Support to R&D Strategy and accompanying measures for battery based energy storage

Roadmap for R&I and accompanying measures 2018-2027 and short-term prioritisation (D10)

- Final version –

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Executive summary

The R&I roadmap 2018-2027[1] is a deliverable of the BATSTORM project, focused on stationary battery energy storage in Europe.
Chapter 1 presents an introduction on the setting of the BATSTORM project and objectives of the roadmap as well as providing a reader guidance to the report. Chapter 2 deals more with the background on the current policy context and market in which this roadmap is set, also describing current and future roles of battery storage and related EU industry. Chapter 3 presents the actual roadmap, indicating its goals and milestones, describing the related actions and providing an overview of priorities and planning.

Chapter 4 summarises current state of technology development and potential improvements per chemistry types. Chapter 5 suggests research and cooperation clusters for activities to be implemented/started in the short term.

Figure 1 summarizes the overall objectives (vision) and goals of this roadmap.

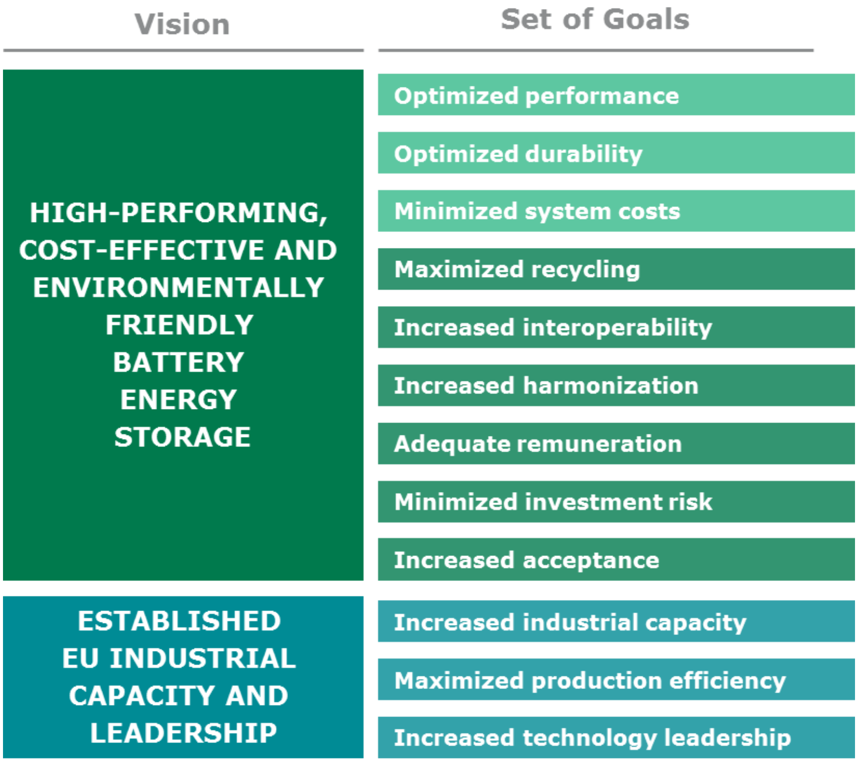

Figure 1: Overall strategic objectives and accompanying goals of the roadmap.

[1] This roadmap builds upon work and especially stakeholder consultation done before summer 2017. Originally the timeframe of the roadmap was to be 2017-2026 to cover a 10 year period. As follow-up work and fine-tuning continued beyond end-2017, the start date of the roadmap has been set to 2018.

Milestones as well as actions are defined to reach those goals. The high and very high priority actions as defined in this roadmap are shown in Table 1.

Table 1: Overview of actions rated with 'very high' and 'high' priority.

#	Action	Priority	Related goals	Type of action
2	Develop alternative materials for BES while continuing investment in advancement of today's cutting edge technology	**high**	Optimized Performance & Minimized System costs	Research
4	Develop advanced battery management solutions (thermal, electrical)	**high**	Optimized Performance, Optimized durability & Minimized System costs	Research
13	Support (large-scale) recycling and second use through adaptation of regulation	**high**	Maximized recycling	Policy
18	Create and maintain knowledge sharing platform	**high**	Increased harmonization	Policy and industry
19	Identifying and proposing best practises on battery connection and pre-qualification requirements	**very high**	Increased harmonization	Research and Policy
27	Continue development of safety standards	**high**	Increased acceptance	Industry and policy
28	Propose duty cycle and testing standards and performance certification	**high**	Increased acceptance	Research and policy
30	Facilitate industry collaboration across sectors and financial support	**very high**	Increased industrial capacity	Policy and industry
31	Estimate the market potential/demand for BESS	**high**	Increased industrial capacity	Research

This Roadmap 2018-2027 is established via a stakeholder consultation process to identify barriers, gain an overview of recent research and industry achievements, and prioritize further need for action.

Abbreviations

aFRR	Automatic Frequency Restoration Reserve
BESS	Battery Energy Storage System
BMS	Battery Management System
BMWI	Federal Ministry for Economic Affairs and Energy Germany
DSO	Distribution System Operator
EFR	Enhanced Frequency Response
ENTSO-E	European Network of Transmission System Operators for Electricity
EOL	End Of Life
FCR	Frequency Containment Reserve
FRR	Frequency Restoration Reserve
IEA	International Energy Agency
IP	Intellectual Property
ISO	International Standardisation Organisation
KPI	Key Performance Indicator
LCOS	Levelized costs of storage
LFP	Lithium Iron Phosphate batteries
Li-ion	Lithium Ion batteries
LTO	Lithium titanate batteries
mFRR	Manual Frequency Restoration Reserve
RES	Renewable Energy Sources
R&I	Research and Innovation
RT&D	Research Technology and Development
SET Plan	Strategic Energy Technology Plan of the European Commission
SOC	State of charge
TSO	Transmission System Operator

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1 Introduction

1.1 Intended audience

This 10 year R&I roadmap 2018-2027 (D10) is intended for policy makers, funding institutions, manufacturers, grid operators, energy market actors, research institutes and other stakeholders. It provides an overview of goals, milestones and actions with respect to the introduction of battery-based energy storage in the EU energy system. Additionally it provides an implementation plan for the short term actions as identified in the roadmap. It usefully complements the recently adopted SET Implementation Plan on Batteries[2].

1.2 Background and objectives

This 10 year R&I roadmap 2018-2027[3] is a deliverable of the BATSTORM project, a service project initiated by the European Commission in order to support the prioritization of R&D topics to be funded on the topic of battery-based energy storage. It is complementary to the roadmaps and implementation plans developed earlier in the Grid+Storage project[4] that mainly focused on the integration of non-battery energy storage systems in distribution and transmission grids. It covers the full RT&D chain from applied research to demonstration projects and extends to non R&I issues. The selection of topics is based on a thorough analysis of finalized and ongoing research projects and inputs from a varied set of stakeholders. The interaction with stakeholders has been an iterative and flexible process throughout the entire project. This roadmap also builds upon deliverables and work earlier developed in the BATSTORM project. Especially the socio-economic analysis of [BATSTORM D7], Technical analysis of ongoing projects [BATSTORM D12] and the stakeholder consultation response (see Appendix A: Stakeholder interaction) are a solid basis for many of the goals and actions identified in this roadmap.

There are several other initiatives active in the field of storage and battery-based storage. Notably, the Batteries Temporary Working Group active within the Strategic Energy Technology Action Plan covers both stationary battery storage as well as e-mobility and issued an Implementation Plan in November 2017[5]). Since recently, the Battery Alliance formed in October 2017 following initiative of Commission's Vice President Šefčovič also pays considerable attention to batteries' related R&I. The future work of SET Plan Batteries working group will be closely coordinated with the Battery Alliance.

The Working Group on Storage of European Technology and Innovation Platform Smart Networks for Energy Transition (with a broader focus on storage and sector coupling) is also to be mentioned. In addition,several associations have developed position papers, roadmaps or action plans in various levels of detail, and most often with clear focus on the industry segment they represent. Throughout the BATSTORM project we have reviewed their publications and used these as input for this roadmap.

[2] https://setis.ec.europa.eu/sites/default/files/set_plan_batteries_implementation_plan.pdf
[3] This roadmap builds upon work and especially stakeholder consultation done before summer 2017. Originally the timeframe of the roadmap was to be 2017-2026 to cover a 10 year period. As follow-up work and fine-tuning continued beyond end-2017, the start date of the roadmap has been set to 2018.
[4] http://www.gridplusstorage.eu/
[5] https://setis.ec.europa.eu/sites/default/files/set_plan_batteries_implementation_plan.pdf

1.3 Document structure

In chapter 2 background information is presented relevant for the roadmap process. This includes a summary of the EU policy context and introduces some important market drivers, the current and future expected role for battery-based energy storage in the EU energy system and finally a sketch of the current situation of the EU battery industry. In chapter 3, the general roadmap process within the BATSTORM project is outlined. Next, the core content of the roadmap is described. Based on two main strategic objectives, a set of goals and milestones are derived. This is translated into actions to reach the goals are proposed, which are also prioritized. In chapter 4 we provide an overview of R&D activities and achievements to date. In chapter 5 we briefly present a selection of research clusters that could cover the prioritized short term actions.

2 Background

2.1 EU policy context

Europe is a leading region when it comes to the introduction of renewable energy sources into the electricity system in order to mitigate climate change and to reduce the dependency on energy imports. The European Commission has clearly communicated its ambition in the SET plan [EC 2016a] as well as the Clean Energy Package [EC 2016d]. It has also implemented several instruments to stimulate research and technology development to cope with the challenges that result from this shift towards low-carbon energy such as the Horizon 2020 Work Programmes on *'Secure, Clean and Efficient Energy'* [see e.g. EC 2017]. Energy storage (including battery energy storage) can play a vital role in facilitating renewable energy sources in addition to a great number of other energy storage applications[6]. This will require the improvement of existing storage technologies, the development of new more cost-effective and better-performing technologies and the establishment of markets and regulation to stimulate the integration of storage systems in the distribution and transmission grids. Recently, establishment of EU-based mass production capacities for battery cells has been set as an important political priority for the EU which has led to creation of the EU Battery Alliance.

In its communication 'Towards an Integrated SET Plan' [EC 2015], the European Commission set forward 10 targets of which topics #4 *("Increase the resilience, security and smartness of the energy system")* and #7 (*"Become competitive in the global battery sector to drive e-mobility forward"*) are directly related to the topic of this roadmap. The latter action resulted in the agreement between different representatives of the European Commission services, the EU Member States and the battery industry on targets to realize this action 7, which are presented in the document "SET-Plan ACTION n°7 –Declaration of Intent" [EC 2016e]. According to this DoI, R&I should aim at *"developing and demonstrating technology, manufacturing processes, standards and systems, which have the potential of driving high-efficiency (>90%) battery based energy storage system cost below €150/kWh (for a 100kW reference system) and a lifetime of thousands of cycles by 2030 to enable them to play an important role in smart grids"*. In addition, R&I should contribute to achieving the following additional technical and cost parameters, like an increase in cycle life (3000-5000 in 2020 and 10000 in 2030) and a reduction of costs for stationary applications requiring deep discharge cycle (to 0.1 euro/kWh/cycle in 2020 and 0.05 in 2030).

The recently approved SET Implementation Plan on Batteries[7] includes a number of measures specifically targeted at stationary battery-based storage systems, in addition to e-mobility and cross-sectoral priorities:

- Advancement of batteries for stationary energy storage (Activity 1.3);
- Hybridisation of battery systems for stationary energy storage (Activity 3.1);
- Second use and smart integration into the grid (Activity 3.2).

[6] In [BATSTORM D7] a list of potential applications for batteries in the European energy system is given. These applications have been divided into four main categories, i.e. End-User Applications (Residential and Industrial), Ancillary Services, Transmission & Distribution (T&D) System Applications and Renewable Generation applications (RES applications).
[7] https://setis.ec.europa.eu/sites/default/files/set_plan_batteries_implementation_plan.pdf

Also the recently approved SET Implementation Plan to Increase the resilience and security of the energy system[8] includes plenty of activities involving storage. Here are a few examples of actions specifically focussed on storage:

- A4-IA1.3-5 Increase the flexible generation by means of the use of integrated storage in generation assets;
- A4-IA1.4-1 Multiservice storage applications to enable innovative synergies between system operators and market players;
- IA1.4-2 Advanced energy storage technologies for energy and power applications.

There is of course a dependency between efficiency, cost and durability of battery systems, which needs to be considered when setting target values and evaluating the potential role of battery systems in the energy system, which will be considered in this roadmap.

To achieve this aim, R&I should focus on a variety of battery chemistries and R&I efforts should cover materials, cells, modules but with a focus on battery systems targeting modularity and re-configurability and considering both second life and recycling aspects according to the declaration. Other mentioned requirements include enhanced safety through risk mitigation as well as increased efficiency, reduction in the use of critical materials, reduced environmental impact and implementation of Eco-design (energy savings and solvent reduction) for advanced battery materials/components manufacturing processes. Furthermore, interoperability, system integration at pack level, integration into the grid, standardization, regulations, workforce and education are mentioned as important elements.

The BATSTORM roadmap process will take into account the initiatives and focus areas as sketched above and translate them into specific battery related (R&I) goals and milestones for the coming decade to overcome the gaps and barriers which have been identified during the course of the project. Further information on this can be found in Appendix B: Overview of identified actions. The EU's Clean Energy Package, which was issued end of 2016 [EC 2016d], is instrumental for continuing to open energy markets and secure access for energy storage, including battery systems, and already addresses some of the gaps and barriers which were identified within the BATSTORM project. The most important measures proposed in this package which will improve the environment for energy storage, and by extension battery storage, include [EC 2016b]:

- The introduction of a definition of energy storage[9];
- Clarification of the role of TSOs/DSOs with respect to storage[10];
- The requirement to consider storage in the network planning process;
- Requirement for DSOs to procure services (non-frequency ancillary services) through markets ensuring effective participation of all market participants including storage facilities, save under some specific conditions as outlined in article 36 of the proposed recast of the Electricity Market Directive [EC 2016b];
- Requirements for TSOs to procure ancillary services (especially frequency reserves) through markets ensuring effective participation of all market participants including storage facilities,

[8] https://setis.ec.europa.eu/system/files/set_plan_esystem_implementation_plan.pdf

[9] *"Energy storage means, in the electricity system, deferring an amount of the electricity that was generated to the moment of use, either as final energy or converted into another energy carrier"* [EC 2016b]

[10] TSOs/DSOs shall in principle not be allowed to own, develop, manage or operate energy storage facilities, unless a) a market based approach for storage services fails; b) the storage facility is needed for the efficient, reliable and secure operation of the transmission, respectively distribution system AND c) it is approved by the regulator. [EC 2016b]

save under some specific conditions as outlined in article 54 of the proposed recast of the Electricity Market Directive [EC 2016b].

2.2 External market drivers

Besides the policy context as sketched in the previous section, there are also external market drivers influencing the development of battery based energy storage. External market drivers are not the focus of this BATSTORM project, but in some cases they can have an extremely large influence on the actual deployment of batteries or on EU industry development. Two external market drivers and their potential impact are briefly described here.

Recent developments in the domain of **electric vehicles** (EV) have accelerated[11], with large reductions in (Li-ion based) battery costs, improvements in performance and plans for increased production of batteries for EVs in Europe [EC 2016c]. These continuing developments could positively impact the stationary battery market. For example with learnings from cost reduction, searching for joint storage functions or technology improvements which could spill over to the stationary market. Also some stakeholders indicate that there could be ambivalent influences, including actors focusing on the stationary battery market being pushed out of the market by large EV battery players or reduced attention for battery technologies which might be more suitable to perform stationary storage services. A detailed analysis of the possible impacts that the electric vehicle market and its swift developments could or should have on the stationary battery storage market is explicitly not in scope of this roadmap. Still several milestones and actions have been set with the e-mobility synergy in mind.

A second external market driver is the effect that **other storage technologies or other flexibility options** can have on the role of battery based storage. The need for flexibility in the energy market can be fulfilled by batteries, but also by competing types of energy storage (e.g. pumped hydro storage, flywheels, compressed air energy storage, ultra-capacitors, P2G, thermal technologies) or other flexibility options (such as supply-side and demand side flexibility options). Some of these technologies are already mature, but there are many still in various stages of development (early research, demonstration, pilot etc.) or nearing end of lifetime (e.g. gas-fired power plants which are being mothballed). The growth and progress of these alternative technologies, their costs in comparison to battery storage and the types of services they can provide, will impact the eventual role and deployment of battery storage in Europe. An in-depth analysis of alternative technologies is not within the scope of the BATSTORM project. Earlier work in the BATSTORM project gave projections of how well these competing technology can provide certain energy services in comparison to battery based energy storage and how battery deployment for some applications could evolve [BATSTORM D7]. Other projects could provide more insights in the potential of competing flexibility options, like the ESTMAP project[12], the EASE/EERA updated roadmap (of October 2017 [EASE/EERA 2017]), the REEEM roadmap on policy-related aspects of energy storage technologies, or the broader sketch of the electricity system in the GRID+Storage project.

[11] Electrification and hybridisation is not only taking place in the passenger car sector but also in niche markets, e.g. forklift trucks, ground support equipment, agriculture, construction etc.
[12] http://www.estmap.eu/

One additional element to mention here is not so much an external driver, but also a more general aspect that could limit the use of BESS, namely data and cyber security. Data and cyber security issues are still seen as a threat for all battery applications (e.g. for those installed close to the end customer these include the collection of production and consumption data in order to control the battery system or a smart grid). Data and cyber security measures need to be further developed and adopted to the different use cases. However, since this threat is not specific or only for battery storage, this will not be dealt with in depth in this roadmap.

2.3 The current and future role of BESS in the EU energy system

The value of energy storage for the energy system lies in the application service they can provide in the system. In [BATSTORM D7] a list of potential applications for batteries in the European energy system is given. These applications have been divided into four main categories, i.e. End-User Applications (Residential and Industrial), Ancillary Services, Transmission & Distribution (T&D) System Applications and Renewable Generation applications (RES applications). Table 2 gives an overview of the different services that are considered.

Table 2: Description and typical requirements of potential applications for batteries in the EU energy system. Adapted from [BATSTORM D7].

Category	Application	Description
End-user applications	Self-Consumption	Using energy storage to maximize self-consumption from solar PV
	Energy Cost Management	Using energy storage to reduce the direct grid user cost for electricity[13]
	Backup Power	Providing backup power to end-user by means of energy storage in case of grid failure[14]
Ancillary services	Voltage Support	Injection or absorption of reactive power to maintain the voltages in the grid within a secure, stable range.
	Frequency Containment Reserve	Operating reserves necessary for constant containment of frequency deviations from nominal value to maintain the power balance in the whole synchronously interconnected system.
	Frequency Restoration Reserve	Operating reserves necessary to restore frequency to the nominal value and power balance to the scheduled value after sudden system imbalance occurrence.
	Replacement Reserves	Operating reserves used to restore the required level of operating reserves to be prepared for further system imbalance.
	Black start capability	The ability to restart a part of the grid following a blackout.
	Island operation capability	The ability to supply a grid area in isolation of the synchronous grid over extended periods of time.
T&D System Applications	Grid Congestion Relief	Using energy storage to avoid grid congestion during peak periods.
	Grid Upgrade Deferral	Using energy storage during peak periods to defer grid upgrades.

[13] Depending on the overall cost structure (energy cost, distribution and transmission fee, other costs and charges), this can entail e.g. time-of-use management or lowering peaks at certain moments.
[14] This includes using energy storage to provide back-up power for a certain time span, to protect on-site loads against short events which affect the power quality and to assure high service reliability (e.g. during transfer to on-site generation).

Category	Application	Description
	Substation On-Site Power	Provides power at substations in case of grid failure by means of energy storage.
Renewable generation Applications	Energy Revenues Optimization	Using energy storage in conjunction with VRES to optimize the income from VRES[15]
	VRES integration	Using energy storage to optimise the output from VRES to increase supply quality and value.

Based on the analysis in [BATSTORM D7] and stakeholder input, there are some applications which can be considered as the ones with the largest potential for the EU energy system, both at short and longer term. The first application is **self-consumption** of electricity from distributed renewable generation and buffered by battery based energy storage. The self-consumption use of battery storage experienced a strong increase over the last few years and was mainly driven by the German market [Agora 2014, RWTH 2016, Fraunhofer 2015a]. In other European markets residential storage systems are on the verge of profitability and therefore the number of installed systems is expected to raise considerably the coming years. Another promising application is **fast frequency response** provided by BESS, i.e. Frequency Containment Reserves (FCR), Automatic Frequency Restoration Reserve (aFRR) as applied across Europe, and even faster response variants such as Enhanced Frequency Response (EFR) as defined in the UK [National Grid 2016a]. Additional commercial battery-based applications were announced or already set up for FCR among others in Germany, the Netherlands, Belgium and Ireland. In addition to the above, two other applications show longer term potential. Of course, while booming in the short term, in the long-term market for such type of services will stay limited in view of the very nature of such services. **Distribution grid services** provided by battery based energy storage for grid congestion relief is one of them. With rising integration of both distributed electrical generation and loads, it is estimated that the market for grid congestion relief by means of battery storage will grow significantly, mainly within the distribution grid. Finally, the **integration of renewable electricity generation, especially on islands and in micro-grids** with battery based energy storage are seen as promising applications, as a substitution for fossil-based backup generation. It should however be stressed that batteries can and will probably offer multiple services and that depending on the characteristics of the energy system, certain applications will prevail.

Batteries are an attractive flexibility option for several reasons. Even if there are differences depending on the specific chemistry adopted, they are generally flexible and can be used both for power intensive and energy intensive applications. BESS offers opportunities in terms of modularity, controllability and responsiveness.

There are different technologies for battery storage, and technological innovations are ongoing. Table 3 gives an indication of the technical capability of the current main battery technologies to offer the identified applications, based on purely technical characteristics. The table shows that the potential applications for different battery technologies can vary greatly. Overall though, a battery technology can be found which shows good or even very good prospects for each of the identified applications. The overview focusses on technical suitability. If cost aspects are considered, the table might show another picture, depending on the business case for each application in combination with the costs of production of the different battery technologies.

[15] This application includes complying with the nominated power schedule to avoid imbalance costs.

Table 3: Ability of different battery technologies to offer services for the (future) EU energy system, current state of play (consortium's assessment based on work done in [BATSTORM D7]).

Application	Important storage characteristics	Lead-Acid – VRLA	Lead-Acid –Flooded	Lithium-Ion	Nickel based
Self-Consumption	Long discharge duration Long cycle life	Suitable	Less suitable	High suitability	Suitable
Energy Cost Management	High efficiency	Suitable	Less suitable	High suitability	Suitable
Backup Power	Reliability Low standby losses Long calendar life	High suitability	High suitability	High suitability	Less suitable
Voltage Support	Fast response time	Less suitable	Not applicable	High suitability	Less suitable
Frequency Containment Reserves	Reliability Fast response time Bi-directional	Less suitable	Not applicable	High suitability	Less suitable
Frequency Restoration Reserve	Reliability	Suitable	Less suitable	High suitability	Suitable
Replacement Reserves	Reliability Long discharge duration	Suitable	Less suitable	Suitable	Suitable
Black start capability	Low standby losses Long calendar life	High suitability	High suitability	High suitability	Less suitable
Island operation capability	Long discharge duration Long cycle life	High suitability	High suitability	High suitability	Less suitable
Grid Congestion Relief	Long calendar life Low standby losses	Suitable	Less suitable	Suitable	Suitable
Grid Upgrade Deferral	Mobility	Less suitable	Less suitable	Suitable	Suitable
Substation On-Site Power	Reliability Long calendar life Low standby losses	High suitability	Suitable	High suitability	Less suitable
Energy Revenues Optimization	Long discharge duration Efficiency Low operating cost	Suitable	Less suitable	High suitability	Suitable
VRES integration	Reliability Efficiency Fast response time	Suitable	Less suitable	High suitability	Suitable

High suitability / Suitable / Less suitable / Not applicable

There are also several battery technologies still in development, which could in the future also have the ability to offer the services within the future EU energy system. Projections for the technical potential of these technologies can be made but since research is still ongoing, exact future technical characteristics are uncertain. Taking into account the business case for a specific application, it could be worthwhile to develop several battery technologies for various applications.

Table 4: Ability of different battery technologies under development to offer services for the (future) EU energy system, based on their estimated technical potential (consortium's assessment based on work done in **[BATSTORM D7]**).

Application	Important storage characteristics	Metal-Air	Molten-Salt	Sodium-Ion	Redox-Flow	Hybrid Flow
Self-Consumption	Long discharge duration Long cycle life	High suitability	High suitability	Not applicable	Suitable	Suitable
Energy Cost Management	High efficiency	High suitability	Less suitable	Less suitable	Less suitable	Less suitable
Backup Power	Reliability Low standby losses Long calendar life	Suitable	Not applicable	High suitability	Not applicable	Not applicable
Voltage Support	Fast response time	High suitability	Suitable	Less suitable	Less suitable	Less suitable
Frequency Containment Reserves	Reliability Fast response time Bi-directional	High suitability	Suitable	Suitable	Less suitable	Less suitable
Frequency Restoration Reserve	Reliability	High suitability	Suitable	Suitable	Suitable	Suitable
Replacement Reserves	Reliability Long discharge duration	Suitable	High suitability	Less suitable	High suitability	High suitability
Black start capability	Low standby losses Long calendar life	High suitability	Not applicable	Suitable	Not applicable	Not applicable
Island operation capability	Long discharge duration Long cycle life	High suitability	Not applicable	High suitability	Not applicable	Not applicable
Grid Congestion Relief	Long calendar life Low standby losses	Suitable	Less suitable	Suitable	Less suitable	Less suitable
Grid Upgrade Deferral	Mobility	High suitability	Less suitable	Less suitable	Less suitable	Less suitable
Substation On-Site Power	Reliability Long calendar life Low standby losses	High suitability	Not applicable	Suitable	Not applicable	Not applicable
Energy Revenues Optimization	Long discharge duration Efficiency Low operating cost	High suitability	Less suitable	Less suitable	Less suitable	Less suitable
VRES integration	Reliability Efficiency Fast response time	High suitability	Suitable	High suitability	Suitable	Suitable

High suitability / Suitable / Less suitable / Not applicable

For delivering the envisioned services, several battery storage technologies can thus be used. For this roadmap **no technology selection or prioritization is made**. All battery technologies could in theory become reasonable investments for multiple applications if they meet qualification criteria and can reach cost competitive levels, and thus be considered for further research incentives.

In chapter 4 we present more detail on the current status of the various technologies and the main elements for improvements through research and innovation.

2.4 Recent trends and current EU battery industry development

At this moment the market of stationary battery energy storage systems is dominated by lead-acid and lithium-ion batteries. The latter technology, encompassing a whole family of applied chemistries, is expected to experience rapid growth in the coming one or two decades. This is mostly due to its recent overall performance improvement and rapidly decreasing costs, mainly driven by the market sectors of e-mobility and consumer electronics. Currently however, the lithium-ion cell manufacturing is almost exclusively covered by Asian manufacturers and also the first big production facilities in the EU will be facilities belonging to Asian companies such as LG Chem, Samsung, SK Innovation and CATL.
Stationary battery energy storage applications pose other requirements to the battery system than the automotive or consumer electronics batteries. It is true that the former sector can benefit from improvements made in the other leading battery markets, which are currently focusing on lithium-ion technologies, but it can't be ignored that there is a viable place for other battery technologies.

For the different battery technologies, strengths or presence of EU industry can differ. For example EU industry is quite well established in various niche markets and most of the elements in the value chain of lead acid batteries, while for other battery technologies and sectors, only some elements of the value chain are present.

The following parts of the value chain are selected as focus of this roadmap (Figure 2). This selection is based on where there is already a good position of the current EU industry, or where there is potential for growth. It also reflects a view of where it is essential to gain a position to enable competition on other levels.

Figure 2: Selected value chain elements that are assessed in this roadmap (compilation by EMIRI, EUROBAT, EASE, and Technofi, 2016).

The first part of the value chain selected for further assessment in this roadmap is the development and production of **battery materials**. The selection of the right materials and the way of producing these materials have a high impact on the overall footprint and economics of the battery. The expansion of the current position of EU industry in this part of the value chain can strengthen Europe's influence on the environmental impact of batteries, the economics of batteries and the security of supply of material production. There is already quite some advanced research ongoing in Europe in this field, complemented with existing competitive companies, which provides a good starting position for further expansion. Depending on the battery technology, major resources necessary for the production of battery cells and components are often sourced outside of the EU. This is especially the case for Li-ion based batteries. However, research is ongoing to substitute scarce materials for various battery technologies with others that might even be sourced within the EU [Universität Jena 2015].

The second part of the value chain selected is **cell production**. Currently Europe does not have a very strong position in cell production especially for the technologies where the greatest increase in demand is expected, particularly Li-ion. Increasing the position of the EU in this part of the value chain does have important advantages. Also this growth in demand increases risks of supply shortages and dependencies on external supply. Expanding Europe's cell production capacities and securing supply of critical materials or developing alternative materials could strongly reduce these risks, while increasing EU industry capacity and opportunities for employment. An increased role in cell production would provide opportunities for overall cost reduction and increased sustainability, quality and performance of the batteries. In Europe there is a solid basis in engineering knowledge and production experience in related sectors like electric vehicles and lead acid batteries, which may provide building blocks for the expansion of cell production.[16]

The third element of the value chain which would be a good focus point for European industry is the **integration of battery systems**. The EU currently has a strong position in this part of the value chain with existing networks and a range of market players. This part of the value chain is closely linked to the actual application of the batteries. It requires the involvement of local industries and therefore it is also essential to maintain and further develop this part with increased battery deployment.

The fourth focus point in the value chain is **recycling**. While for lead-acid a collection and recycling rate of 99% has already been achieved, the recycling for newer battery technologies still needs to be scaled up and further developed [EUROBAT 2015]. The scarcity of materials for those technologies combined with an increasing demand sets the scene for recycling. Furthermore increased attention within Europe related to the sustainability of the production process and overall better use of materials and resources give higher priority for the EU industry on the recycling part of the value chain. Efficient production cycles, including recycling options nearby, could also in the longer term lead to cost reductions, reduced environmental impacts and reduced dependence on external materials. Recycling is key area to expand for Europe to increase the sustainability of battery technologies, and to develop a leader position in this field.

Table 5: Overview of the parts of the battery value chain which have been selected for the roadmap.

Selected part of the value chain	Perceived overall role of EU in international competition (varies per technology)	Reasons for selection
Battery materials	Average	• Selection of right materials has strong impact on the overall ecologic footprint and the economics of the batteries • Ongoing advanced research • Existing competitive companies
Cell production	Weak	• Large future demand and therefore (risk of) supply shortages and dependencies if Europe's cell production capacities are not increased • Cell at the heart of the value chain • Substantial opportunity to reduce costs and increase sustainability of cell production processes • Existing knowledge should be translated to a stronger global role
Integration	Strong	• Make use of existing networks and strong position of market players • Local industries necessary for successful integration
Recycling	Average	• Great opportunities for cost reductions and increased sustainability with efficient processes

[16] This is in line with the intentions of the SET-Plan. [EC 2016c]

3 Roadmap

3.1 Process

Figure 3 below describes the process that has been followed to develop a roadmap. The process on the left shows the generic process as described by the IEA in its publication "Energy Technology Roadmaps, a guide to development and implementation" [IEA 2014]. As shown in the figure, the process starts from a set of **goals**. Based on these ultimate goals, a number of **milestones** is derived that establish a credible path toward these goals. From these milestones a number of **gaps and barriers** are identified that stand between today's practice and the achievement of the defined milestones. Finally a number of **actions** is defined to tackle these hurdles, which are then prioritized and planned in time.

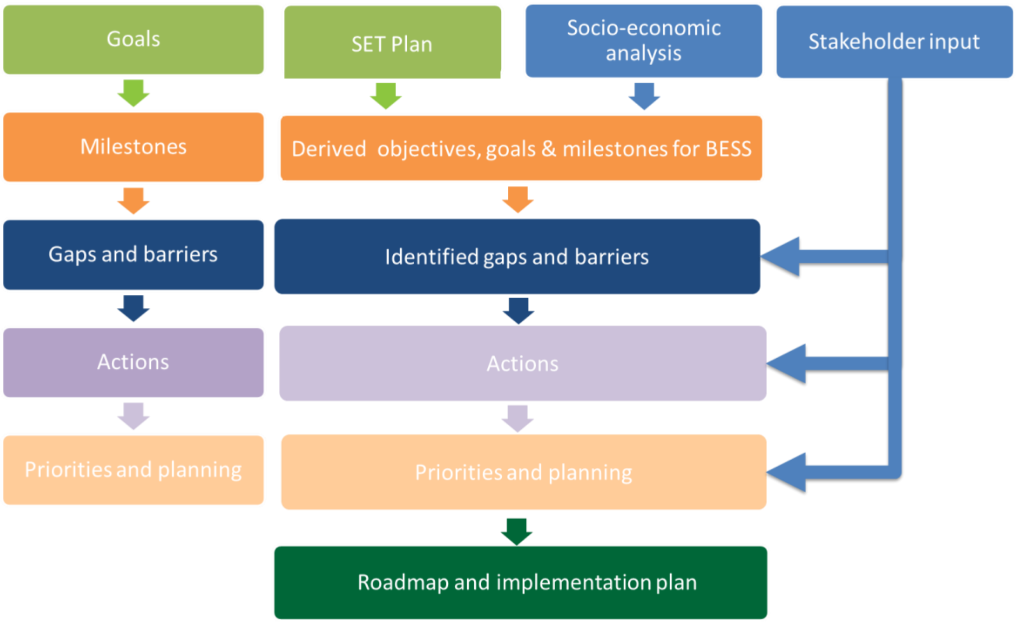

Figure 3: Generic (left) and applied (right) roadmap and implementation plan[17] (short term priorities) process.

From the overall SET plan targets [[EC 2016e]], two overall strategic objectives for the BATSTORM 10 year R&I roadmap 2018-2027 are defined. For both strategic objectives a number of more specific goals and milestones for battery energy storage systems (BESS) are derived. This analysis was enriched with stakeholder input to come up with a definitive set of goals and milestones. To reach those goals and milestones, actions have been defined (also based on an analysis of the current state and identified gaps and barriers) through multiple iterations. Finally a prioritization of the actions was included in this iteration resulting in this BATSTORM 10 year R&I roadmap 2018-2027.

[17] This implementation plan presents research clusters covering the short term priorities as identified based on the roadmap.

3.2 Goals and milestones

Starting from the targets presented in the SET plan, the two overall strategic objectives for the BATSTORM 10 year R&I roadmap 2018-2027 are defined as:

1. Development and deployment of high-performing, cost-effective and environmentally friendly battery energy storage in the EU energy system;
2. Establishing EU industrial capacity and leadership in the global battery sector.

For both strategic objectives a set of goals and milestones are defined which contribute to reach these strategic objectives. These goals are presented in Figure 4.

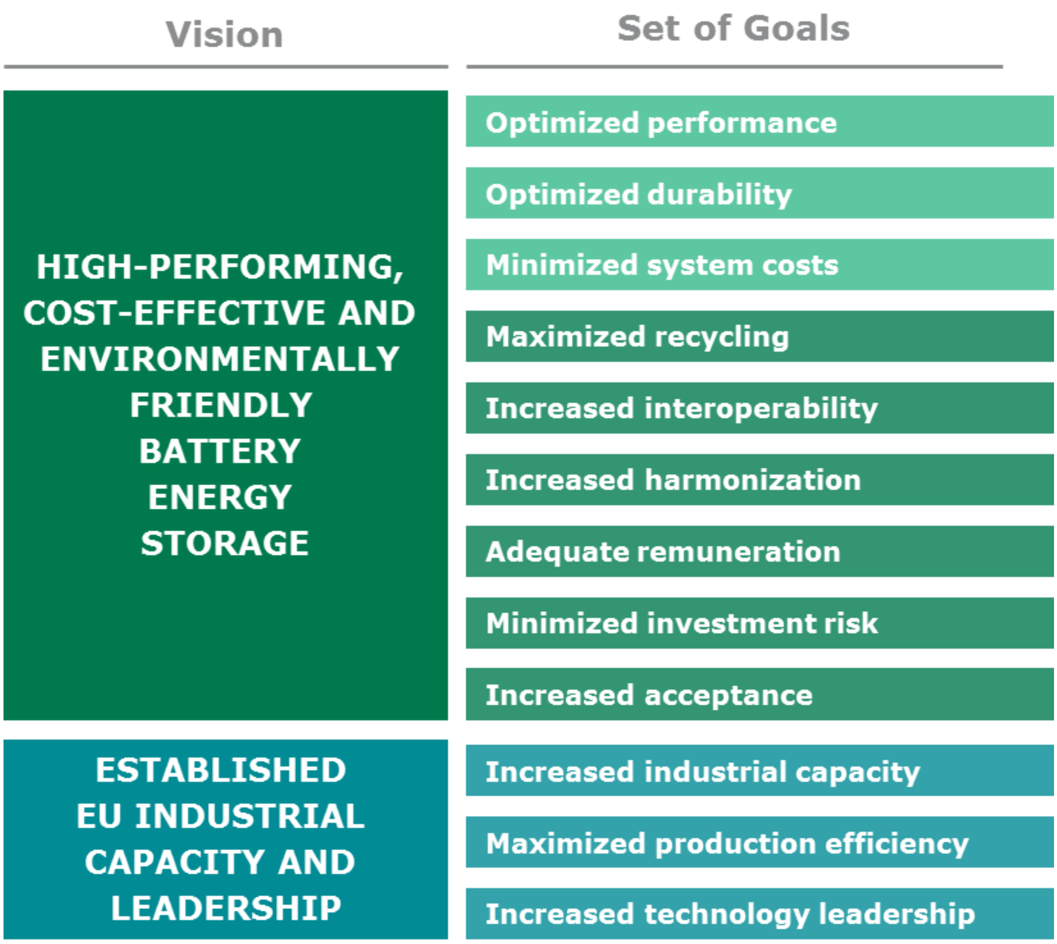

Figure 4: Overall strategic objectives and accompanying goals of the roadmap.

In this section each of these goals is described in more detail. Also milestones are identified to reach a goal, with suggested performance indicators to measure progress.

The first three goals are interlinked. There is a dependency between efficiency, durability and cost for battery systems, which needs to be considered when setting target values. A lower efficiency could for example be accepted if revenue losses can be compensated by a longer lifetime and/or a lower investment cost. Although we present specific target numbers for the three parameters in the roadmap, other values could also be acceptable as long as the economic viability of the battery technology can be proven for a specific application or combination of services, taking into account the combined effects of efficiency, cost and durability. The target numbers for these first three goals presented in this roadmap should thus be seen as indicative and not be used to give preference to certain battery technologies. Different technologies can compete based on their different strengths and weaknesses.

In the following section each proposed goal is described. Following the description of a goal and related milestones, actions are defined which are needed to reach those milestones. Some actions might be linked to multiple goals. For each action a label has been added to indicate if an action relates to a research action, a more policy/regulatory related action or an action that relates to market or industry (e.g. to be initiated by industry or market stakeholders). Thus the labels 'research', 'industry' or 'policy' are used to indicate the nature of each action.

3.2.1 Optimized performance

To assess the performance of battery technologies, multiple indicators can be introduced. A lot of them are interdependent and not all of them are crucial for a given application. The most common performance indicators are calendar and cycle life, battery costs, the energy and power density, and the efficiency of battery systems. This section deals with the energy and power density and round-trip efficiency.

Energy density relates to the amount of energy which can be stored per unit of mass or volume and is hence expressed in Wh/l (volumetric) or Wh/kg (specific or gravimetric).
The volumetric (W/l) and specific (W/kg) **power density** on the other hand relate to the loading capabilities of a battery, the rate at which energy can be transferred to and from the battery.

The **round-trip efficiency** of a storage technology in general is given by the ratio between total energy storage system output (discharge) and total energy storage system input (charge) as measured at the interconnection point. For batteries this percentage is defined by characteristics such as the battery's internal resistance and the efficiency of the power conversion components. For some battery technologies the round-trip efficiency can vary due to operating conditions such as charge and discharge rates, depth of discharge, temperature, etc. In that case usually the optimal values are given.

It has to be noted that for a given battery cell chemistry and space constraints, the cell performance can be optimized either for energy capacity or for power. The improvement potential is intrinsically limited by the system itself. There is a trade-off between power and energy capabilities for a battery energy storage solution which has to be tackled for every given end application. An exception to this rule are flow batteries, where energy and power density are decoupled, and hybrid energy storage systems.

The field of electro-mobility has required battery technologies with significant energy and power densities. Large-sized cells for high energy and high power applications are already available in the market. Current lithium ion batteries are reaching values of 85-135Wh/kg and 95-220Wh/l (90-235Wh/kg and 200-630Wh/l on cell level). Work is in progress in the automotive industry to close the gap with batteries for consumer electronics (250Wh/kg on cell level). With respect to power densities values of 330-400W/kg and 350-550W/l have been reached at pack level.

For most stationary applications the above mentioned values for pack level energy (85-135Wh/kg) and power density (350-550W/l) of currently available battery technologies are acceptable because volume and/or weight constraints are not as strict as in automotive applications. Nevertheless, since space can be scarce in some environments (cities, inside houses, etc.) volumetric power and energy density is of some concern for some of the possible applications. Especially for residential systems aimed for self-consumption optimization this may be an issue since people are not willing to reserve significant space for technical installations.

Battery systems developed for stationary applications can definitely benefit from improvements on energy and power density for automotive applications. Therefore the table below presents target values which are set for the latter [EC 2016e]. However, for stationary applications, different performance requirements are more important such as a long lifetime (calendar life and cycle life) and a low total cost of ownership, complemented by a safety component. It has to be noted though that cost reductions on the storage solution can be achieved by improvement of the energy and/or power density, as well as with increased cell voltage. If those parameters can be increased, a reduction in the number of battery cells needed can be achieved, resulting in reduced costs. Possibly hybrid solutions where more energy performant storage technologies are combined with more power performant ones can be a technical and economical solution, which in addition has the potential to increase the lifetime of the total system.

The round-trip efficiency of a battery is more important for example for the self-consumption, microgrids and island operation cases, in comparison to other applications like fast frequency response and distribution grid services. In the self-consumption case the alternative for using self-produced electricity is purchasing electricity from the grid. This means that any losses, due to storage of electricity in the battery, will have to be made up by price differences. In the case of island/microgrid operation it is advisable that 4 hours of storage capacity is available. Efficiency can play an important factor in this application. Current values of round-trip efficiencies for best performing state of the art battery technologies are in the range of 85-90% [Fraunhofer 2015]. The total efficiency of a battery energy storage system including the power conversion components of the setup of course depend on the efficiency of the inverter. Therefore it is important that appropriate inverters are developed, tailored to the right power and voltage ranges of the proposed battery packs with high efficiency over a broad power range.

Table 6 presents the milestones and current values as defined for the performance indicators related to optimized performance. It has to be stressed that those values are not minimal requirements to be reached by every technology in order to take up a role in the possible storage applications. The numbers relate to potential improvements for best of class technologies and for energy and power density are set for automotive applications. Whether a given technology will be part of the portfolio of solutions for a given stationary application, will depend on the interdependency between different performance indicators such a calendar and cycle life and costs.

Table 6: Milestones defined for the goal 'Optimized performance'.

Performance indicator	Current value	Milestone 2020	Milestone 2027
1. Improve round-trip efficiency *(including inverter)*	85-90% *for best performing state of the art battery technologies* [Fraunhofer 2015]	> 90 %	> 95 %
2. Improve energy density to the extent it may drive cost down; in addition, volumetric energy density may be important for home applications	83-135 Wh/kg and 95-220 Wh/l (pack level) 90-235 Wh/kg and 200-630 Wh/l (cell level) [EC 2016e]	235 Wh/kg and 500 Wh/l (pack level) 350 Wh/kg and 750 Wh/l (cell level) [EC 2016e]	250 Wh/kg and >500 Wh/l (pack level) 400 Wh/kg and >750 Wh/l (cell level) [EC 2016e]
3. Improve power density to the extent it may drive cost down.	330-400 W/kg and 350-550 W/l (pack level) [EC 2016e]	470 W/kg and 1000 W/l (pack level) 700 W/kg and 1500 W/l (cell level) [EC 2016e]	>470 W/kg and >1000 W/l (pack level) >700 W/k and >1500 W/l (cell level) [EC 2016e]

For the performance indicators described above the following actions have been identified. Most of the identified actions also have positive effects on the energy density, durability, safety and/or the cost of the battery system.

Action 1: Develop integrated design (battery cells, power electronics) *(research)*

To better match the different components in the battery storage solutions and to benefit optimally from their capabilities, an integrated design from cell to system level is key. Focus areas for research are connection points at cells and interconnections between them, module design and interconnections, connection to the battery management system, connection to the energy management system, cooling design and integration, and power electronics dimensioning and connection. At this moment (R&I and industrial) activities are tackling specific parts of this design chain, resulting in partial improvements at the system level.

Action 2: Develop alternative materials for BES while continuing investment in today's cutting edge technology *(research)*

One route for improvements for stationary battery solutions in terms of cost, lifetime, safety as well as energy and power density, is through the development of advanced materials for different components of a battery cell, e.g. electrodes, electrolytes, binders, separators and packaging. Since in this action the focus is on cell level and not on the system level, the term BES (battery energy storage) rather than BESS is used.

With respect to battery electrodes, improvements can still be made on current chemistries, including the most wide spread Li-ion chemistries. Electrolyte materials will need to be stable at higher voltages and the same prevails for novel separator materials. Solid-state developments in polymer or solid electrolytes may lead to higher safety levels.

All developments focused on alternative materials need to be connected in a way so that they can guarantee low cost and long cycle life, possibly in combination with a high power and/or energy density. These upcoming materials and technologies are seen as a crucial potential for the European players. This work should further be deployed in order to prepare for future market needs such as the rise of new applications but also to assure further efficiency increase and cost reductions. It is also crucial to translate the research results to market readiness. Demonstration cases and pilot projects are necessary to translate from research to deployment.
This priority corresponds to priorities of the SET Implementation plan on batteries[18] including Action 1.3 (Advancement of batteries for stationary storage) and, to some extent, Action 1.1 (Advancement of Li-ion batteries) and Action 1.4 (Post-Li-ion batteries).

As on substance research priorities on material level established within Batstorm project did not contain additional elements compared to the SET-Implementation plan on Batteries, the latter should be used as the reference document.

At the same time, conclusions in chapter 4 show which technology has what improvement potential. This information can serve as a useful tool in planning and evaluating future research and innovation calls.

It is to be noted that in the November 2017 Clean Mobility Package the Commission announced that the H2020 financing for battery research would be increased to EUR 200 million in the period 2018-2020 (from initial level of EUR 100 million). Already now two relevant calls are foreseen in the H2020 Work Programme[19].

Action 3: Improve power electronics *(research)*

The power electronics and the battery pack to which it is connected should in the first place be interoperable. Improvements can be made on this by further standardisation. A second point of improvement is a high level of efficiency of the power electronics over a broad power range. Also the electromagnetic compatibility of the power electronics and the battery and its battery management system (BMS) need further attention.

It is to be noted that Horizon 2020 call LC-SC3-ES-6-2019: "Research on advanced tools and technological development" also covers power electronics for batteries and software to manage combined or hybridised decentralised energy systems.

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18 https://setis.ec.europa.eu/sites/default/files/set_plan_batteries_implementation_plan.pdf

19 LC-NMBP-27-2019: Strengthening EU materials technologies for non-automotive battery storage
Call LC-SC3-ES-6-2019: Research on advanced tools and technological development (call inter alia covers development of a new generation of reliable, robust and cost-effective energy storage technologies, storage management systems, in particular batteries, able to provide high specific energy rates, large number of life cycles, fast response to the electrical network demands and low maintenance).

Action 4: Develop advanced battery management solutions *(research)*

The primary function of a BMS is to guarantee the safe operation of the storage system. Also features can be implemented that can enhance the battery performance and lifetime, e.g. cell balancing, state of charge/health/function (SoC/SoH/SoF) estimation. Those and other features improving the performance of batteries next to safeguarding them, need to be further developed and improved (e.g. more energy efficient cell balancing, more accurate SoC/SoH/SoF estimation) for all technologies, i.e. battery chemistries. The hardware topology of the BMS and the connection with other parts of the storage solution is another factor that might have an influence on performance but also on the recyclability, and so future research can be stimulated on this aspect. There is currently no standard topology which might benefit the above. Currently there are more than 100 commercially available (non-interoperable) BMS's. From the research point of view, little work is performed with a focus on battery energy storage. For automotive applications and for Li-ion batteries, there is for example the Everlasting project that is currently on track so synergies might be looked for with this activity.

Action 5: Control internal electrochemical reactions *(research)*

A good understanding of the parameters that influence electrochemical reactions within the battery is vital for a correct, performant and durable exploitation of the storage solution. When their effect is known, proper monitoring and control features can be designed and implemented in the storage solution. This action is not only dealing with the fundamental electrochemical reactions taking place inside a battery cell, which for most battery chemistries are well understood, but also encompasses the possible site reactions having an influence on the battery's performance.

Action 6: Develop hybrid-technology solutions *(research)*

For applications or combinations thereof where there is a need for high energy and high power capacity, hybridization of batteries with other storage technologies (e.g. supercapacitors) can contribute to a better power and life performance. Research should focus on a more generic approach on which (combination of) applications are most suited for hybrid solutions and if so, which technologies should be linked. The next step is the interoperability check between the chosen technologies: how are they physically (e.g. power connections) and virtually (e.g. battery/energy management systems) coupled so that they can be seamlessly integrated in one storage solution?

It is to be noted that this action corresponds to one of actions in the SET Implementation Plan on batteries, namely Action 3.1 "Hybridisation of battery systems for stationary energy storage".

3.2.2 Optimized lifetime

The lifetime of battery technologies can be measured by two indicators: calendar life and cycle life. Both indicators define the time (either in cycles or in calendar years) until a technology reaches its end of life (EOL). The EOL is usually defined by the reduction of the initial capacity. In stationary storage sector the EOL criterion is often defined at 60% of the initial capacity. In power applications the EOL is often defined by an increase in impedance.

The **calendar life** is the elapsed time before a battery reaches the defined end-of-life characteristics in terms of calendar years, whether it is in active use or inactive. For most battery technologies this depends highly on the operating temperature and the state-of-charge, especially during inactive periods. **Cycle life** on the other hand, is the number of charge/discharge cycles a battery can perform before its capacity falls below the EOL criteria. The cycle-life is usually affected by temperature, the charge and discharge rate (C-Rates)[20] and the depth of discharge (DoD) [Saft 2014].

The lifetime of Li-Ion batteries increased significantly during the last years. Different battery technologies can reach different results and currently there is also a large spread between different manufacturers for the same technology. Today there are battery technology providers that guarantee more than 10 years or 10,000 cycles at a given DoD for modern Li-Ion batteries [RWTH Aachen 2016] and projections of more than 10,000 to 60,000 cycles are made for next generation technologies [EASE/EERA 2017, Thielmann et al. 2015].

Redox-Flow batteries have less installed systems and their lifetime is therefore more difficult to assess. Producers provide numbers of up to 100,000 cycles and 20-30 years life expectancy [Taylor et al. 2012; VIONX Energy 2017]. This high durability is explained with the fact that the electrolyte material does not degrade [EPRI 2006]. The lifetime is therefore restricted mainly by the pumps that are expected to last at least 10 to 15 years and can be easily maintained in order to prolong the life expectancy. Also the electrodes and membranes can be a factor in the durability but they can be replaced if the cell and stack designs allow for it. This maintenance adds however to the total cost of ownership.

For future developments after 2020 also metal air, lithium sulphur and sodium-ion batteries could potentially play a role in the energy system. Currently they have a significantly shorter cycle life compared to the technologies described above.

The performance indicators for durability do not have the same importance to all possible battery applications. While the calendar life has an effect on the business case of all applications as the durability is highly interlinked with the lifetime costs of the battery, the cycle life is most important for applications with a high frequency of cycles.

The milestones as defined by the SET working group of the European Commission listed in Table 7 help quantify the goals and make the progress tangible. The examples from different battery manufacturers as listed above show that the targets set by the EC SET-Plan – Declaration of Intent [EC 2016e] have already been reached in some cases.

Table 7: Milestones defined for 'Optimized lifetime' based on [EC 2016e].

Performance indicator	Current value	Milestone 2020	Milestone 2027
Improve calendar life *(EOL-criteria: 80% of rated capacity)*	8 – 10 years	15 years	20 years
Improve cycle life *(EOL-criteria: 80% of rated capacity)*	3000 cycles	5000 cycles	10,000 cycles

"**Action 4: Develop advanced battery management solutions**" and "**Action 5: Control internal chemical reactions**" described in the previous section also contribute to increased lifetime.

[20] C-rates are the charge and discharge rates of batteries. A battery that is rated at 1C means that a fully charged battery rated at 1Ah can provide 1A for one hour. The same battery discharging at 0.5C should provide 500mA for two hours, and at 2C it delivers 2A for 30 minutes.

The following list of research actions target both the optimization of cycle and calendar life but also the development of standards that support the implementation of new solutions. Calendar life highly depends on temperature and the management and control regarding the state of charge (SOC).

Action 7: Develop simulation and modelling tools *(research)*

To improve on the prevention of some battery ageing phenomena and the mitigation of the development rate of others, there is a need for advanced simulation and modelling tools. For current battery technologies this will lead to a better understanding of encountered phenomena, potentially leading to better replacement and maintenance planning including a reduction of related costs, whereas for new technologies this is an important feature in the development phase to check on future characteristics and potential calendar and cycle life.

Action 8: Propose solutions for fault detection and protection *(research)*

Batteries are typically constructed with multiple components all prone to possible defects during the operation of the storage solution. To ensure a safe operation and the durability of the system, a proper fault detection and protection should be in place. In most systems, a reactive system using fault-triggered alarm signals, governed by the battery management system (BMS), is present nowadays which is usually based on a combination of voltage, current and temperature measurements. A preventive approach which would allow to anticipate future faults would be beneficial, so that maintenance periods can be properly timed and unnecessary and costly replacements can be avoided. Examples in this field are local pressure, volume expansion and more advanced temperature measurements which can be integrated. Of course part of the research should be dedicated to the cost-effectiveness of the proposed solution.

3.2.3 Minimized system costs

Battery system cost reduction is crucial so that battery technologies can play a role in the future energy system. The overall goal of cost reduction is to reduce the costs to a point that gives batteries the opportunity to compete with supply- and demand-side flexibility options and other storage options.

The battery system **investment cost** is used to quantify the milestones related to battery system cost reductions. The **investment cost** includes all costs for the battery itself (cells) as well as the battery management and control system and relevant electronic components. The boundaries are confined over the casing or tanks. Inverters and power electronics are thus excluded, as these components are very application specific. One drawback of using the investment cost is that it does not give an indication on the operational cost differences.

Another relevant parameter would be the Levelized Costs of Storage (LCOS) for a given application which includes both the investment and operational costs per discharged kWh. This indicator is highly dependent on the application as different parameters such as the demand profile, the lifetime and roundtrip efficiency have an impact on this indicator. The quantification of this parameter for every application is out of scope of the BATSTORM project.

Costs of battery systems are naturally important for all battery applications. However the different use patterns lead to the fact that the costs for power applications are mainly €/kW driven, while the costs for energy applications are rather driven by the kWh costs or cost per discharged energy (LCOS).

Further cost reduction potential of battery storage is driven by economies of scale, especially for Li-ion due to the expected increase of e-mobility. Experts see cell costs decreasing to just over 100 €/kWh until 2025 [VDE 2015]. System costs however are higher as the cell connection, housing and control system also need to be included. Also for other technologies cost decreases are expected due to steep learning curves and targeted research on new materials and efficiency and durability increase.

Taking into account learning curves and increased penetration, the milestones are set as in Table 8. The cost milestones set in this roadmap are in line with the long-term goal as agreed on by the different stakeholders in the **"SET-Plan ACTION n°7 –Declaration of Intent"** [EC 2016e], which **aims at a battery based energy storage system cost below 150 €/kWh by 2030, also referring to a cost of less than 0.05 €/kWh/cycle by that time.**

Table 8: Milestones defined for 'Minimized system costs'.

Performance indicator	Current value	Milestone 2020	Milestone 2027
Decrease system investment costs *(System includes: cells, battery management, control system, casing or tanks;* *not included: Inverters and power electronics)*	Approx. 380 €/kWh for advanced technologies	350 €/kWh	150-200 €/kWh

In order to reach the milestones set for cost reduction, the actions listed for the goals "optimized performance" and "optimized durability" are recommended again (thus **Action 1 till Action 8** as presented in the previous 2 sections).

3.2.4 Maximized recycling and re-use

The success of battery based energy storage depends also on its environmental impact. Sustainability is considered one of the most important characteristics of a storage technology. Common understanding is that storage technologies without closed-loop value chains cannot contribute to the energy transition. Especially research on the recycling of Li-ion batteries has been conducted in the past and needs to continue to reach cost-effectiveness in recycling. The **maturity of the recycling process** and **collection rate of batteries** are selected as indicators.

For some battery technologies, like lead-acid, nickel-cadmium and nickel-metal hydride, the recycling technologies and collection circuits are established and operational. For automotive lead-acid batteries, collection rate is 99% of which 100% is recycled, scoring higher than any other consumer product sold on the European market [EUROBAT 2015]. Replicating the lead-acid battery industry's infrastructure of independent recycling companies for other battery technologies such as Li-ion batteries might however not be straightforward. Lead-acid batteries are easier for recyclers to process because they are more uniform in chemistry and configuration. [EPRI 2016]

The milestones for this goal are depicted in Table 9. Those targets hold for every commercially proven battery technology except for lead-acid and nickel-cadmium. For those, as stated before, the recycling circuits are fully operational and separate targets were set by the Battery Directive [EC 2006]. In terms of recycling efficiency 65% of the average weight should be recycled for lead-acid whereas for nickel-cadmium this is 75%. For all other battery technologies targets are set at 50% under currently applicable rules. Currently this means that for example for Li-ion batteries, for which the recovering of lithium is a costly process, less than 1% of lithium is recycled whereas for other elements like nickel, copper or cobalt (globally more than 68%) this recovery rate is higher.[21] It is worthwhile to note that multiple chemistries require specific recycling solutions and that therefore at this moment the number of recycling facilities are limited in scope and scale. In Europe the current battery recycling capacity is about 8000Tonnes/year for Li-ion batteries, concentrated mainly in Belgium. By the year 2020, it is envisaged to establish recycling at the end of a battery's life cycle as a feasible process. The target for this timeframe is a collection rate of 70%, starting from the 2016 position of 45% [EC 2016c]. This rate needs to be increased to 80% by 2027 with an established commercial recycling industry in Europe.

Table 9: Milestones defined for 'Maximized recycling' – *not applicable for lead, nickel and sodium based technologies.*

Performance indicator	Current status	Milestone 2020	Milestone 2027
Maturity recycling process	Limited	Feasible recycling	Commercial recycling
Collection rate	45% (sept 2016)	70% collection rate	80% collection rate

It is clear that current recycling efficiency rate by weight of 50% (for Li-ion) batteries will have to be reviewed upwards to foster recycling and underlying innovation.

The needed actions to reach these milestones include battery research actions, such as the design of modular battery batteries (see action 9), but also material research specifically targeted towards improved recycling (see action 10). In addition actions related to the development and roll-out of the recycling process and supporting regulatory measures have been identified (action 11 to 14).
The below actions resonate well with proposals of SET-Plan working group on batteries in the Implementation Plan adopted in November 2017 [2017b], notably Action 1.5 "Recycling of batteries" . The latter also stresses the need for development of reversed logistics, including development of low cost packaging for safer and more efficient recycling.

Action 9: Design modular batteries *(research)*
In order to enable efficient and cost-effective recycling of battery cells, an increased modular structure of batteries with higher accessibility to individual cells will have great advantages. Recycling processes can then be tailored to the cell level. Research initiatives should thus include the design of such increased modular battery packs offering techno-economically viable solutions as the counteract for current so-called modular commercially available but proprietary solutions.

Action 10: Substitute materials for recycling *(research)*
Using proper materials is key to the efficiency and cost-effectiveness of recycling. While main components of battery cells, such as lithium, are basically not interchangeable without a complete redesign and development of a different battery technology, other components in a battery can be replaced by materials better suited for the recycling process. Although recycling processes are often energy and labour intensive, requiring significant processing and refining, they can be economical for batteries containing e.g. cobalt and nickel in the cathode, but they are not so for designs with manganese.

[21] http://closeloop.fi/wp-content/uploads/2017/05/Li-raw-materials-20170517.pdf

Action 11: Further develop recycling process *(research)*

Few research projects on recycling have been conducted [BATSTORM D5]. Initial experiences with processes to fully discharge batteries and separate their materials exist. In order to make recycling feasible and establish industry-wide processes, further research should be conducted. One of the issues to look more in detail to is the purity of the retrieved materials in order to be used again.

Action 12: Build up pilot plant for closed-loop recycling *(industry + policy)*

In addition to fundamental research, a pilot plant for closed-loop recycling for non-lead-acid and nickel-cadmium battery technologies, should be developed. It will demonstrate the feasibility of recycling on a large scale and reveal further potential for improvement for both the recycling processes and the cell design. The variety and geographical distribution of end of life batteries has to be taken into account in the choice of location.

Action 13: Support (large-scale) recycling and second use through adaptation of regulation *(policy)*

Incentives to deploy recycling can pose a strong driver for research and innovation in battery recycling and should be complementary to a dedicated research programme. Putting strict regulation on the disposal and recycling of batteries will steer market players into a beneficial direction. Currently an evaluation of the Battery Directive[22] is ongoing, due end of 2017. This will probably lead to recommendations for update anyway, possibly including further stimulation of recycling of batteries. Based on the experiences gathered in one or several pilot plants for battery recycling, more large-scale recycling facilities should be established in Europe. This will achieve economies of scale, reduce the costs of recycling and create a leading position of Europe in this activity.

Action 14: Facilitate second life battery applications *(research + policy + industry)*

Related to recycling is the second life use of battery systems.

A specific example is that of batteries for mobility that need to meet more demanding requirements. Synergies are also possible with other battery diversification markets such as forklift and marine batteries. The frequent cycling and related aging causes batteries to fall below these stringent performance indicators such as capacity (e.g. <80% of initial value) or power delivery capability (e.g. internal resistance increase by 100%). Such batteries may still be perfectly capable of serving applications of stationary storage and can have a second life use if they comply with the required safety and performance standards. This has the main advantages of longer lifecycles and postponed recycling as well as lower costs.

SET Implementation Plan on Batteries (Action 3.2 "Second use and smart integration into the grid") highlights key aspects to be explored, including intelligent life-long battery management system.

There have been demonstration projects with second life batteries especially for self-consumption on residential level but also on larger scales for grid-connected battery storage (e.g. ELSA 2016, NETfficient – both H2020 projects). Still, a real industry and structured processes for the second life use of batteries from electric vehicles need to be developed. The techno-economic feasibility of second life use needs to be demonstrated. Clear standards for testing remaining lifetime, efficiency and ensuring safety in a second life redevelopment need to be developed. Furthermore more insights and

[22] DIRECTIVE 2006/66/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 6 September 2006, on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC1

best practices are needed on which technologies and which applications are especially suited for second life use, especially if the industry goes towards strong cost reductions and clear recycling paths. Finally also in the remanufacturing process (removing battery from first life application, dismantling (Action 9 complementarity) and quality analysis of the different components) there are still margins for further cost reduction.

3.2.5 Increased interoperability

To unlock the potential benefits of battery storage, there is a need for interoperability.

At this moment most battery energy storage systems are project specific solutions which are built using proprietary components. The connections of those with e.g. existing control software is often cumbersome, time-consuming and hence expensive. Moreover, connection of proprietary pieces can result in decreased reliability and safety. A non-proprietary set of specifications and standards are required to address the current limitations.

Interoperability between the physical storage system (or any other smart grid appliance) and higher lying management or control systems is also essential.

Several actions have been identified which will contribute to the increase of interoperability.

Action 15: Propose interface and communication protocol standards *(research + policy)*
Specifications should be listed and standards should be developed on the level of both the components of a battery energy storage system as well as the connection with the higher level control (e.g. energy management systems, utility control software).
For the storage system components the focus should be primarily on the way how inverters, batteries and electricity meters are communicating with each other and which operational requirements need to be deployed. The datasheets of those subsystems should also be transparent and made up in a standardized way so that system integrators can make the best objective choice of assets.

In the higher level control the focus should be on data exchange: which communication standards will be used and which kind of data is to be transferred to ensure a reliable and safe operation.
Detailed interface and communication standards are a follow-up of the Smart Grid Mandate M/490[23] issued by the European Commission. After completion of the work under Mandate M490, ICT standardisation work in the area of smart grids should continue within CEN/CENELEC and ETSI. Further development of harmonised open communication protocols based on standard components and interfaces will enable "plug-and play" capability for any new entrant to the network, such as distributed renewables, stationary domestic storage (including batteries) or electric cars, or the use of open architectures based on global communication standards.
The challenge towards seamless deployment and communication of ESS and EVs is not primarily due to the outstanding development of new standards but rather about defining which of the standards from the SGAM library to use in which way. A definition of common standards to use will allow seamless connection of batteries from all EU manufacturers to a digital layer and provision of innovative services and thus scaling up.

[23] M/490 requested CEN, CENELEC and ETSI to develop a framework to enable European Standardisation Organisations to perform continuous standard enhancement and development in the smart grid field. Some of these standards are relevant also for storage.

In practical terms, one should *inter alia* arrive at open standardised and interoperable BMS, ESS and EV application programming interfaces. Unless EU industry moves quickly, it's highly likely that *de-facto* standardisation will be imposed by a non-EU leading market player(s).

Horizon 2020 project DT-ICT-10-2018-19: Interoperable and smart homes and grids is one of the planned R&I projects of some relevance to the above topic. Past and future calls under Chapter 10 "Secure, Clean and Efficient Energy" of H2020 Work Programmes are also relevant.

Action 16: Propose automatic and remote control concepts *(research)*
To fully exploit the opportunities for batteries in the specified applications, automatic and remote control concepts should be designed. In those, it has to be defined which control actions are taken care of by the battery storage systems itself and which ones are governed by remote control, following the standards as developed in the previous action. The actual control concept used can depend on the application case, contractual arrangements and grid codes.

Action 17: Develop interoperable BMS *(research)*
The interoperability of a battery management system with other elements in the overall system, e.g. inverter or energy management system (EMS; e.g. home/building EMS as well as electricity grid planning tools), is nowadays not guaranteed. Part of this barrier will be removed by the first action defined in this goal of improved interoperability but this action goes one step further implying interoperability between different management systems. In this way it will be more easy and hence more cost-efficient to combine different batteries, with each their own BMS, in one system if the application requires this configuration. Also, this can reduce the time and related cost during the construction of battery packs using second life battery modules, because those do not have to be separated first from their BMS anymore before re-installation.

3.2.6 Increased harmonization

Europe is still going through an ongoing integration of markets (wholesale & reserves). Nevertheless participation of small-scale storage, demand response and aggregators is not always allowed in these markets. Also when allowed, technical prequalification rules are sometimes not existing or unclear for the case of storage. In addition technical grid connection requirements may still differ across European Member States or be non-existing. This makes it very complex for investors to understand the market potential, connection procedures, replicate battery projects in different EU countries and estimate the feasibility of investments in BESS.

Currently a number of countries have developed technical connection rules specifically for storage, and some have specific prequalification guidance for balancing reserve products. At European level CEN/CENELEC has started its efforts on developing standards on technical aspects for battery storage.The 2016 Clean Energy Package [EC 2016d] when implemented, will provide for key provisions as regards market access rules for storage, including battery-based storage.

The milestones for this goal are depicted in Table 10. As there are already a lot of activities ongoing it is expected that with increased efforts already by 2020 a favourable harmonisation can be reached. In terms of knowledge sharing a widely used best practice database is envisaged that includes an open access BESS benefit analysis tool. With continuing efforts regarding the harmonisation of European grid code requirements it is foreseen that by the year 2020 European-wide technical specifications and network codes can be generated.

Table 10: Milestones defined for 'Increased harmonization'.

Performance indicator	Current status	Milestone 2020	Milestone 2027
Level of knowledge sharing	Ad-hoc for individual publicly funded research	Widely used best-practice database	(N/A)
European grid code requirements	Country-specific connection rules and procedures	European-wide technical specifications and network code	(N/A)

All actions as identified within this project are presented in the following section.

Action 18: Create and maintain knowledge sharing platform *(policy + industry)*

A platform is envisioned that provides both a database of ongoing projects that are funded by the EU or on national or regional level and gives insights on:

- The location of the storage system;
- The technology type and applications;
- The challenges addressed (technical/regulatory/market/acceptance);
- Relevant project results;
- Success stories;
- Relevant implied standards and regulation;
- Contact information.

The US DOE database that is currently the largest and most known database for international storage projects is very relevant in terms of general information on all storage technologies and applications. However, a dedicated platform to connect all battery storage projects to provide in-depth information on projects and connect projects would be valuable. Improved knowledge sharing on battery project outcomes are vital to replicate success stories, lower barriers for new market entrants and advise financing institutes on the potential of BESS. It would also stimulate ongoing harmonization actions of grid codes and market rules. By connecting relevant players and providing the opportunity to share best practises both in the database but also over discussion threads, this knowledge sharing would go beyond pure research and innovation, but also cover best practices of understanding cost benefit analyses, engagements with stakeholders, and remaining barriers. A regular networking event would support these efforts.

The BRIDGE initiative that unites H2020 smart grids and storage projects[24] to create a structured view of cross-cutting issues is a good starting point for this action. Indeed, most of the projects under the BRIDGE initiative have a battery "component" and are therefore able to contribute knowledge with regards to issues and successes related to battery integration. Currently, the BRIDGE initiative is working on the first report specifically dedicated to the integration of batteries into the grid.

[24] Projects resulting from calls of Chapter 10 "Secure, Clean and Efficient Energy" of H2020 Work Programme 2014-2015, 2016-2017 and soon Work Programme 2018-2020.

Action 19: Identifying and proposing best practises on battery connection and pre-qualification requirements - ***research + policy***

Harmonized connection rules (both technical specifications as well as market access rules) are being established at several levels in Europe.

Technical specifications

Detailed technical specifications for compliance testing of mass-market products are developed within CEN/CENELEC or IEC. The IEC TC 120 is currently working on safety considerations for grid integrated EES systems.

European Network Codes and Guidelines (covering connection, operational and market rules)

At the other end, the Electricity Market Directive and Regulation as well as European Network Codes (developed by ACER and ENTSO-E, and enforced as European Commission Regulation) tackle cross-border issues in a systemic European manner.

Battery units would have to comply with technical requirements to be granted grid connection by the system operator and to qualify for the delivery of ancillary services. Such technical connection rules would include specifications on technical capabilities for frequency management, voltage management, robustness, controllability and other aspects. A clear set of rules would provide clarity across the EU on characteristics that batteries have to comply with to fully access the potential of balancing markets, other ancillary services and to be used as alternative options for grid investments.

To avoid divergence in technical specifications and compliance procedures, it is advised to start with identifying best practices within stakeholder expert group(s). Upcoming H2020 calls will contribute to this discussion. E.g. call "LC-SC3-ES-5-2018-2020: TSO – DSO – Consumer: Large-scale demonstrations of innovative grid services through demand response, storage and small-scale (RES) generation" intends to define and test:

1) Standardised products and key parameters for grid services;
2) The activation process for the use of assets for network services;
3) The settlement process for payment related to the services.

Action 20: Harmonize connection procedures ***(policy)***

Procedures for connecting BES to the electricity grid or for qualifying them to offer certain services to the energy system are currently non-harmonized across Europe. Although, several countries have adopted or are currently drafting specific rules and procedures for batteries to deliver one or more services to their grid, the integration of batteries would greatly benefit from general approaches and common rules and procedures for field tests, use of standards, and simulation based compliance tests, at EU level where possible. The implementation of standard products for ancillary services as foreseen e.g. in Commission 2017 Regulation on electricity balancing[25] and in the Clean Energy package will clarify the suitability of storage technologies to provide these services.

The access of storage to day-ahead and intraday market will also be facilitated by the proposed provision in the recast of the Electricity Market Regulation. This provision stipulates that market participants should have the possibility to trade energy as close to real time as possible (15 minutes time intervals or less by 1 January 2025). Similarly, market operators shall provide products which are

[25] Commission Regulation related to the present Electricity Market Regulation.

sufficiently small in size - 1 Megawatt or less - to allow for the effective participation of demand-side response, energy storage and small-scale renewables.

Action 21: Streamline metering and telemetry requirements (*research* +*policy)*
Metering and telemetry requirements vary from one market to the next and can increase the costs of providing energy services and receiving settlements. Therefore, it is necessary to study existing metering and telemetry requirements in jurisdictions across the EU and research best practices in metering and telemetry configurations.

3.2.7 Adequate remuneration

To support the integration of renewable energy in the system, the need for more and diversified flexible resources in the energy system (e.g. flexible generation, storage, demand management, coupling with other energy sectors) is recognized. Battery storage can deliver various services within the energy system, for both regulated and non-regulated parties. It should be able to compete with other technologies. This requires a correct valuation of battery services in competition with the other flexible sources, as to give the right investment signals and focus on societal cost optimum.

In addition, batteries have certain valuable characteristics, making them especially suitable to offer particular services. As they are typically very reliable and give fast responses they may be highly suitable for services such as the Enhanced Frequency Response service introduced by National Grid in the UK. As the technology has the potential, it deserves consideration whether services tuned for batteries should be introduced. Again here it needs to be checked with real system needs and it needs to be ensured there is sufficient competition among providers (including other technologies).

Most battery systems deployed today are used for a single application and are very often underutilized. There is thus an opportunity to increase the utilization factor of batteries and come to a more interesting business case for the battery owner by combining multiple services. Essentially allowing a battery owner to switch between revenue streams with the same asset implies short-term obligations while long-term ones may be preferred. The stacking of revenues thus implies settling for a long-term obligation (with an ensured revenue stream) and with the option to use the asset for other revenues if the battery is unused. National market rules would need to allow for that.

On a more overarching level, changing the manner of pricing in the current energy system would also be beneficial to battery storage. Current electricity tariffs very often do not reflect real energy costs or system needs, certainly not for small consumers. Implementing more dynamic pricing schemes would allow battery owners to change their consumption pattern based on these tariffs, thereby creating additional value for themselves (through lower energy bills), but also for the energy system as a whole. Clean Energy Package foresees the right of each consumer to at least one dynamic price contract. It also enables MS to modulate grid tariffs in function of time of use – however it is for MS to avail of this possibility.

The implementation of more dynamic pricing schemes would benefit a lot of other elements in the energy system and will therefore not be solely driven by battery storage. This change is therefore not considered in scope of this roadmap.

The milestones for this goal are depicted in Table 11.

Table 11: Milestones defined for 'Adequate remuneration'.

Performance indicator	Current status	Milestone 2020	Milestone 2027
Participation of distributed resources in wholesale and reserve markets	Different situation across Member States	Barriers removed in all Member States	(N/A)

All proposed actions to reach these milestones are targeted toward the creation of an appropriate market framework so that batteries can compete with other flexibility options and can be fairly rewarded for the offered services.

Action 22: Propose best-practises to value the strengths of BESS services *(policy)*
Batteries have valuable characteristics such as reliability and responsiveness, making them especially suitable to offer specific services. If the energy system benefits from such performance, then compensation and procurement should be defined accordingly. This action entails the identification of the current and future power system need of these ancillary services, the definition of these services, and best practice definition for incentivising/ remunerating them, e.g. EFR in the UK or the "Pay for performance" regulation in the Californian ISO could be considered

In addition to technical strong characteristics of batteries, they also have indirect benefits e.g. in the field of grid investments, based on fast commissioning time and avoided line/cable works. The EU's Clean Energy Package already states grid planners need to consider flexibility alternatives for normal asset development [EC 2016d]. In this respect, DSOs should also be allowed to enter into multi-year contracts with battery owners. It needs to be ensured that all impacts of BESS are taken into account here.

Action 23: Monitor market distortions and act *(policy + industry)*
Although some solutions are technically viable, several regulatory barriers and market distortions (e.g. storage paying grid fees both as consumer and generator) still remain that prevent the economic viability. These distortions should be identified and appropriate measures should be taken to remove them. The Clean Energy Package [EC 2016d] already takes this as a guiding principle and explicitly addresses storage as an actor that needs to have the same rights to participate in wholesale and reserve markets without barriers, and asks for rules that allow for aggregation of decentralized providers. In monitoring of market design and participation (by EC, ACER or in regional cooperation) specific attention needs to be given to barriers and best practices for BESS participation.

Action 24: Create higher transparency for system needs *(research + industry)*
This action is strongly linked to action 22 which aims at setting the appropriate legislative and regulatory mechanisms in place for system operators to consider alternatives (incl. BESS) in system planning. This action 24 focuses on the specific tools and data a TSO, DSO or any other market actor has at its disposal. These tools, based on a detailed grid hosting capacity analysis and transparent stakeholder input process for grid planning, should provide the possibility to assess the need and value of specific services at different locations. An example of such transparency tool of distribution hosting

capacity is the Californian Distribution Resources Plan (R.14-08-013) developed through the Californian regulator CPUC [CPUC 2014].

3.2.8 Minimized investment risk

Although some applications are on the verge of profitability, investment decisions in batteries currently rely on highly uncertain forecasts. There is no guaranteed income since future market circumstances cannot be predicted on the mid- and longer term and contracts are very often too short (typically one year). This also leads to difficulties when trying to get battery projects financed. Exceptionally long-term tenders may be launched, as in the 2016 UK capacity tender giving 15-year contracts to over 500 MW of batteries [National Grid 2016b]. With the obligation prescribed in the Clean Energy Package [EC 2016d] for system planners to consider batteries as an alternative for more conventional asset solutions, more of such long-term contracts may materialize. But this may all remain relatively marginal for the overall forecasted battery deployment in Europe. A conscious political decision may be taken to stimulate batteries much like was done with renewables during early deployment years. An example related to this is the German low-interest KfW loans and repayment bonuses from BMWI for residential users in combination with PV [KFW 2016].

While for other technologies (such as solar PV) an automated and even standardized investment process is in place, such a process is currently missing for battery storage (both for small, residential batteries as well as for larger systems). Therefore banks often react reluctantly to investment requests. There are several reasons for this: a long-term track record of battery technologies in the energy system is still lacking and the technologies are not yet standardized, the volume of credit for battery systems is still too low and long-term stable cash flows are currently uncertain (e.g. due to uncertainty on evolution of market prices).

Several (temporary) measures might be needed to minimize the perceived investment risk, gain experience and increase the bankability of battery projects. Also the action already listed under increased knowledge sharing (action 18) would benefit this goal of lowering investment risks.
No specific milestones have been identified for this goal. The outcomes of the actions could be seen as short-term targets. Note also that very general energy system actions such as tools to forecast price trends, or gaining experience with long-term PPAs, may have value in limiting BESS investment risks, but are here not described as these are not battery specific.

Action 25: Establish guide on financing options *(policy)*
Actions could be taken to facilitate financing options as a temporary measure for example by regional, national, or even European authorities (within available instruments such as European Regional Development Fund; InnovFin EDP initiative financed by EC and EIB). This will minimize the perceived investment risk for future projects once the temporary measures are abolished.

In order to select and collect financing options, best practices examples would be helpful, including examples of financing battery deployment. One example of such an action to be considered is the German support scheme from KfW and the German Development bank which offers low-interest KfW loans and repayment bonuses from BMWI (Federal Ministry for Economic Affairs and Energy) funds for residential battery storage systems in conjunction with photovoltaic systems [KFW 2016]. This action includes designing incentive programs and tax credits for energy storage.

As regards underlying research, the EC should keep on taking up the role as an enabler via funding mechanisms like the framework programme H2020. Research and innovation actions (RIA), innovation actions (IA) and grants like ERC and MSCA are good examples of funding channels which support the defined and required R&D activities. Whenever a given technology, product, tool or service is still in the early stage of development the EC contribution to the total project budget should reach 100%, referring to maximum support typically encountered in RIAs and ERC/MSCA grants. The level of support from the EC decreases when the technology, product, service or tool is closer to commercial viability.

Action 26: Adopt standardized method for life cycle cost analyses *(policy + industry)*
Aside from uncertainty on the potential remuneration of batteries (see 3.2.7), there is also uncertainty related to the cost of a battery system during their lifetime. Different approaches exist to estimate these costs. The existing methodologies should be analysed, compared and an appropriate methodology should be developed taking into account the environmental and cost impact during construction as well as during operation, including the recycling phase. Such fine tuning could be part of the battery recycling initiatives, but this would not cover the full scope of the action. It is advised the industry itself agrees on transparent principles to assess life cycle costs, which could also facilitate investment decisions on upgrades, acquisitions and other second-life opportunities.

3.2.9 Increased acceptance

Field projects in the residential sector have shown that while some participants welcome the opportunity to host battery storage systems, others display reluctance towards batteries in their homes. Safety issues are often stated as a reason, which may to some extent be caused by media pictures of burning electric vehicles or exploded smartphones. Naturally, these rare cases are very present in the public perception and have a negative impact on the acceptance of stationary battery storage.

Safety issues and costs involved with battery storage need to be communicated in a fair and objective way to the public in order to increase acceptance. The proposed actions are therefore as described below. No specific milestones have been identified for this goal, the actions are evident in contributing to the goal and are difficult to group in relevant milestones. Therefore these have not been defined.

In addition to the below mentioned actions a number of actions described in the previous chapters are of direct relevance to the subject of increased acceptance. This includes action 2 targeted at development of battery materials and action 4 targeted at development of advanced battery management systems, both R&I actions relevant for increasing safety of batteries. Also some other actions, like action 15 targeted at increased interoperability is important for increased acceptance as it greatly facilitates the use of batteries.

Action 27: Continue development of safety standards *(industry + policy)*
High power and high energy battery applications that are installed close to humans have several risk factors. Safety standards for battery cells as well as battery systems including the ancillary technologies are of high relevance. The IEC and CENELEC have already developed a variety of safety, performance

and dimension standards under the Technical Committees IEC TC21 and CEN/CENELEC TC 21X, most of them referring to Lead-Acid batteries in mobile applications. Also efforts regarding other technologies and for stationary applications are ongoing. Examples are IEC 62485-5 ED1 - Safety requirements for Lithium-ion batteries for stationary applications, IEC 62932-2-2 ED1 Safety requirements for Flow Battery Systems for Stationary applications and IEC 62984-3-1 ED1 Safety requirements and tests of Sodium-based batteries. These documents are currently under the status of reviewing and approving. Additionally new technologies and applications should be added to existing work consistently. As a large community of battery experts is present in these working groups, additional required work on this could also be assigned to or consulted with the working groups of these committees. This makes sure, that existing codes are supplementing and not overlapping with existing standards and reduces double work.

Action 28: Propose duty cycle, testing standards and performance certification *(research + policy)*

Current standards[26] are not always up to date with current and future applications of batteries in the energy system, leading to incorrect projections of calendar and cycle life. This has of course a big impact on the evaluation of the feasibility for battery deployment, given a certain use case.

There is a need to develop harmonised test methods for half cells and cells to improve battery comparability and create the required data for modelling needs at application level.

More real-life representative application-based duty cycle standards, testing standards and performance certificates are to be developed and agreed upon. As there are tests proposed to assess e.g. lifetime, capacity, power, currently there are no standardized tests for state of charge (SoC) and state of health (SoH) estimation nor to develop models to evaluate those parameters. This action should be continued and even more intensified in the activities of the related existing technical committees within standardization bodies like e.g. IEC TC21 on secondary cells and batteries (ex. published the IEC 61427.2 "Batteries for RES storage in on-grid applications", which described the test requirements and methods for four grid applications, independent from the battery technology used). The same approach is to be followed with respect to the TC 120 who published recently the IEC 62933 series for battery requirements related grid connectivity.

Action 29: Propose data and cyber security measures *(research + policy + industry)*

Data and cyber security issues are still seen as a threat for all battery applications that are installed close to the end customer and include the collection of production and consumption data in order to control the battery system or a smart grid. Even if this is not a battery specific issue, it needs mentioning for the sake of completeness.

Data and cyber security measures need to be further developed. As this is a general issue for all smart grids technologies/appliances it has to be addressed in holistic/generic manner. Different fields of research including ICT as well as energy system expertise evolve from this need.

Relatively low importance (see chapter 3.3) given by stakeholders to this measure can be explained by the fact that this is not a battery-specific measure. At the same time, the general importance of this measure should not be underestimated.

[26] A list is provided here:https://batterystandards.vito.be/standard-survey?title=&field_survey_target_tid=All&field_survey_application_tid=641&field_survey_type_tid=All&field_survey_life_phase_tid=All&field_survey_objective_tid=All&field_survey_editor_tid=All&field_survey_year_value=&field_survey_geography_tid=All&=Apply

3.2.10 Increased industrial capacity

The industrial capacity of the European battery industry was addressed by the European Commission, battery manufacturers and the automotive industry many times. The EU is already home to some manufacturers, which are well positioned in the global sector especially in Lead Acid and specialised niche markets. Also additional production capacity is planned to be built by European and non-European investors. LG Chem EV battery plant in Poland that is designed to provide 100,000 batteries per year. Samsung in Hungary plans to deliver 80,000 batteries per year. Also SK Innovation plans to establish its presence in Hungary. Also the Daimler subsidiary ACCUMOTIVE is producing EV batteries in Germany and started construction of a second battery factory, which will also produce batteries for stationary storage. However, the large majority of global cell production capacity remains in Asia and the U.S. The automotive industry expects to be dependent to a large extent on imports of battery cells, exposing their sourcing to various risks.

A local industrial capacity capable of serving the demand is in the interest of European car manufacturers. Similarly, it will be of benefit to the integration of renewable energy and the energy transition. An increased industrial capacity is in the interest of battery manufacturers and integrators, car manufacturers, the energy sector and the public. Industrial plans currently being developed by NorthVolt (SE), Terra-E (DE) and SAFT (FR) are therefore a positive development and should be supported within the limits of applicable rules.

The milestone for this goal is depicted in Table 12. This milestone, based on the [EC 2016c], relates to both stationary as well as batteries for electric vehicles.

Table 12: Milestones defined for 'Increased industrial capacity'.

Performance indicator	Current status	Milestone 2020	Milestone 2027
Annual EU cell production capacity	Unknown	2.2 GWh	5.0 GWh

Several actions are foreseen to enable and stimulate this increase in industrial capacity. These are listed and described in the following paragraph. Note that actions 30 and 31 are also directly relevant contributors to the goal of 'adequate remuneration'. Furthermore action 13 (Support (large-scale) recycling and second use through adaptation of regulation) is also relevant for this goal on increased industrial capacity.

Action 30: Facilitate industry collaboration across sectors and financial support (consortia) *(policy + industry)*

The sector for grid connected batteries needs to work closely together with the automotive sector as this is one of the largest driver and the directing customer for batteries. Synergies can be found all along the value chain from material research to system integration. Also synergies with the traditionally strong sector of motive applications for niche markets where electrification is further increasing too (e.g. forklifts, ground support equipment, agriculture, construction and mining equipment, vessels and trains) can be exploited. Therefore, industry collaboration across sectors should be facilitated.

Most European stakeholders also see the need for building up industrial capacity. First European and international players have started building up production. However more investment to close the gap

between research progress and market uptake with high quality batteries from Europe is necessary. Industry consortia can bring knowledge from different branches together and exploit synergies by complementing expertise. Leading edge research can find its way to the market if market players all along the value chain are included. This was the approach used by the Batteries WG of the SET-Plan and is now followed by the Battery Alliance with 80 industrial and innovation actors involved in different work streams. The alliance is now proposing 20 priority actions to establish a full competitive value chain in Europe.
To facilitate common efforts of EU battery value chain players the Commission should aim at fast clearance of projects satisfying State aid rules on Important Projects of Common European Interest It should encourage MS to use co-financing under available EU financing instruments to the maximum (especially regional support funds earmarked for relevant regions).
InnovFin Energy Demonstration Projects facility launched by EC and EIB in 2015 is actively involved in the new projects in the pipeline, including NorthVolt. EIB is expected to be involved also beyond InnovFin EDP facility.

Action 31: Estimate the market potential/demand for BESS *(research)*
As the main challenges for low industry capacity in Europe is connected to the uncertainty about the future market size, research on the future market potential of different battery applications and technologies in Europe and worldwide is proposed. The socio-economic analysis [BATSTORM D7] gives further insights, however a scenario model for Europe considering all applications and technologies is still not available. It would be important for the different stakeholders to have estimates both in MWhs and MW Numbers and trends could quantify the risks and push investments in the right areas

1) A **macro-analysis** and;
2) A **case-specific** level e.g. based on project CBAs.

The **macro-economic analysis** needs to be developed in order to efficiently analyse the benefits of storage to the electricity system and deduct the market potential for batteries in different market and regulation environments. It's positive that long-term energy system models (like PRIMES from NTUA and POTEnCIA from JRC) were recently complemented by METIS model[27] which is focusing on the short-term operation of the energy system and markets. It is a modular energy modelling tool covering with high granularity (geographical, time) the whole European energy system. Simulations adopt a MS-level spatial granularity and an hourly temporal resolution. For instance, it can provide hourly results on the impact of higher shares of variable renewables or additional infrastructure built.

To the extent possible, it will have to be explored how in the future the models could be further enhanced to better determine overall potential for battery storage determine market for battery-based storage[28] for specific segments, including frequency control, self-consumption, integration of big renewable electricity generation and grid enhancement substitution.

The second **case specific model** will be based on project and location specific Cost Benefit Analyses and show the advantage of the investment of storage for specific grids and market environments. The Battery Storage Evaluation Tool (BSET) developed by the Pacific Northwest National Laboratory (DOE laboratory) and the Energy Storage Valuation Tool (ESVT) developed by EPRI for the Californian Grid

[27] https://ec.europa.eu/energy/sites/ener/files/power_market_module.pdf
[28] As current temporal resolution of existing models does not go below 1hr, very fast response services cannot be fully valued. At the same time it has to be admitted that in the long run such services will not constitute big share of battery based storage market.

are two best practise examples that show the need and the success of such models. Such CBA models help assessing the economic benefit of a high number of battery applications and can show the different sensitivities applications have regarding specific regulatory and market environments and potential changes such as network tariffs, dynamic pricing.

To create those two models and/or update and interlink existing ones, research institutes and consultancies with expertise in energy markets, energy infrastructure and energy regulation should do research and develop those tools that give answers to macro-economic as well as micro-economic/case specific technical questions.

3.2.11 Maximized production efficiency

Initiatives to increase the efficiency of battery cell production is also mainly driven by the automotive sector with openly addressed cost targets. A roadmap has been developed by a major industry association [VDMA 2014]. It identifies various challenges and potential for improvement in Li-ion battery production processes. Several actions are foreseen to improve the efficiency in production by either improving quality or reducing time and costs of the production process. The identified actions in that roadmap to maximize production efficiency are applicable not only to Li-ion technology but should also be pursued to improve other relevant technologies in similar ways. These actions have been summarised and translated to more general and technology-neutral research initiatives below.

Action 32: Redesign or reduce clean rooms and drying rooms as part of cell production plants *(research)*

Many steps of the cell production process require clean rooms and drying rooms. Today, most steps of the battery production take place in classic clean rooms, in which the technicians operate, making it a greater challenge and more cost-intensive to maintain required environmental parameters. The introduction of smaller, more efficient, encapsulated clean rooms and drying rooms, so-called mini environments, can help to reduce the operating costs and increase production efficiency [VDMA 2014]. Research on new designs for clean rooms and drying rooms can stimulate this process, help to install new processes earlier and therefore reduce the costs significantly.

The relevance of this action is recognised also among Batteries SET-Plan Action 2.2 Foster development of cell and battery manufacturing equipment. Notably it stresses the need to reduce (and eventually eliminate) the need for clean rooms and drying rooms, with water-based processing or closed assembly lines.

Action 33: Propose process adaptions towards continuous operation *(research)*

The development of continuous operation increases the degree of automation in the process and reduces production time and costs. In order to enable continuous processes (e.g. in mixing) research on new machinery and materials is needed. In the case of mixing of the materials for Li-ion batteries, the process today takes up about two hours' time, but could potentially be halved [VDMA 2014]. This research need of process adaptations is true for all technologies and materials and can lead to significant costs decrease.

This corresponds well to the spirit of Batteries SET-Plan Action 2.2 Foster development of cell and battery manufacturing equipment.

Action 34: Automate the production process of BESS *(industry)*

Many working steps in battery production have not yet been fully designed for automated high-volume production but have a high potential for automation and digitisation. [VDMA 2014]. Europe has many high potential companies that provide leading edge machinery and automatization equipment. However this advantage has not yet been fully exploited within the battery industry and still poses opportunities for higher efficiency within the production process and advantages against competition from outside Europe.

While stakeholders within Batstorm project didn't rate activities 32 and 33 as high priority activities, it's to be stressed that production speed and decreasing of rejects was highlighted as important priority within SET-Plan action on Batteries (notably Action 2.2).
Similarly EU Battery Alliance stresses the need for R&I calls co-defined with industry should include production lines with extensive use of automation.
Most probably relatively low ranking is to be explained by the fact that this is not so much stationary storage specific priority. The relevant action is more targeted at producing (small) battery cells used in EVs in speedy and non-expensive way (which further increases their outlet potential also in stationary sector).

3.2.12 Increased technology leadership

The view on global cell production capacity resembles the battery patent landscape with companies in Japan, China, South Korea and the U.S. having the largest shares of filed patents for battery technology. The declared vision and aim of this roadmap is to establish a leadership role of Europe in battery technology. While the technology and industry is mature in some sectors and applications, innovations for the new applications of stationary storage can be expected. The goal is to position European companies well in the global competition and to secure technology leadership. In 2011 [PV Magazine 2014] the EU filed 530 patents related to electrochemical storage, in comparison to 410 from the US and 2100 from Asia. This gives a share of about 17% for the EU, while Asian countries dominate the patents in this field. As a performance indicator for technology leadership, the share of relevant patents filed can be used. A quantified milestone for this performance indicator has not been set, but an increase in the share of the EU in global patent filing is targeted.
Post Li-Ion and advanced materials are seen as a crucial potential for the European players. At the same time research on today's cutting edge Li-ion technology should continue as indicated in action 2. Many other activities in the previous chapters are relevant to gaining technology leadership. In addition, the following activities were identified.

Action 35: Facilitate eco–efficient production pilot lines and storage-oriented living lab projects *(research + industry)*

As identified also by SET Plan batteries' WG and the Battery alliance it's key to gain experience in mass production market already today before next generation technology becomes available.
Facilitation of eco-efficient production lines is important step before venturing into mass production. The Battery Alliance stakeholders consider it important to establish a European open access pilot line network to gain manufacturing experience.

Living lab projects are also crucial. They involve all stakeholders in the innovation process and thus ensure higher user acceptance and user interoperability. Living lab research projects could include safety demands, innovative applications and human-machine interaction. There are currently some related living lab projects ongoing:

- The Spanish SUNBATT Living Lab explores the options of second life batteries;
- The Belgian living lab site Th!nk E (financed within H2020 STORY project) tries to realize a grid-supporting zero-energy building in a renovation context;
- The Dutch Living Lab Smart Charging is an open platform which facilitates the development of Smart Charging and related concepts.

Living labs could be co-funded in the context of smart specialisation actions under development funds such as the ERDF. They have also already been discussed in the context of Horizon 2020.

Action 36: Create bridge between research funded and patent filing *(policy + industry)*

IP development should become a stronger KPI for future R&I programs[29]. This also serves the goal of boosting EU competitiveness and innovation. The IP policy of an R&I program needs to be clear and transparent to all possible stakeholders and well embedded in the program's structure, guidelines and procedures, as to ensure maximum value creation. IP development should become a strong KPI for future R&I programs. This value creation should not only related to R&I programs dealing with high technology readiness levels (TRL), where currently there is already support to some extent, but also to more fundamental research activities at lower TRL. Advisory, operational and strategic support should be provided when new foreground IP has been created (checking for opportunities for protection, giving advice on ways of protection and possibly also monitoring independently the compliance of the stakeholders with the IP policy).

In this respect, dissemination and exploitation support services successfully launched by the Common Support Centre for H2020 should be further developed.

[29] It is noted that sometimes there is a conflict the 'obligation' of publicly funded research to make their findings public/available for a wider audience, which conflicts with IP development.

3.3 Priorities and planning

In the previous sections a set of actions are defined that are required to reach the listed milestones and goals. Not all of these actions are rated similar on impact or urgency, nor are they foreseen to have a similar duration time to reach the desired outcome.

Impact is reflected in the extent to which an action contributes to a goal or the overall objective. Furthermore if an action contributes to multiple goals, this increases the impact of that action.
Urgency indicates which actions should be initiated earlier in the timeline, e.g. based on the dependency of other actions on the implementation or start of a given action.
Duration of an action is not to be neglected. Some actions will need several years to come to results, for example in case where substantial research and investment is required. Others might be actions with shorter duration, for example if they relate to harmonizing procedures or determining market potential. This duration in combination with the set timeline of the milestones is also taken into account when assessing urgency, but is mostly used in assessing the timeline of the actions (see the end of this section).

The actions as defined and described in this roadmap directly relate to the barriers and opportunities as analysed in the BATSTORM project. These barriers are currently impeding a large take off of the stationary battery energy storage market within Europe. As sketched in the projections presented in the Socio-economic analysis [BATSTORM D7], a total capacity between 7,600 MW and 9,800 MW could be reached in Europe by 2020 and between 11,500 MW and 14,500 MW in Europe by 2025. These projections will only develop in the indicated way if the underlying assumptions are valid. For example, they depend on market factors (e.g. penetration and deployment of renewables, influence of EV market) but also on developments in regulation, support by industry and governments and developments in research and innovation.

If no action is taken these projections will not be reached. Reaching the projections is not the objective per se, but it would be an indication that there are not sufficient batteries deployed to prevent issues in grid and energy markets or to reach climate goals. If the market, policy environment and research efforts are not facilitated or in place, this can have relevant implications, for example:

- Less competition on cost-effective solutions to facilitate renewable energy integration;
- Industry going overseas / losing against outside EU competition(e.g. resulting in loss of jobs, reducing macro-economic benefits and industry leadership);
- Higher system operation costs;
- Safety issues with installed batteries;
- Delay and cost overruns in the installation of batteries and related infrastructure.

For some actions industry could play a role (research and innovation), but several others need to be initiated by policy makers, incl. direction and funding for fundamental or less applied research, regulation design and market monitoring.

For the European Commission the level of effort will thus influence the eventual speed and cost-effectiveness of battery deployment and market development. If efforts in the field of research are made, costs for battery systems will go down, performance of batteries will improve and Europe's technology leadership will improve.

If efforts on the market/regulation side are made, deployment of batteries within Europe will happen on a faster pace, transaction costs can be reduced, system safety can be better guaranteed and industry can be enabled to gain a better position in the battery value chain.
Efforts on multiple fields can reinforce each other. If a higher effort is made, the full projections can be realised at the sketched timeline or even beyond, resulting in benefits like reduction of system costs, increased renewable energy integration, increased socio-economic benefits, etc. Besides deployment, also for industry positioning the need to take action is relevant. If medium or low effort is applied, it can result in a reduced position of EU industry in the field of battery production and supply chain.

The actions as indicated in this roadmap are all important to increase battery deployment and further develop the battery industry. For some actions, an external push is essential, since markets and voluntary initiatives in business as usual cannot tackle them on their own, or simply take more time.
Therefore the resulting label of 'very high, and high priority' should not be interpreted as the other actions not being relevant or important, but that these actions should be focus points of the European Commission, Member States and industry since they will have the largest impact on short and longer term, and are currently actually impeding further developments. Market increase as sketched in the projections is at risk if the actions labelled high and very high are not tackled by the European Commission. The actions with 'very low/low' priority are not regarded as not important, but they might be not-impeding, could be solved by market or other stakeholders, could be temporary or focusing on niche applications. All actions described in the roadmap, based on discussion with stakeholders, bring value.

All dimensions have been rated high/medium/low for impact and urgency. This rating is based on stakeholder input, previous work in the domain of battery technologies and expert judgment. A combination of the dimensions impact and urgency results in an indication of the priority of that action. The following table (Table 13) shows the actions ranked as 'very high' or 'high' priority.

Table 13: Overview of actions rated with 'very high' and 'high' priority.

#	Action	Priority	Goals
2	Develop alternative materials for BESS while continuing to work on cutting edge Li-ion technology	high	Optimized Performance & Minimized System costs
4	Develop advanced battery management solutions (thermal, electrical)	high	Optimized Performance, Optimized durability & Minimized System costs
13	Support (large-scale) recycling and second use through adaptation of regulation	high	Maximized recycling
18	Create and maintain knowledge sharing platform on battery-based energy storage projects	high	Increased harmonization
19	Identifying and proposing best practises on battery connection and pre-qualification requirements	very high	Increased harmonization
27	Continue development of safety standards	high	Increased acceptance
28	Propose duty cycle and testing standards and performance certification	high	Increased acceptance
30	Facilitate industry collaboration across sectors and financial support	very high	Increased industrial capacity
31	Estimate the market potential/demand for BESS	high	Increased industrial capacity

The full table with the ranking on the three dimensions is presented in Appendix D: Priority rating of actions. In the table below (Table 14) the full ranking for all actions is given, but sorted based on the resulting priority ranking.

Table 14: Priority ranking of the actions identified.

#	Action	Impact	Urgency	Priority
19	Identifying and proposing best practises on battery connection and pre-qualification requirements	**3**	**3**	**very high**
30	Facilitate industry collaboration across sectors and financial support	**3**	**3**	**very high**
2	Develop alternative materials for BESS and continue research on today's cutting edge Li-ion technology	**3**	**2**	**High**
4	Develop advanced battery management solutions (thermal, electrical)	**3**	**2**	**High**
13	Support (large-scale) recycling and second use through adaptation of regulation	**3**	**2**	**High**
18	Create and maintain knowledge sharing platform	**2**	**3**	**High**
27	Continue development of safety standards	**2**	**3**	**High**
28	Propose duty cycle and testing standards and performance certification	**2**	**3**	**High**
31	Estimate the market potential/demand for BESS	**2**	**3**	**High**
1	Develop integrated design (battery cells, power electronics)	**2**	**2**	**Medium**
3	Improve power electronics	**2**	**2**	**Medium**
6	Develop hybrid-technology solutions	**2**	**2**	**Medium**
7	Develop simulation and modelling tools	**2**	**2**	**Medium**
8	Propose solutions for fault protection and detection (sealing foil cells)	**2**	**2**	**Medium**
9	Design modular batteries	**2**	**2**	**Medium**
11	Further develop recycling process	**2**	**2**	**Medium**
12	Build up pilot plant for closed loop recycling	**2**	**2**	**Medium**
15	Propose interface and communication protocol standards	**2**	**2**	**Medium**
17	Develop interoperable BMS	**2**	**2**	**Medium**
20	Harmonize battery connection procedures	**2**	**2**	**Medium**
22	Propose best-practices to value BESS services	**2**	**2**	**Medium**
23	Monitor market distortions and act	**1**	**3**	**Medium**

24	Create higher transparency for system needs	**2**	**2**	**Medium**
25	Establish guide on financing options	**2**	**2**	**Medium**
35	Facilitate living lab projects	**2**	**2**	**Medium**
36	Create bridge between research funded and patent filing	**2**	**2**	**Medium**
14	Facilitate second-life battery applications	**2**	**2**	**Medium**
5	Control internal chemical reactions	**2**	**1**	**Low**
10	Substitute materials for recycling	**1**	**2**	**Low**
16	Propose automatic and remote control concepts	**1**	**2**	**Low**
26	Adopt standardized method for life cycle cost analyses	**1**	**2**	**Low**
29	Propose data and cyber security measures	**1**	**2**	**Low**
32	Redesign or reduce clean rooms and drying rooms as part of cell production plants	**2**	**1**	**Low**
21	Streamline metering and telemetry requirements	**1**	**1**	**very low**
33	Propose process adaptions towards continuous operation	**1**	**1**	**very low**
34	Automate the production process of BESS	**1**	**1**	**very low**

Urgency is an element also indicating the desired starting date of an action. In the following overview the timeline of action is given. Some actions depend on others to happen first (sequential), others are regarded as high urgency, and thus should start sooner rather than later. Please note that the timeline sketched is qualitative and will also depend on the level of effort put towards the actions by all stakeholders (government, industry, research institutes, etc.).

The indicative timeline is presented in Figure 5. The red box in the timeline indicates the period 2018-2020, which are actions required in short term. These actions are included and the basics of the research and collaboration clusters as identified in Chapter 5.

#	Action	2018	2019	2020	(2021-2027)
1	Develop integrated design (battery cells, power electronics)				
2	Develop alternative materials for BES while continuing investment in today's cutting edge technology				
3	Improve power electronics				
4	Develop advanced battery management solutions				
5	Control internal electrochemical reactions				
6	Develop hybrid-technology solutions				
7	Develop simulation and modelling tools				
8	Propose solutions for fault protection and detection				
9	Design modular batteries				
10	Substitute materials for recycling				
11	Further develop recycling process				
12	Build up pilot plant for closed loop recycling				
13	Support (large-scale) recycling and second use through adaptation of regulation				
14	Facilitate second-life battery applications				
15	Propose interface and communication protocol standards				
16	Propose automatic and remote control concepts				
17	Develop interoperable BMS				
18	Create and maintain knowledge sharing platform				
19	Identifying and proposing best practises on battery connection and pre-qualification requirements				
20	Harmonize connection procedures				
21	Streamline metering and telemetry requirements				
22	Propose best-practices to value the strengths of BESS services				
23	Monitor market distortions and act				
24	Create higher transparency for system needs				
25	Establish guide on financing options				
26	Adopt standardized method for life cycle cost analyses				
27	Continue development of safety standards				
28	Duty cycle and testing standards and performance certification				
29	Propose data and cyber security measures				
30	Facilitate industry collaboration across sectors and financial support				
31	Estimate the market potential/demand for BESS				
32	Redesign or reduce clean rooms and drying rooms as part of cell production plants				
33	Propose process adaptions towards continuous operation				
34	Automate the production process of BESS				
35	Facilitate eco–efficient production lines and storage-oriented living lab projects				
36	Create bridge between research funded and patent filing				

Figure 5: Indicative timeline of the proposed actions, including selection of actions proposed for action in the next two years.

The short term priorities are those actions high/very high priority or those that are required to start in the coming two years (indicated in the red box in the picture). These short term priorities are further grouped into possible research clusters in chapter 5.

4 Monitoring of R&D achievement

In the recent past, a large number of EU- and nationally funded R&I projects with respect to storage and more specifically battery energy storage systems have been finalized or just started. An extensive overview of projects has been compiled in the scope of the technical analysis deliverables [BATSTORM D12] where a more in depth project monitoring is presented, especially analysing characteristics like technology, size, funding sources, actors, readiness levels and geographic location.

In this chapter a short summary of this project monitoring is provided by focusing on the key themes of the projects. This section also provides an overview table of the most common battery technologies, their current status and areas of improvement.

Europe has the human capital and expertise to continue the research and development on novel promising battery technologies. By focusing hereon, a leading global position in the battery sector could be within reach.

Ongoing work on novel non lithium-ion battery technologies should be continued and further supported. Some of the technologies, e.g. some redox flow batteries, are already more developed than others, e.g. metal-air or new ion-based systems, and hence closer to the market.
Novel technologies, which facilitate high energy densities such as Lithium-sulphur (Li-S) and Lithium-air, generally fail realization and commercialization. Causing effects are electrolyte stability, cell poisoning, clogging phenomena and utilization of active species and electrodes. Thus, solution can be found only on the material level and require new materials and designs and a high level of expertise.
Further novel technologies, which provide already a sufficient reversibility and require less intensive work on the material level such as redox-flow and molten salt systems, find a more rapid way into larger testing systems and integration concepts. Nonetheless, also these technologies as well as the already proven lithium-ion technology possess a high potential for improvement on the material level regarding electrode design as well as electrolytic solutions.
The main focus on the system level in the scientific review is on the Li-ion technology, similar to the project analysis. However, reasons for this are to be found in the high demands on safety, maintenance of a tight thermal range and sophisticated battery state estimation technics of the Li-ion batteries. System issues concerning further novel technologies are less dominant in the scientific literature due to the technology being still on a basic research level or less challenging demands on the system setup are asked.

The grid integration of energy storage is more an issue of interoperability than of technical connection requirements. Most prominent is the lack of one common, preferable open communication concept and a variety of different ICT hardware which requires transformation/translation at multiple sections in the communication path. Moreover, the expected increase in smart grid devices, virtual power-plants or pooled storages demands an enhancement of the current ICT infrastructure in terms of capacity, latency and reliability. Also cybersecurity becomes more and more a pressing consideration.

The lion's share of research on the material and the system level is still performed on the most advanced and highly established Li-ion technology. On the material level the majority of research work is taking place on the investigation of new electrode materials and designs, while on the system level all issues relating to Li-ion batteries are addressed.
Novel technologies, which are not yet established on the market, seem to be addressed (and also not sufficiently) at materials' level. Even though the integration level is highly addressed by a lot of projects, it still contains a variety of unsolved problems. Most of the projects use the energy storage to solve a geographical and application restricted problem by dealing with energy management and control issues. However, the knowledge gained from the variety of projects has to be merged to a European master plan.

The table below presents an overview of the main battery technologies, an indication of their current status and main elements for possible improvements. This gives elements that could be part of research projects and could thus be part of the research and collaboration clusters as described in the following chapter 5.

Table 15: Overview of status and possible improvements of main technologies based on EASE/EERA roadmap[30] and BATSTORM deliverable D12.

Technology	Current status	Main elements for improvement
Lead-acid	Mature and leading secondary battery market technology with low investment costs. Works best for applications with few deep discharge cycles. Industry in EU at stake due to Asian Li-ion competition.	Incremental performance improvements of the lead-acid batteries (life-time, partial state of charge, densities, power, including graphite R&D)
Nickel-based	Nickel-cadmium (NiCd) and Nickel-metal-hydride (NiMH): Mature technologies. Share of NiCd (toxic) in secondary battery market is decreasing. NiMH is currently widely used in small consumer electronics and hybrid electric vehicles.	Incremental performance improvements with respects to volumetric power density and lifetime.
Lithium-ion	Commercially available batteries with relative good performance. Limited industry in Europe. Performance indicators for commercially available Li-ion technologies at cell level: *Specific energy: 274 Wh/kg* [31] *Energy density: 700 Wh/l* *Costs: 250 €/kWh* *Power: 3 000 W/kg* *Life time: 5000 cycles (C anode)*	Sizeable potential of improvements in costs and performance. For example through: > More energy by enabling a stable high voltage solvent that enables a reversible reaction over several hundreds of cycles; > Longer lifetime of new materials by improving structural stability of new anode materials such as Si-C; > Application of new materials with less noble metals and less processing treatment by using new blends of layered oxide and spinel cathodes and their stability.

[30] EASE/EERA European Energy Storage Technology Development Roadmap, draft available online at http://ease-storage.eu/public-consultation-ease-and-eera-energy-storage-roadmap/

[31] Achieved for consumer cells (cylindrical 18650) with limited cycle life time. Industrial cells achieve about 170 Wh/kg today.

Flow Batteries	Technology in development, with main advantage its long lifetimes with a proven capability to operate over more than ten thousand charges and the ability to decouple power and energy. The active materials can be rejuvenated by adding fresh electrolyte.	Improvements required are substantial cost reduction (membrane and materials), longer lifetime of the membrane, and possibly improvements in power and energy density > Material cost reduction (active species and in particular the ion-exchange membrane); > Ion-exchange membrane that provides high ion-selectivity, ion-conductivity and permeability and chemical stability of all components; > Optimization of the active surface area and electrode geometry to provide a uniform product distribution and an appropriate permeability; > Alternative couples of active species and electrolytes to improve the power and energy density, safety and to reduce corrosion.
Sodium-ion (Na-ion)	Technology in research phase, in which it is aimed for a radical decrease in cost with respect to the lithium ion technology while ensuring sustainability and performance in terms of safety, cycle life, and energy density (NAIADES, HiNaPc, NAPANODE, NExtNCNaBatt).	Improvements required in cycle life and electrolyte stability.
Sodium-based Molten Salt batteries	Sodium-sulfur (NaS, molten salt) and Sodium-nickel-chloride (ZEBRA) Commercial Technology with low costs and high availability of materials as strong points. *Costs: 3 000 €/kW* *Cycle life costs: \$0.04–\$0.75/kWh/cycle*	Improvements required in life time (cycle life time and calendar life time) and reduction of investment costs (€/kW). > Limited capacity due to the undesired formation of solid sodium polysulfides increasing the internal resistance; > Thermal losses due to high operating temperature →remedy: new (solid) low-temperature materials with a high ion conductivity and a close contact to the electrode.
Lithium-sulfur (Li-S)	New technology in R&D phase.	Improve both its cycle and calendar life, rate capability, increase its energy density using less electrolytes, and reduce its high level of self-discharge. The use of metallic lithium as anode requires improvements in safety.
Metal-air Systems (Lithium-air, Zinc-air)	Technologies in development, either in demonstration (Zinc-air) or laboratory phase (Lithium-air).	Improvements depend on the exact materials used, but in general improvement in energy density, round-trip efficiency and power-to-energy ratio are required.

The tables below present an overview of the most demanding issues in the development of technologies on material and system level, where the latter is only dealing with technologies that are in an advanced, post-research, phase.

Table 16: Most demanding issues on the material level for six considered technologies.

Battery technology	Positive electrode	Negative electrode	Electrolyte	Separator, membrane
Lithium-ion	> Expensive additives > Advanced crystalline structures	> Structural stability of new electrodes	> Stability of electrode and high voltages	No particular issues
Lithium-sulfur	> Trap for polysulfides > Loss of active material	> Lithium dendrites > Solid Electrolyte Interface stability	No particular issues	> Deposition of polysulfides
Lithium-air	> Pore clogging > Passivation	> Lithium dendrites > Solid Electrolyte Interface stability	> Stability of electrodes and towards high voltages > Low oxygen solubility and diffusivity	> Gas-selective membrane
Zinc-air	> Bifunctional catalysts > Carbon dioxide poisoning	> Zinc dendrites > Electrolyte decomposition and hydrogen production	> High zincate solubility	> Carbon dioxide air-cleaning
Sodium-based molten salt batteries	> Discharge byproducts	No particular issues	> Low-temperature electrolyte	> Low-temperature separator
Redox-flow	> Uniform pore-size distribution and permeability	No particular issues	> Limited solubility > Shunt currents	> Expensive and highly demanding ion-exchange membrane

Table 17: Most demanding issues on the system level for three advanced technologies.

Battery technology	Electrical imbalance	Thermal management	Battery management	Assembling, packing, housing
Lithium-ion	> Costly, complex balancing and low-quality manufacturing cause reduced specific power, capacity and cycle life > Overcharge and overdischarge cause cell failure	> Beyond temperature range: decreased performance and life time and cell destruction > PCM development	> Fast, cost-efficient and precise state estimation	> Lack of a recommended practice and EU-standard > Safety requirements and system complexity increase costs
Sodium-based (molten salt)	*No particular issues*	> Thermal insulation	> Fast, cost-efficient and precise state estimation	> Corrosion of materials, sealings and containers
Redox-flow	*No particular issues*	*No particular issues*	> Fast, cost-efficient and precise state estimation	> Uniform material delivery > Size and complex design due to pumps and tanks > Corrosion of materials

Table 18 presents a mapping of the recent EU battery energy storage related projects (started later than 01-01-2013) against different battery technologies.

Table 18: Overview of some EU funded battery energy storage projects per technology.

Technology	Projects
Li-ion	**Material level:** eCAIMAN, LeydenJar, SPICY, LIB-Si anode, SUPER-Lion, FIVEVB, MAT4BAT, SINTBAT, CATHDFENS, HS-GLASSion, BATMAN, SiGrAM, OMICON **Battery material characterisation and modelling**: COMBAT, SPICY, HI-C, MARS-EV, BATTERIES2020, SIRBATT, SAFE LIB, E-MOBILE, INFLUENCE) **Cell design and architecture**: SPICY, MARS-EV, BATTERIES2020, COMBAT **Sustainable production and scalability**: eCAIMAN, FIVEVB, BATMAN **Battery management systems:** Everlasting, OSEM-EV, OPTEMUS, ICAB, INCOBAT. Safety and reliability is typically covered in all projects to some extent but is for example the dedicated theme in the SAFE LIB project. Some of the projects aim specifically at improvements in the e-mobility sector (Everlasting, LeydenJar, SPICY, OSEM-EV, OPTEMUS, MAT4BAT, MARS-EV, BATTERIES2020, INCOBAT) which can be beneficial for future solutions in stationary energy storage applications. Some of projects specifically concentrated on **second life applications/integration in the grid**: NETFFICIENT, ELSA.
Na-ion	NAIADES, HiNaPc, NAPANODE, NExtNCNaBatt
Al-ion	ALION
Sodium-based (Molten Salt)	TILOS (integration of Zebra batteries; no materials research)
Li-S	ALISE, HELIS, ECLIPSE
Metal-air	FunLAB (Li-air), LI-AIR CATHODES (Li-air), ZAS (Zn-air), ZnR (Zn-air), Eair
Flow batteries	GREENERNET, MFreeB, GLOBE, Flowbox, EnergyKeeper
Others	CAMBAT (Ca/Mg-ion), BATCA (Ca/Mg-ion), ARTIST (Mg-ion), BAoBaB (Acid/Base)

5 Summary on possible research and collaboration clusters

Based on the actions listed in 3.3 as high/very high priority or those that are required to start in the coming two years a set of short term priorities are identified (see Table 19). Those short term piorities are grouped into research and collaboration clusters (R&C) as listed in Table 20. To form logically fitting research calls or collaboration activities, actions that take place on the same level (material, cell, battery system, integration) and that also have a logical correlation are matched.

Table 19: Actions to be initiated in 2018-2019 resulting from ranking and indicative timeline.

#	Action	Impact	Urgency	Priority	Label
1	Develop integrated design (battery cells, power electronics)	2	2	medium	Research
2	Develop alternative materials for BES	3	2	high	Research
3	Improve power electronics	2	2	medium	Research
4	Develop advanced battery management solutions (thermal, electrical)	3	2	high	Research
7	Develop simulation and modelling tools	2	2	medium	Research
13	Support recycling through adaptation of regulation	3	2	high	Policy
15	Propose interface and communication protocol standards	2	2	medium	Research and policy
18	Create and maintain knowledge sharing platform	2	3	high	Policy and industry
19	Sharing and proposing best practices on technical battery connection requirements	3	3	very high	Policy
20	Harmonize connection procedures	3	2	medium	Policy
22	Propose best-practices to value the strengths of BESS services	2	2	medium	Policy
23	Monitor market distortions and act	1	3	medium	Policy and industry
24	Create higher transparency for system needs	2	2	medium	Research and industry
27	Continue development of safety standards	2	3	high	Policy
28	Propose duty cycle and testing standards and performance certification	2	3	high	Research and policy
29	Facilitate industry collaboration across sectors and financial support	3	3	very high	Policy and industry
30	Estimate the market potential/demand for BESS	2	3	high	Research
35	Create bridge between research funded and patent filing	2	2	medium	Policy and industry

Table 20: R&C clusters of short term priorities (implementation plan 2018-2019)

#	R&C cluster	Level	Corresponding roadmap actions
1	Research on cutting edge materials and technologies	Material/cell	Develop alternative materials for BES and continue research on cutting edge battery technologies (Action 2)
2	Performance and safety of batteries	System level	Develop integrated design (battery cells, power electronics) (Action 1)
			Improve power electronics (Action 3)
			Continue development of safety standards (Action 27)
			Propose interface and communication protocol standards (Action 15)
3	Increased lifetime of batteries	System level	Develop advanced battery management solutions (thermal, electrical) (Action 4)
			Develop simulation and modelling tools (Action 7)
			Propose duty cycle and testing standards and performance certification (Action 28)
4	Grid connection rules	Integration level	Propose interface and communication protocol standards (Action 15)
			Harmonize connection procedures (Action 20)
			Sharing and proposing best practices on battery connection requirements (Action 19)
5	System needs and market potential	Integration level	Create higher transparency for system needs (Action 24)
			Propose best practices to value BESS services (Action 22)
			Monitor market distortions (Action 23)
			Estimate the market potential/demand for BESS (Action 30)
6	Inter-sectoral Collaboration: Industrial capacity and technology leadership	Cross-level	Facilitate industry collaboration across sectors and financial support (Action 29)
			Create and maintain knowledge sharing platform (Action 18)
7	Circular economy	Cross-level	Support recycling and second use through adaptation of regulation (Action 13)
			Facilitate second life battery applications (Action 14)

Annex E contains useful references to projects relevant for different clusters.

References

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Appendix A: Stakeholder interaction

Stakeholder interaction has been an essential part of the BATSTORM project. The following categories of stakeholders have been contacted throughout this project:

- Technology providers
- Market players
- PPPs
- Utilities
- Financing
- NRAs & MS
- TSOs/DSOs
- NGOs
- Research
- Associations
- Government officials.

The consultation of these stakeholders has taken place in several manners:

- Workshops
- Project website
- Survey
- Interviews
- Detailed/open interactions
- Attendance of conferences, discussions and workshops.

The main source of concrete input for the development of the roadmap have been the range of **workshops** held. Table 21 presents and overview of the workshop held within the scope of this project, which all contributed either to the building blocks of the roadmap, or directly to roadmap itself.

Table 21: BATSTORM workshops contributing to the roadmap.

Name	Date	Description	Location
Kick off workshop	16-03-2016	To kick-off the project, inform about goals and methodology of the project, interactive session on possibilities, challenges and hurdles.	Dusseldorf (IRES/ESA conference)
Expert meeting	21-04-2016	Presentation and interactive feedback session on the draft Implementation Plan 2016-2018, progress update on the project overall.	Brussels
1st Roadmap workshop	20-09-2016	Presentation of socio-economic analysis (projections), interactive session on barriers and actions.	Brussels
2nd Roadmap workshop	21-02-2017	Interactive session on structure of roadmap, actions and prioritization of actions.	Brussels
Final Roadmap workshop	06-06-2017	Presentation of the draft roadmap, feedback by stakeholders and discussion on proposed priorities.	Brussels

A **project website** (http://www.batstorm-project.eu/) was designed at the start of the project, providing basic information on the project, contact form, and some news items. publication of results The deliverables from the project were also published on the website which allowed stakeholders to review them and provide feedback on the deliverables. The website was also used for announcements on the workshops, the online survey and news items.

An **online survey** has been held in 2016, which provided input on the underlying fields of analysis (socio-economic, policy, market and technical). The online survey thus did not provide detailed questions directly on the roadmap but provide input required to develop the roadmap (e.g. input for the socio-economic analysis and barrier analysis). A range of **interviews** have been performed approaching a wide range of stakeholders to directly ask their input on a range of topics. Furthermore there have been several **detailed/open interactions**. For example stakeholders who we after an interview approached for a second set of detailed questions, requesting background information or data or asking for detailed review on draft documents. Another example of this type of interaction is more detailed conversations we had with associations. Lastly BATSTORM team members have attended **network meetings, conference and discussion meetings**. For example interaction and presentations during relevant conferences, but also participating in discussions on parallel roadmaps or position papers.

BATSTORM

Appendix B: Overview of identified actions

Table 22: List of actions derived from stakeholder consultation (workshops, interviews, online survey).

Vision	Goal	Action
Development and deployment of High-performing, cost-effective and environ-mentally friendly battery energy storage	Optimized performance	Develop integrated design (battery cells, power electronics)
		Develop alternative materials for BES while continuing investment in today's cutting edge technology
		Improve power electronics
		Develop advanced battery management solutions (thermal, electrical)
		Control internal electrochemical reactions
		Develop hybrid-technology solutions
	Optimized lifetime	Develop simulation and modelling tools
		Propose solutions for fault protection and detection (sealing foil cells)
	Maximized recycling and re-use	Design modular batteries
		Substitute materials for recycling
		Further develop recycling process
		Build up pilot plant for closed loop recycling
		Support recycling and second use through adaptation of regulation
		Facilitate second-life battery applications
	Increased interoperability	Propose interface and communication protocol standards
		Propose automatic and remote control concepts
		Develop interoperable BMS
	Increased harmonization	Create and maintain knowledge sharing platform
		Identifying and proposing best practises on battery connection and pre-qualification requirements
		Harmonize connection procedures
		Streamline metering and telemetry requirements
	Adequate remuneration	Propose best-practices to value the strengths of BESS services
		Monitor market distortions and act
		Create higher transparency for system needs
	Minimized investment risk	Establish guide on financing options
		Adopt standardized method for life cycle cost analyses
	Increased acceptance	Continue development of safety standards
		Propose duty cycle and testing standards and performance certification
		Propose data and cyber security measures
Established EU industrial capacity and leadership	Increased industrial capacity	Facilitate industry collaboration across sectors and financial support
		Estimate the market potential/demand for BESS
	Maximized production efficiency	Redesign/reduce clean rooms and drying rooms in cell production plants
		Propose process adaptations towards continuous operation
		Automate the production process of BESS
	Increased technological leadership	Create bridge between research funded and patent filing
		Facilitate eco–efficient production pilot lines and living lab projects

Appendix C: Overview of set milestones

Goal	Performance indicator	Milestone
Optimized performance	Power density	**2020:** 1000 W/l (pack level) & 1500 W/l (cell level) **2027:** >1000 W/l (pack level) & > 1500 W/l (cell level)
	Round trip efficiency	**2020:** >90% for best performing state of the art battery technologies **2027:** >95% for best performing state of the art battery technologies
Optimized durability	Calendar life *(EOL-criteria: 80% of rated capacity)*	**2020:** 15 years **2027:** 20 years
	Cycle life *(EOL-criteria: 80% of rated capacity)*	**2020:** 5,000 cycles **2027:** 10,000 cycles
Minimized system costs	System investment costs	**2020:** 350 €/MWh **2027:** 200 €/MWh
Maximized recycling	Maturity recycling process	**2020:** Feasible recycling **2027:** Commercial recycling
	Collection rate	**2020:** 60% collection rate **2027:** 80% collection rate
Increased interoperability	(N/A)	(N/A)
Increased harmonization	Level of knowledge sharing	**2020:** Widely used best-practice database with open access BESS cost benefit analysis tool **2027:** (N/A)
	European grid code requirements	**2020:** European-wide technical specifications and network code **2027:** (N/A)
Adequate remuneration	Participation of distributed resources in wholesale and reserve markets	**2020:** Barriers removed in all Member States **2027:** (N/A)
Minimized investment risk	(N/A)	(N/A)
Increased acceptance	(N/A)	(N/A)
Increased industrial capacity	Annual EU cell production capacity	**2020:** 2.2 GWh **2027:** 5.0 GWh
Maximized production efficiency	(N/A)	(N/A)
Increased technology leadership	Share of relevant patent filed	(N/A)

Appendix D: Priority rating of actions

#	Action	Impact	Urgency	Priority	Label
1	Develop integrated design (battery cells, power electronics)	2	2	medium	Research
2	Develop alternative materials for BES while continuing investment in today's cutting edge technology	3	2	high	Research
3	Improve power electronics	2	2	medium	Research
4	Develop advanced battery management solutions (thermal, electrical)	3	2	high	Research
5	Control internal electrochemical reactions	2	1	low	Research
6	Develop hybrid-technology solutions	2	2	medium	Research
7	Develop simulation and modelling tools	2	2	medium	Research
8	Propose solutions for fault protection and detection (sealing foil cells)	2	2	medium	Research
9	Design modular batteries	2	2	medium	Research
10	Substitute materials for recycling	1	2	low	Research
11	Further develop recycling process	2	2	medium	Research
12	Build up pilot plant for closed loop recycling	2	2	medium	Industry and policy
13	Support (large-scale) recycling and second use through adaptation of regulation	3	2	high	Policy
14	Facilitate second-life battery applications	2	2	medium	Research, policy and industry
15	Propose interface and communication protocol standards	2	2	medium	Research and policy
16	Propose automatic and remote control concepts	1	2	low	Research
17	Develop interoperable BMS	2	2	Medium	Research
18	Create and maintain knowledge sharing platform	2	3	High	Policy and industry
19	Identifying and proposing best practises on battery connection and pre-qualification requirements	3	3	very high	Research and policy
20	Harmonize connection procedures	2	2	Medium	Policy

21	Streamline metering and telemetry requirements	**1**	**1**	**very low**	Research and policy
22	Propose best-practices to value the strengths of BESS services	**2**	**2**	**Medium**	Policy
23	Monitor market distortions and act	**1**	**3**	**Medium**	Policy and industry
24	Create higher transparency for system needs	**2**	**2**	**medium**	Research and industry
25	Establish guide on financing options	**2**	**2**	**medium**	Policy
26	Adopt standardized method for life cycle cost analyses	**1**	**2**	**low**	Policy and industry
27	Continue development of safety standards	**2**	**3**	**high**	Industry
28	Propose duty cycle and testing standards and performance certification	**2**	**3**	**high**	Research and policy
29	Propose data and cyber security measures	**1**	**2**	**low**	Research, policy and industry
30	Facilitate industry collaboration across sectors and financial support	**3**	**3**	**very high**	Policy and industry
31	Estimate the market potential/demand for BESS	**2**	**3**	**high**	Industry
32	Redesign or reduce clean rooms and drying rooms as part of cell production plants	**2**	**1**	**low**	Research
33	Propose process adaptions towards continuous operation	**1**	**1**	**very low**	Research
34	Automate the production process of BESS	**1**	**1**	**very low**	Research
35	Facilitate eco–efficient production pilot lines and storage-oriented living lab projects	**2**	**2**	**medium**	Research and industry
36	Create bridge between research funded and patent filing	**2**	**2**	**medium**	Policy and industry

Appendix E: Research projects & research clusters

Table 23 below gives an overview of recent EU-funded battery energy storage related projects, started later than 01-01-2013, mapped against the 6 R&C clusters as defined and presented in section 5. The projects are ranked per type of project and it is immediately striking that there is a clear diversity between the different clusters.

Table 23. Overview of EU funded battery energy storage projects. Abbreviations explained at the end of table.[32]

Acronym		R&C 1	R&C 2	R&C 3	R&C 4	R&C 5	R&C 6	Start date	End date
NAIADES	RIA[1]	X			X			1/01/2015	31/12/2018
eCAIMAN	RIA		X					1/05/2015	30/04/2018
FIVEVB	RIA		X	X				1/05/2015	30/04/2018
SPICY	RIA		X					1/05/2015	30/04/2018
ALION	RIA	X			X			1/06/2015	31/05/2019
ALISE	RIA	X						1/06/2015	31/05/2019
HELIS	RIA	X						1/06/2015	31/05/2019
OPTEMUS	RIA		X					1/06/2015	28/02/2019
OSEM-EV	RIA		X	X				1/06/2015	31/05/2018
ZAS	RIA	X						1/06/2015	31/05/2018
ECLIPSE	RIA	X						1/12/2015	30/11/2017
EVERLASTING	RIA		X	X				1/09/2016	31/08/2020
LiRichFCC	RIA	X						1/10/2016	30/09/2019
BAoBaB	RIA	X						1/05/2017	30/04/2021
NETFFICIENT	IA[2]				X	X		1/01/2015	31/12/2018
TILOS	IA				X	X		1/02/2015	31/01/2019
ELSA	IA				X	X		1/04/2015	31/03/2018
SINTBAT	IA		X	X				1/03/2016	29/02/2020
GREENERNET	IA	X			X			1/07/2016	30/06/2018
INVADE	IA				X	X		1/01/2017	31/12/2019
HI-C	CP[3]		X					1/09/2013	28/02/2017
INFLUENCE	CP		X					1/09/2013	31/08/2016
SIRBATT	CP		X	X			X	1/09/2013	31/08/2016
INCOBAT	CP		X					1/10/2013	30/09/2016
BATTERIES2020	CP-IP		X	X				1/09/2013	31/08/2016
MAT4BAT	CP-IP		X	X				1/09/2013	28/02/2017

[32] R&C 7 is not reflected in this table, since it was added by the Commission to a later version after the analysis of projects had been performed

MARS-EV	CP-IP		X	X				1/10/2013	30/09/2017
COMBAT	ERC-CG[4]		X					1/06/2014	31/05/2019
MFreeB	ERC-COG	X						1/06/2017	31/05/2022
HiNaPc	ERC-POC	*X*						*1/01/2017*	*30/06/2018*
HiPerBat	ERC-SG		X					1/01/2013	31/12/2017
E-MOBILE	ERC-SG		X					1/10/2013	30/09/2018
OMICON	ERC-STG		X					1/04/2015	31/03/2020
BATMAN	ERC-STG		X					1/05/2016	30/04/2021
CAMBAT	ERC-STG	X						1/01/2017	31/12/2021
HS-GLASSion	*MSCA-IF-EF-ST[5]*		*X*					*1/08/2015*	*31/07/2017*
GLOBE	*MSCA-IF-EF-ST*	*X*						*1/09/2015*	*31/08/2017*
LIB-Si anode	MSCA-IF-EF-ST		X	X				14/09/2015	13/09/2017
SAFE LIB	*MSCA-IF-EF-ST*		X					16/11/2015	15/11/2017
NAPANODE	*MSCA-IF-EF-ST*	*X*						*1/03/2017*	*28/02/2019*
NExtNCNaBatt	MSCA-IF-EF-ST	X						1/03/2017	28/02/2019
SUPER-Lion	MSCA-IF-EF-ST		X					1/04/2017	30/11/2018
BATCA	MSCA-IF-EF-ST	X						16/05/2017	15/05/2019
ARTIST	MSCA-IF-GF	X						1/07/2015	31/12/2017
CATHDFENS	*MSCA-IF-GF*		*X*					*1/09/2016*	*31/08/2019*
FunLAB	*MC-CIG[6]*	*X*						*25/04/2014*	*24/04/2018*
LI-AIR CATHODES	*MC-IOF*	*X*						*2/09/2013*	*1/09/2016*
ECOSTORE	MC-ITN	X					X	1/10/2013	31/12/2017
MeRIT	SME-1[7]				*X*			*1/03/2015*	*31/05/2015*
SiGrAM	SME-1		*X*					*1/07/2015*	*31/10/2015*
BATMAN	SME-1		*X*					*1/09/2015*	*29/02/2016*
ActiveGrid	SME-1				*X*	*X*		*1/03/2016*	*31/07/2016*
LeydenJar	SME-1		X	X				1/04/2017	31/08/2017
ICAB	*BSG-SME[8]*		*X*					*1/09/2013*	*31/12/2015*

1. **RIA = Research and innovation actions**
2. **IA = Innovation action**
3. **CP = Cordis Programme**
4. **ERC = European Research Council Consolidator Grants**
5. **MSCA = Marie Skłodowska-Curie actions**
6. **MC = Marie Curie Action**
7. **SME = HORIZON 2020 DEDICATED SME INSTRUMENT**
8. **BSG-SME = FP7 ‛ Research for SME'**

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