd life BESS • Eco-design methodology & LCA (1st life BESS onto 2nd life BESS and third-life or recycling) **Sizing and SL-BESS applications** • 2nd life BESS aging modelling; sudden death detection, identification, understanding & modelling • Development of 2nd life -BESS sizing methodologies • Aging of safety devices (CID, PTC, venting valves, etc.) of 2nd life BESS **SL-BESS management** • 2nd life BESS indicators (SOC, SOH, SOF, ...) reliability • Reliable 2nd life BESS indicators (SOC, SOH, SOF, ...) and Methodologies for predictive maintenance of **2nd life BESS in stationary applications** • Cloud / deported / universal / open-source BMS and associated power electronics for 2nd life BESS (ST3) • Specific 2nd life BESS strategy of use, management & control laws definition & implementation	
	Cross-cutting topics	
	• Further reduce costs to be competitive with stationary 1st life BESS • Modularity and design-to-reuse • Automated processes for logistics: from EOL 1st life BESS to 2st life BESS • The developments of standards for SoH and safety assessment of batteries at the end of first life • Development of methodology and elaboration of scenarios & assumptions for the societal cost-benefit analysis of 2nd life BESS use strategies	• Development of a complete value chain dedicated to second-life applications • Identify other business case than grid support to absorb future large upcoming end of life EV or BESS volumes
ST6 Medium-to-long term BESS	• Accelerate development of close-to-market long-term / long-duration batteries technologies, considering modularity and scalability aspects, increase of performance and cost parameters; • Promote pilot projects and demonstration to define the business case • Detailed analytic studies & modelling of the BESS optimal contribution to the medium- to long-term flexibility	• Significant advancement of promising technologies for long-term long-duration batteries to meet competitive cost and performance parameters and considering sustainability aspects