BATTERY STORAGE TO DRIVE THE POWER SYSTEM TRANSITION

Flexibility needs and opportunities

Variable renewable energy sources (VRE), including wind and solar photovoltaics (PV), have a pivotal role in the decarbonization objectives of the European Union's (EU) energy system. The rising shares of VRE over the past 15 years surpassed most industry and policy projections, due to large cost reductions and increasing customer willingness to invest in those energy sources. Relying almost entirely on the stochastic weather-determined output of VRE will require a transformation of the way power systems are planned and operated. A growing amount of flexibility will be needed to match variable demand with increasingly variable supply. However, within the current and future energy transition, the role of large conventional plants as flexibility providers for the power system is declining. A '**flexibility gap'** needs to be avoided by introducing new solutions next to the existing ones. Figure 1 summarizes those options including current and new supply flexibility, demand side flexibility and energy storage as flexibility sources, complemented by grids and markets as enablers. Power systems and market actors, especially in the EU, have demonstrated how systems can integrate larger shares of VRE and tap into new flexibility options by reviewing grid planning and operational procedures, and by advancing the design of wholesale and ancillary markets.

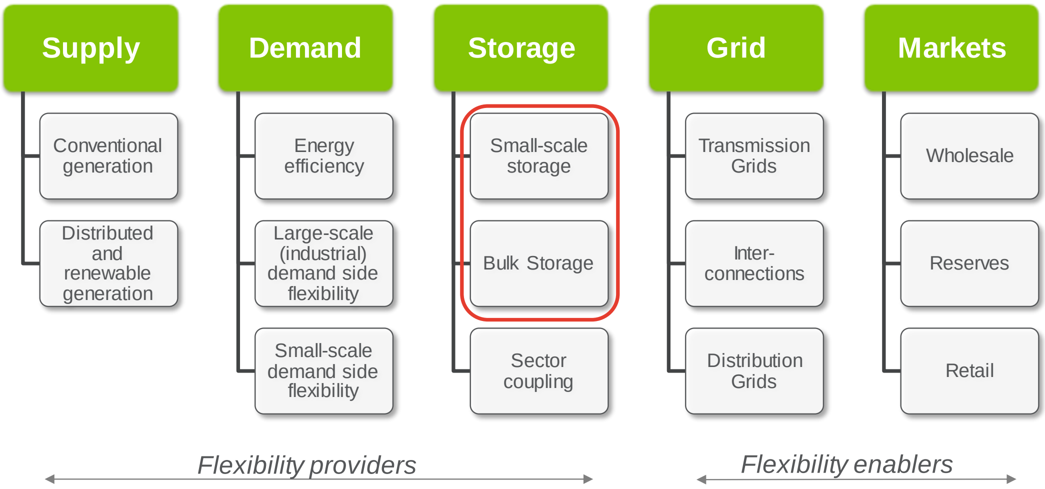

Figure 1. Categorization of flexibility options (right). Own representation based on [Papefthymiou]

S**tationary battery energy storage systems (BESS)** are a well-suited option for short term flexibility needs (in the range of seconds to hours) and can serve various different applications. In general, they are relatively light, have short construction time and don't suffer from lengthy permitting procedures compared to classical grid infrastructure which allows fast project development cycles. Batteries can relatively easy be relocated and are stackable, meaning that energy or power ratings can smoothly be extended or relocated, allowing an adjustable planning in an uncertain and fast changing energy context. Potential customers of storage include power generation unit owners, grid operators and industrial and residential consumers and prosumers, all of whom seek means to operate their system in a most cost-effective manner. Batteries offer substantial opportunities at times where established energy suppliers are shifting from large generation projects to concepts which can be realized in the shortest period of time (e.g. automated installation and deployment of PV and wind parks) [ENEL]. Also grid operators who are under increasing regulatory scrutiny to provide case-by-case the most cost-effective solution for further grid developments are finding benefits in BESS solutions (e.g. network operators association's strategies on storage investments) [ENA]. Similarly, batteries

This paper was based on research done within the EU funded BATSTORM project. More background, information and details can be found in the various deliverables published within this project, available at the project website. These deliverables include a detailed socio-economic analysis, an in-depth technology review of battery technologies and a roadmap for R&I actions and related measures to promote battery based energy storage.

allow consumers and prosumers to increasingly take control of their energy ecosystem (e.g. integrated energy concepts for residential neighborhoods) [BINE]. A number of promising BESS use cases are described in detail in Deliverable “Socio-economic analysis” of Batstorm project [BATSTORM D7], including solar energy self-consumption, frequency regulation, grid upgrade deferral and optimisation of production of variable renewable energy.

Decarbonization of our energy system, market integration, consumer empowerment, and technical leadership all are key objectives in the EU’s energy policy for the coming decades. While renewable energy sources are essential components to reach these objectives, **battery energy storage solutions may be the accelerator that facilitates variable renewables in a cost-effective and flexible manner**.

Recent developments and future trends within the battery energy storage market

During the last decade the trends in the overall worldwide rechargeable battery market (2005: 300 GWh, 2016: 460 GWh) have been mostly driven by the electric vehicles sector [Avicenne]. The mature lead-acid battery technology (2000: 270 GWh, 2016: 362 GWh) is by far the most important battery market in volume and will still remain so in 2025 (about 550 GWh). Of this totally installed lead-acid battery capacity 79% can be found in cars as starting, lighting and ignition batteries (SLI) while a share of 9% is installed in stationary systems to support telecom (4,2%), as UPS (3,5%) or to deliver other energy storage services (1,3%). With the shift in 2012 of almost all car makers towards lithium-ion battery technology for the production of their (hybrid) electric vehicles, this battery market increased from an installed capacity below 2 GWh in 2000 to 90 GWh in 2016 (CAGR 2006-2016: 23%). Whereas the original demand was for 100% originating from the portable electronics industry, this has now seen a decrease to 35%, reserving a share of 50% for electric mobility (cars, buses, etc.), 10% for applications like power and gardening tools as well as electric bicycles, and the remaining 5% for stationary energy storage services. The forecasts for the lithium-ion battery market predict a CAGR (compound annual growth rate) of 15% between 2016 and 2025, resulting in a total market size in volume of 300 GWh, taken by the electric vehicles sector for about 65%. 7% of this market could be installed as stationary energy storage solutions [Avicenne]. These applications can even increase since the lithium-ion technology is highly suitable for most of the related services and cost is expected to continue the decreasing trend of the recent years (see Figure 2). Those cost reductions were mainly driven by economies of scale, improvements in production processes as well as increased efficiencies due to technology improvements. Hence, it is expected that lithium-ion will become the biggest battery market in value by 2020. Next to lead-acid and lithium-ion batteries, the remainder of the total battery market is nowadays almost entirely taken by the nickel-based battery technologies, Nickel metal-hydride (NiMH) and Nickel Cadmium (NiCd). Their market share, both in volume and value, is however declining in favour of lithium-ion and new promising battery technologies (including.molten salt and flow batteries which start being deployed in big-scale stationary storage projects, such as 200MW/800MWh vanadium flow battery projectin Dalian, China and 108MW Sodium Sulphur battery system in Abu Dhabi).

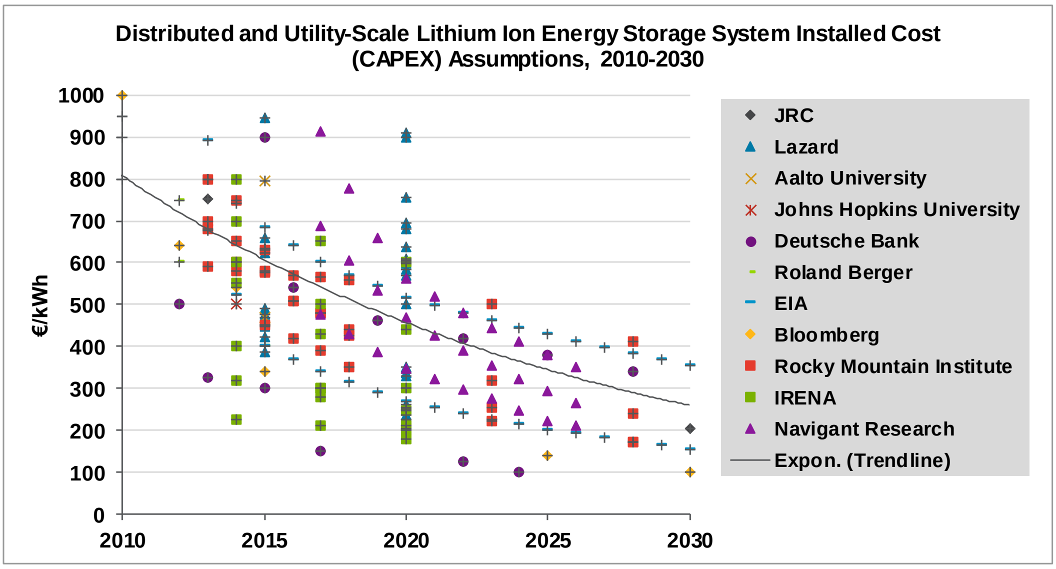

Figure 2. Past and forecasted Lithium-Ion Battery system costs for distributed and utility-scale batteries. Own representation based on [IRENA] [EPRI] [RMI] [Bloomberg] [EIA] [Roland Berger] [Deutsche Bank] [Castillo] [Zakari] [Lazard] [JRC 2014] [Navigant].

Currently, stationary battery energy storage, with 36 GWh globally installed capacity, only plays a limited role in the overall demand for batteries. However, it clearly benefits from cost reductions, supply chains and technology improvements of automotive and possibly other battery applications since nowadays often the same battery technology is being used in these different applications. Projections for stationary battery energy storage need to take into account evolutions in these other sectors but it has to be noted that dedicated technology development towards this application should be supported to find the optimal battery solution based on the specific requirements.

Within Europe, the deployment of batteries is both driven by consumer (distributed residential as well as commercial and industrial -C&I storage) as well as grid operator and utility needs (distributed and centralized storage systems).

While not yet in the stage of mass deployment throughout Europe, stationary batteries are already being installed/tested in a **multitude of applications** and use cases. They can either be installed behind-the-meter at residential, commercial or industrial scale to support the integration of distributed generation of variable renewable energy sources (VRE) while at the same time leading to cost savings for the storage owner (e.g. by reducing grid charges).

Larger storage systems at utility scale are installed to support the grid centrally by providing ancillary services such as frequency regulation or by relieving transmission or distribution congestions locally. In some areas (e.g. Great-Britain), batteries can also qualify for capacity remunerations. Some leading countries have already adapted market rules and guidance so that batteries can participate with an increasing role in the energy market. European legislative proposals for Europe's electricity markets (legislative package Clean Energy for all Europeans) aim to remove barriers for deployment of energy storage throughout the EU. European frontrunners for distributed and utility scale storage today are Germany and the UK based on past financial incentives and ancillary service products respectively. In the coming decade countries such as Italy, Spain and France are expected to also become important players on this market as battery storage solutions should be able to compete with other technologies in ancillary services and grid investment options (see Figure 6 and Figure 7in the Annex I). Several lessons learned from these countries have been summarised in Policy recommendations [BATSTORM WP5]. While some EU countries perform well and are growing in terms of deployment of battery storage, the biggest battery projects so far were taking place outside EU. Next to the aforementioned current lack of EU regulatory framework and storage supporting market design this could in part also explained by the EU so far having higher reliability and less exposure to extreme weather-related risks. Hence the EU in general currently relies less on batteries for the security of power supply.

Europe has seen a growth of 49% in 2017 compared to 2016 with the installation of about 600 MWh electrical energy storage (largely taken by battery systems). A continuous growth is foreseen for 2018 (about 850 MWh) and 2019 (1150 MWh) resulting in an installed capacity of 3.5 GWh (excluding pumped hydro storage), coming from 0.6 GWh in 2015.

With further decreasing costs, reduction of regulatory hurdles and new business cases, the deployment of battery storage in Europe is projected to increase to more than 11 GW in 2026 (from the present level of less than 1 GW) creating a large flexibility potential for utilities, grid operators and independent actors.

While currently utility scale, front-of-meter, batteries dominate battery storage market, it is expected that by 2026 distributed behind-the-meter storage will almost catch up with in terms of deployed capacity. Here it should be mentioned that technically and marketwise it is possible to use behind-the meter storage capacities for providing services not only locally but also at utility scale (including frequency regulation) [BATSTORM D7]. Indeed, in some jurisdictions, like Norway and Germany[1], already today home batteries and EV batteries are used through aggregators for provision of services to TSOs.

Off-grid applications of energy storage, from individual energy systems for homes, telecom towers to microgrids, are not common in Europe, given the dense electricity network throughout the inhabited areas of EU. At the same time capability to offer possibility to operate in off-grid mode is very important for islands with weak interconnection. More generally, batteries are set to play a very important role not only in de-carbonising islands which nowadays often are supplied by expensive diesel-based generation (move to RES+storage), but also ensuring security of supply[2].

Battery solutions

How a battery works: the basics

A battery converts chemical energy into electrical energy. It is typically made of three major parts: an **anode**, a **cathode** and an **electrolyte**, each made of a different material and. In very basic terms, chemical reactions between the materials generate energy.

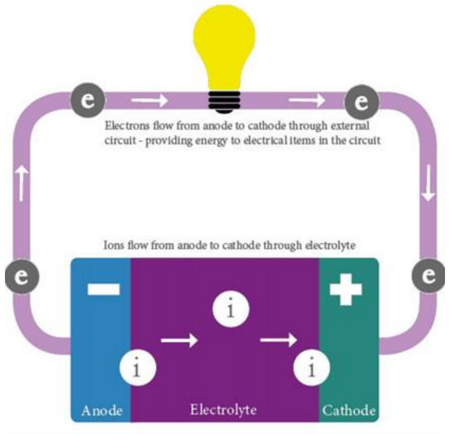

Figure 3. Schematic overview of the functioning of an average battery.

The chemical reactions mainly occur when the battery is plugged into an external circuit that connects the anode and cathode, for example, when it is placed into a mobile phone. The reactions cause **electrons** and **ions** to build up at the anode. The electrons flow towards the cathode through the external circuit where they provide electrical power *en route* (to the phone or car, for instance). The ions also flow towards the cathode, but through the electrolyte which separates the anode (also known as the **negative electrode**) and the cathode (also known as the **positive electrode)**. The ions and electrons recombine at the cathode to complete the circuit and keep the reactions running. The anode, cathode and electrolyte make up one **cell** of a battery. A battery can be made up of one or more cells. The voltage increases with the number of cells.

Technology options for battery-based energy storage systems (BESS)

[1] For example, in Germany in Sonnen community, https://sonnenbatterie.de/en/sonnenCommunity

[2] This is *inter-alia* demonstrated by the European projects TILOS, NETfficient, INTERFLEX, and SMILE.

Various technology options exist for BESS. Some technologies are already well established on the market (lead-acid, lithium-ion, nickel-based), also serving the stationary storage market, while others are still at the starting point of deployment or in a demonstration phase still (see Figure 4).

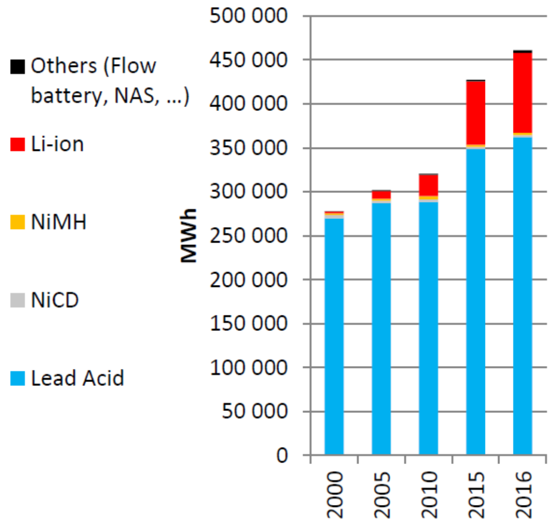

Figure 4. Overview of the volume of the worldwide battery market split per technology in MWh [Avicenne].

Lead-acid batteries is known best from internal combustion engine cars and they are commonly used for uninterruptible power supply (UPS). They have longstanding experience in the market, are available at relative low costs and have a recycling process already fully in place. They have been dominating global battery market even if growth rates are modest compared to growth rates in lithium-ion applications (see Figure 4). Compared to the other, more novel technologies, lead-acid technology is already quite mature and therefore the potential for large improvements is lower.
For **advanced lead-acid batteries** improvement of the cycle life, performance at partial state of charge, power density as well as charge efficiency are the main focus points.

Lithium-ion batteries are known from mobile phone, laptop and similar applications. This is the type of rechargeable battery in which lithium ions move from the negative electrode to the positive electrode during discharge and back when charging. There are numerous lithium-ion sub-types. Batteries with lithium nickel-manganese cobalt oxide cathode (NMC batteries) are a leading contender for automotive applications and have the lowest self-heating rate, while NCA (lithium nickel cobalt aluminium oxide batteries) which currently offer a higher range due to a higher energy per unit of volume but has a slightly lower performance in terms of safety. Lithium iron phosphate batteries (LFP) find a number of roles in vehicle use (especially e-buses), utility scale stationary applications, and backup power. They are one of safest types of lithium-ion batteries but with a relatively low energy density by lithium-ion battery standards. This does not make them suitable for use in electric vehicles, while for most e-busses, on the contrary, the issue of range is not a problem. Lithium-ion battery cells come in different sizes and shapes and, very often, the same battery cells can be used in electric vehicles, home batteries and even grid-scale batteries.

Lithium-ion batteries are commercially available batteries with relative good performance and a compact size. Availability of the raw materials is seen as a potential risk factor of the technology. Improvements in production technology, the use of low cost materials (e.g. partial replacement of cobalt with nickel), the increase of the specific energy, and the increase in life duration (cycle life and calendar life) are key in **lithium-ion battery** related research. Next to this the use of second life batteries, after a first use in automotive applications, is gaining more and more attention. Important gains in terms of performance (e.g. energy density and safety) are expected from **all solid-state lithium** batteries**.**

Types of **nickel-based batteries** are small nickel-cadmium or nickel metal-hydride batteries, the latter mostly applied in small consumer electronics and hybrid electric vehicles. Nickel-cadmium batteries are used in transport applications (like airplanes especially because of their reliability and robustness) and sometimes also used for storage of solar generated energy, because they can withstand high temperatures. In stationary applications they were mostly used for UPS applications.
The nickel-based battery technologies are already mature, and only incremental performance improvements with respects to volumetric power density and lifetime are expected.

Other battery technologies are just gradually entering the market, like **redox-flow** and **molten-salt batteries**. There are several projects applying these batteries (some still in development), but these technologies do not have a long track record of deployment yet to show their expected long-age advantages.

A **flow battery** is a form of rechargeable battery in which electrolyte flows through an electrochemical cell that converts chemical energy directly to electricity. Additional electrolyte is stored externally, generally in tanks, and is usually pumped through the cell (or cells) of the reactor. Flow batteries can be rapidly "recharged" by replacing the electrolyte liquid (in a similar way to refilling fuel tanks for internal combustion engines) while simultaneously recovering the spent material.

The major advantage of this type of battery is that power and energy are not coupled in the same way as other electrochemical systems, which gives considerable design latitude for stationary applications. Additional advantages are good specific energy and recharge efficiency, low environmental impact, and low cost. The disadvantages of this battery technology are system complexity and high initial self-discharge rate [Doughty].

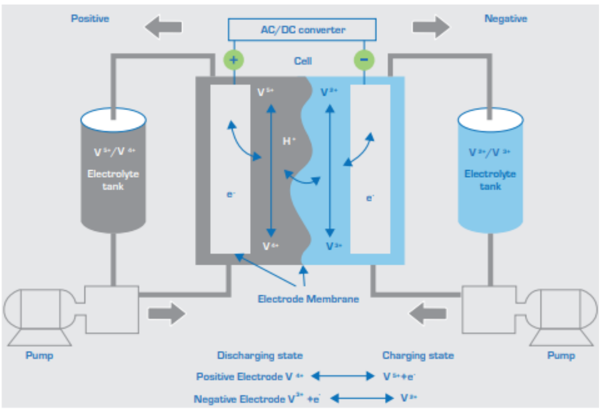

Figure 5. Schematic overview of operation of flow batteries [EASE]

Currently there are two main types of flowing electrolyte batteries that are under development: zinc/bromine and vanadium-redox. Research is being done also on other, more sustainable, flow batteries – notably organic flow batteries.
For Vanadium **redox flow batteries**, substantial cost reduction of the flow battery systems reaching economies of scale, possibly improvements in power and energy density and reduction of corrosion are the primary attention points.
Molten salt batteries, also known as liquid metal batteries, are a commercial technology with low costs and high availability of materials. Examples are sodium-sulfur (NaS, molten salt) and sodium-nickel-chloride (ZEBRA).
A sodium-sulfur battery has a high energy density, relatively high roundtrip efficiency (89-92%), long cycle life, and is fabricated from inexpensive materials. However, because of the operating temperatures of 300°C to 350°C and the highly corrosive nature of the discharge products, such cells are primarily suitable for large-scale, non-mobile applications such as grid energy storage. Another type of molten salt battery is the so-called Zebra Battery (sodium nickel chloride). Its cells have a higher voltage, wider operating temperature range, are less corrosive and have safer reaction products.

Molten-salt battery research, and more in general sodium-based molten-salt technologies, is striving towards improvements in life time (cycle life time and calendar life time) and reduction of investment costs (€/kW).

Sodium-ion batteries, lithium-sulfur, and metal-air batteries are still far from mass commercialisation and basic research is ongoing. **Lithium-sulfur battery** research builds further on current demonstration technologies to improve on both cycle and calendar life, energy density, safety and reduce the high level of self-discharge. With respect to **metal-air** battery technology, of which currently only zinc-air batteries are available as demonstration technology, improvements on round-trip efficiency and the power-to-energy ratio are the first goal. **Lithium-air** batteries, at this moment at prototype level, must increase their cycle life and energy density. Suitable cathode materials at industrial scale for the promising Sodium-ion technology are a big challenge. This technology must improve its lifetime, specific energy, energy density, and power capability. Like for lithium-ion batteries, these values could be tackled by solid-state concepts.

Different (dis-) advantages and hence different fields of application arise from their intrinsic chemical properties and design. Nonetheless, for every field of application a suitable battery technology can be identified, for both power intensive as well as energy intensive applications. Table 1 in the Annex summarizes the main properties of the considered electrochemical energy storages restricted to the distinctive characteristics of the technology. The summary looks slightly ahead and assumes main issues are resolved in the short-term regarding the technologies-under-development of metal-air, sodium-ion and lithium-sulfur with current Technology Readiness Level ranging from 2 (metal air) to 6 (sodium sulphur).
More details on what can be improved as regards to electrodes, electrolyte and other elements of each major type of battery can be found in Deliverable “Technology Review” [BATSTORM D12]. Similarly, references to several relevant projects can be found there.

European action

Europe's Integrated **Strategic Energy Technology Plan** (SET Plan) comprises several key actions directly or indirectly linked to the development of energy storage solutions and battery technologies in particular.

Action 4 of the SET Plan is a tool to coordinate EU and national efforts to "Increase the reliance and security of the energy system". The related Implementation Plan published in January 2018 [TWG4-IP] addresses R&I needs for storage for the future energy system, focusing primarily on integration aspects, while also recognizing that further R&I is needed into storage technologies to cut their cost considerably[3]. Practical coordination of MS R&I efforts in smart energy systems topics is successfully facilitated through the ERA-NET instrument which resulted in joint R&I calls, including calls without EU's co-funding. This complements significant direct R&I funding that EU is providing in the area of smart grids and storage. A recent overview[4] shows important contribution provided by H2020 smart grids and storage projects for developing innovative energy systems solutions involving batteries. Indeed, roughly half of the smart grids projects with demos involve batteries: residential batteries, shared district batteries, batteries coupled with RES and conventional generation, batteries supporting fast charging stations, batteries at TSO/DSO nodes, EV batteries (including 2nd life), etc. Almost all of them are involved in providing multiple services to the energy system thanks to involvement of ICT tools. Now the plan is to seek replication of successful battery-based solutions *inter alia* within the European Innovation Partnership for Smart Cities and Communities.

When it comes to battery chemistry focused R&I, key action 7 of the SET Plan with the objective for Europe to "Become competitive in the global battery sector to drive e-mobility and energy storage forward" is the tool for coordinating EU and national efforts. The related Implementation Plan [TWG7-IP] addresses current technical and non-technical barriers to competitiveness and contains proposals for specific R&I activities to be carried out by private stakeholders and Member States to achieve the performance and cost targets needed to ensure competitiveness of EU in batteries' field [EC 2016e].
The R&I activities have defined objectives according to milestones structured around 3 focus areas being 1) Material/Chemistry/Design + Recycling; 2) Manufacturing; and 3) Application and Integration. As far as stationary battery-based storage is concerned, the Implementation Plan is supplemented by a number of findings from the BATSTORM project.
The Implementation Plan for Batteries under (SET-Plan Action 7) serves as an input to the R&I dimension of the **European Battery Alliance** [EBA] which will be driven forward by the new European Technology and Innovation Platform on Batteries soon to be established. The European Battery Alliance was launched in October 2017 by the EC with the immediate objective to create a competitive manufacturing value chain in Europe with sustainable battery cells at its core. The scale and speed of the necessary investment e.g. in large scale battery cell production facilities, require a cross-border and integrated European approach to address this industrial challenge. In response to recommendations of the "industrial branch" of EBA, successfully coordinated by KIC InnoEnergy, the **Strategic Action Plan on Batteries** was proposed by the European Commission in May 2018 [SAPB]. This plan covers actions on all major issues necessary for succeeding with batteries in the EU: access to raw materials (also through recycling); support to cells manufacturing projects; increased support to research and innovation skills; sustainability; and an enabling regulatory framework.
On R&I side, as a first result of the Implementation Plan under the Batteries Action of the SET Plan and the Strategic Action Plan on Batteries, new R&I funds for battery related innovation projects are made available.
Notably, a new 'next-generation batteries' call under H2020 was published with seven topics for a total budget of €114M in 2019 [H2020 NGB], in addition to the €250M already allocated in previous years. The budget allocation appears to strike appropriate balance between the urgent need to succeed with e-mobility and ensure long-term viability of EU's transport sector and the need to pay sufficient attention to promising energy storage and industrial storage technologies. 70M€ are thus allocated to advanced li-ion batteries and solid-state lithium batteries subjects. The remaining sum is earmarked for advanced redox-flow batteries and other types of non-automotive batteries. 2020 funding is also expected to keep such balance.

[3] Specific actions are targeted at increasing the flexible generation by means of the use of integrated storage, multiservice storage applications to enable innovative synergies between system operators and market players and advanced energy storage technologies for energy and power applications
[4] https://www.h2020-bridge.eu/wp-content/uploads/2018/09/BRIDGE_Battery_report_Aug18.pdf

The way forward

To ensure **battery technologies** can play an increasingly important and competitive role in the energy system, a number of research actions and accompanying actions are proposed in the 10 year Roadmap developed in the framework of Batstorm project [BATSTORM D10].

While the Roadmap is targeting stationary battery storage, it pays non-negligible attention to **lithium-ion batteries and related actions**. And this is for a reason. As indicated before, in the next years the increasing share of lithium-ion technology in stationary sector is likely to continue when it comes to integration of variable renewables[5]. This evolution rides on the waves of the economies of scale created by quickly rising e-mobility sector where this technology is developed with characteristics also fitting the needs of stationary energy storage services. For residential storage, lithium-ion batteries or their successors are for example compact and can be installed also in relatively small homes/apartments (without cellar or attic). In addition, lithium-ion storage capacity will be having an entry in the stationary storage market segment in form of electric vehicles if vehicle-to-grid services develop sufficiently from technical an economical perspective.
So, further technological progress in lithium-ion technology and most perspective successor technologies (especially solid-state lithium batteries and metal-air batteries) and further cost reduction are of clear importance not only for e-mobility but also for stationary energy storage.

At the same time battery **storage technologies more suited for stationary storage than e-mobility should also gain proper attention in terms of R&I spending**, even if stationary storage will never be as big market segment on the battery market as e-mobility. Indeed, in energy sector, demand response mechanisms, grid interconnections, controllable power generation and other energy storage technologies are also coming into play to provide the needed flexibility for the system to accommodate growing amounts of VRE. Still, the energy sector's impact on the batteries market will be expanding, especially when current legal obstacles existing in several EU jurisdictions are gradually removed as provisions of the Clean Energy Package are progressively implemented. Therefore, it is valuable to have the battery technologies most suitable for stationary storage, in terms of costs, performance and sustainability, available and in that perspective one should also assess more novel technologies. Battery characteristics important for EVs such as energy density and power density are not important for many of stationary applications. This paves the way for use of solutions which do not require use of critical raw materials and with simpler designs which facilitates recyclability and sustainability. At the same time cycle life very often is more important for stationary storage which is both related to cost considerations and the need to align battery life with PV and other assets life-time. In some cases, hybridization of batteries with other storage technologies (e.g. supercapacitors) can contribute to a better power and life performance[6]. Deliverable "Technical analysis" [BATSTORM D12] includes some indications about improvements in stationary battery technologies along with recommendations on Li-ion technology.

To ensure batteries perform in an optimal and safe way and have maximum lifetime, it's crucial to invest not only in research on material and cell level but also in **research on battery management systems, as well as modelling tools and development of testing standards**. This should be followed by the **adoption of harmonised duty cycle and testing standards and performance certification as well as new/reinforced safety standards**. Indeed, all of this is crucial for consumer confidence as well as for development of new business models (e.g. second life use of EV batteries). Further **development of harmonised open communication protocols** based on standard interfaces should enable "plug-and play" capability for any new market player, including batteries. 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. One should avoid as much as possible the use of proprietary solutions which will lead to market fragmentation and possibly even market monopolisation. In this respect, it's good that the European Battery Alliance is currently reflecting on how to advance best on this front, using to the extent possible, relevant H2020 ICT and smart grid projects.

[5] Lead-acid batteries, based on a mature technology, are likely to keep an important role in UPS sector.
[6] Use cases with a need for high energy and high-power capacity

Further advances should be made to improve guidelines and processes for **integration of batteries into the grid**. This is something considerable attention is being paid within H2020 smart grid and storage projects and should be continued. Sharing of positive experiences of most advanced Member States is also very important and eventually may be formalised through recommendations/guidelines. The implementation of standard products for ancillary services as foreseen e.g. in Commission 2017 Regulation on electricity balancing[7] and in the Clean Energy package will clarify also the suitability of battery technologies to provide these services.

To push investments in the right areas and diminish associated business risks it's very important to **provide for robust assessments of system needs and market potential**. A macro-analysis and a case-specific level analysis should complement each other.

It goes without saying that **Inter-Sectoral Collaboration along the whole batteries value chain as well as financial support should be stepped** up if the EU is to further accelerate developments in the battery field. What has been started within the European Battery Alliance should be strengthened and continued. While respecting EU State aid rules, all possible support sources should be mobilised. This may include guaranteed EIB loans, regional funding, R&I funding, including more generous support possibilities available for projects classified as Important Project of Common European Interest[8].

It is also recognised that **introduction/strengthening of the rules on recycling, recyclability durability and reuse** are vital for strengthening EU's industrial potential and long-term sustainability of battery production. Indeed, we must build on Europe's strong position in recycling. This should largely be achieved by means of revision of the Battery Directive which is already pre-announced in the Strategic Action Plan for Batteries. Among other things it should ensure recovery of lithium which is not done in current recycling processes.

In total the Roadmap covers 40 actions relevant for development of EU's industrial capacity in batteries field as well as uptake of battery based stationary energy storage [BATSTORM D10].

This paper was based on research done within the EU funded BATSTORM project. More background, information and details can be found in the various deliverables published within this project, available at the project website. These deliverables include a detailed socio-economic analysis, an in-depth technology review of battery technologies and a roadmap for R&I actions and related measures to promote battery based energy storage.

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

[8] Such funding can cover the first innovative production facility, but not mass production

Annex I – Installed Energy Storage Power Capacity

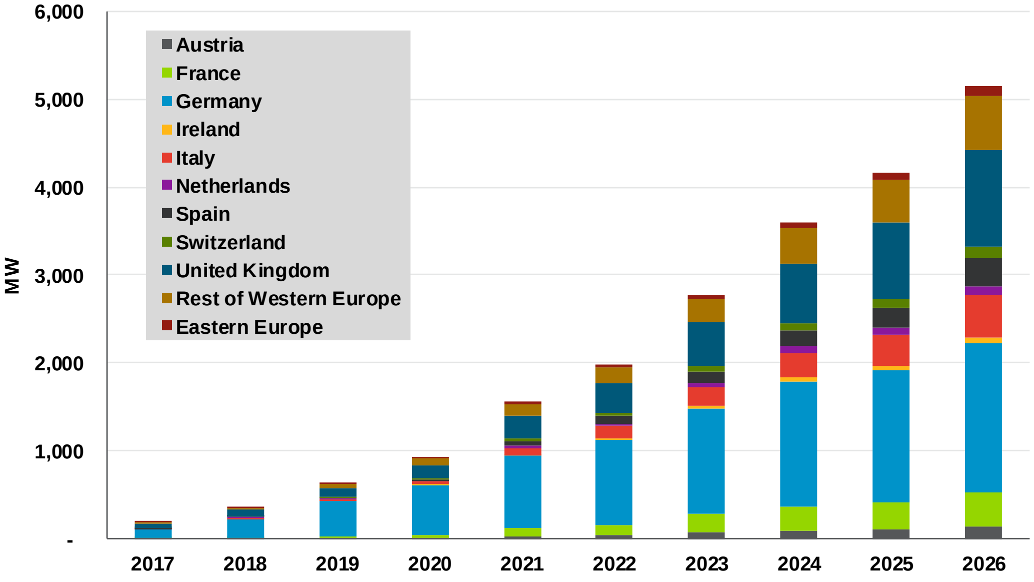

Figure 6. Annual Installed Distributed Energy Storage Power Capacity Additions by EU Country, 2017-2026. Own representation based on [Navigant]

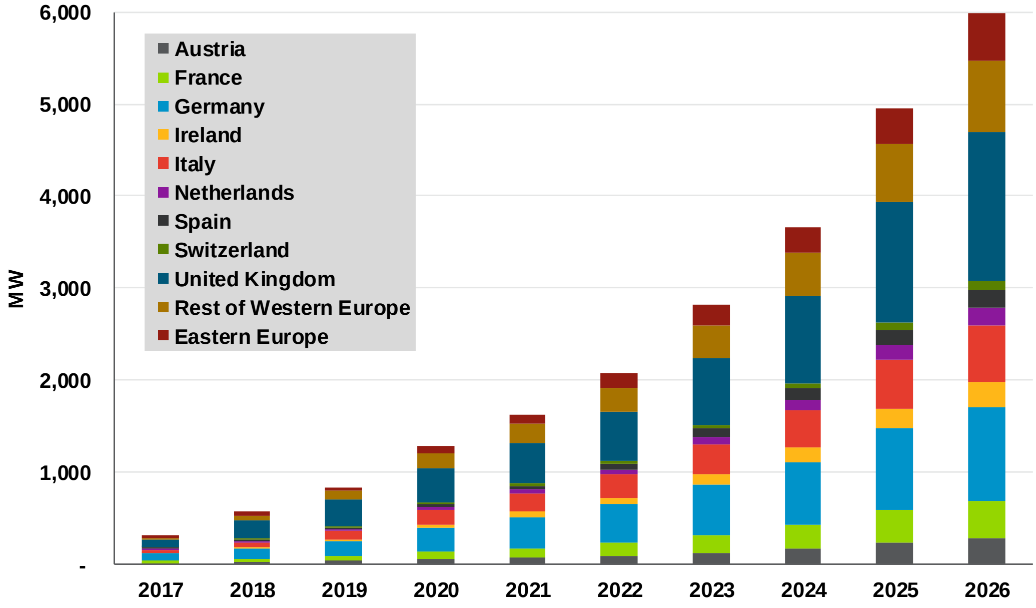

Figure 7. Annual Installed Utility-Scale Energy Storage Power Capacity Additions by EU Country, 2017-2026. Own representation based on [Navigant]

Annex II – Distinctive characteristics of battery technologies

Table 1. Distinctive characteristics of the considered technologies; the evaluation has been performed based on the VRLA Lead-acid, a mean value of the common Lithium-ion, NiMH, Vanadium Redox-flow for the Redox-flow family and Lithium-air for the Metal-air family.

Technology	Lead-acid	Lithium-ion	Nickel-based	Molten-salt	Lithium-sulfur	Redox-flow	Sodium-ion	Metal-air
Energy per unit mass (specific energy)	Low	Good	Less	Good	High	Low	Good	High
Energy per unit volume (energy density)	Low	High	High	Good	High	Low	Low	High
Self-discharge	Good	High	Low	Good	-	Good	-	-
Power per unit volume (power density)	Good	High	High	Good	-	Low	-	-
Cycle life	Less	Good	Less	Good	-	High	-	-
Calendar life	Good	High	Good	High	-	High	-	-
Recyclability	High	-	-	-	-	-	-	-
Cost for material and manufacturing	High	Less	Less	Good	-	Low	High	-
Fast response time	Low	High	Less	Good	High	Good	Less	High
Robustness (thermal)	Good	Low	Low	-	-	-	-	-
Robustness (electrical)	Less	Low	Low	Good	-	High	High	-
Resources	-	-	-	High	-	Low	High	-
Scalability	-	-	-	-	-	High	-	-
Thermal losses	-	-	-	Low	-	-	-	-
Volume change	-	-	-	Low	-	-	-	-
Weight	Low	-	-	-	-	-	-	-

High performat / Good performat / Less performant / Low performant / - No or contradictory information

References

[2030FCE] https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/2030-energy-strategy

[Avicenne] Avicenne Energy: Worldwide Rechargeable Battery Market 2015-2025, 2016. http://www.avicenne.com/reports_energy.php

[BATSTORM D7] "Costs and benefits for deployment scenarios of battery systems", BATSTORM deliverable D7, 22 February 2017.

[BATSTORM D12] "Technical analysis of projects", BATSTORM deliverable D12, 6 February 2018.

[BATSTORM D10] " Support to R&D Strategy for battery based energy storage - Roadmap for R&I and accompanying measures 2018-2027", BATSTORM deliverable D10, 16 April 018.

[BINE] http://www.bine.info/en/publications/publikation/integrales-energiekonzept-fuer-ein-wohnquartier/

[Bloomberg] "Here's How Electric Cars Will Cause the Next Oil Crisis ", Bloomberg, February 2016. Available online: http://www.bloomberg.com/features/2016-ev-oil-crisis/

[Bridge-PO] https://www.h2020-bridge.eu/wp-content/uploads/2018/06/Battery_report_Exe_sum_V1.pdf

[Castillo] Anya Castillo, Dennice F. Gayme, "Grid-scale energy storage applications in renewable energy integration: A survey", Energy Conversion and Management, Volume 87, November 2014, Pages 885-894, ISSN 0196-8904. Available online: http://dx.doi.org/10.1016/j.enconman.2014.07.063

[CEE] https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans

[Deutsche Bank] "F.I.T.T. for investors - Crossing the Chasm", Deutsche Bank, 27 February 2015. Available online: https://www.db.com/cr/en/docs/solar_report_full_length.pdf

[Doughty] Doughty et al, https://www.electrochem.org/dl/interface/fal/fal10/fal10_p049-053.pdf

[EASE] http://ease-storage.eu/energy-storage/technologies

[EBA] https://ec.europa.eu/growth/industry/policy/european-battery-alliance_en

[EBA@250] http://www.innoenergy.com/eit-innoenergys-role-within-the-european-battery-alliance/

[EC 2016e] "SET Plan ACTION n°7 –Declaration of Intent. Become competitive in the global battery sector to drive e mobility forward", 12 July 2016, Available online: https://setis.ec.europa.eu/system/files/integrated_set-plan/action7_declaration_of_intent_0.pdf

[EC Mob] https://ec.europa.eu/transport/modes/road/news/2018-05-17-europe-on-the-move-3_en

[EESS] https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/energy-security-strategy

[EIA] "Annual Energy Outlook 2012", U.S. Energy Information Administration, 2012. Available online: https://www.eia.gov/todayinenergy/detail.cfm?id=6930

[ENA] http://www.energynetworks.org/electricity/futures/energy-storage/energy-storage-overview.html

[ENEL] https://www.enelgreenpower.com/media/news/d/2018/03/enel-green-power-mexico-inaugurates-villanueva-largest-solar-pv-plant-in-the-americas

[EnergyUnion] https://ec.europa.eu/commission/priorities/energy-union-and-climate_en

[EPRI] "Electricity Energy Storage Technology Options - A Primer on Applications, Costs & Benefits", EPRI, 2010. Available online: http://www.epri.com/abstracts/pages/ProductAbstract.aspx?productId=000000000001022261

[ETIP Batt] https://etendering.ted.europa.eu/cft/cft-display.html?cftId=3708

[ETIP SNET] https://www.etip-snet.eu/

[ETIP SNET IP] https://www.etip-snet.eu/wp-content/uploads/2017/10/ETIP-SNET-Implementation-Plan-2017-2020.pdf

[ETIP SNET RM] https://www.etip-snet.eu/wp-content/uploads/2017/03/Final_10_Year_ETIP-SNET_RI_Roadmap.pdf

[H2020 NGB] https://ec.europa.eu/inea/en/news-events/newsroom/horizon-2020-new-next-generation-batteries-call-published

[IRENA] “Battery storage for renewables: market status and technology outlook”, International Renewable Energy Agency, 2015. Available online: http://www.irena.org/DocumentDownloads/Publications/insight_Battery_Storage_report_2015.pdf

[JRC 2014] "Energy Technology Reference Indicator projections for 2010-2050", JRC, 2014. Available online: http://publications.jrc.ec.europa.eu/repository/handle/JRC92496

[JRC LIB] http://publications.jrc.ec.europa.eu/repository/bitstream/JRC105010/kj1a28534enn.pdf

[JRC SPR] http://publications.jrc.ec.europa.eu/repository/bitstream/JRC108043/kjna28837enn.pdf

Lazard] "Lazard's levelized cost of storage analysis", Lazard, November 2015. Available online: https://www.lazard.com/perspective/levelized-cost-of-storage-analysis-10/

[Navigant] various market research reports from Navigant Research

[P4P] https://ec.europa.eu/info/sites/info/files/batteries_p4p-report_2017.pdf

[Papefthymiou] https://www.sciencedirect.com/science/article/pii/S0960148118305196

[RMI] "The economics of grid defection", Rocky Mountain Institute, 2014. Available online: http://www.rmi.org/PDF_economics_of_grid_defection_full_report

[Roland Berger] "Technology & Market Drivers for Stationary and Automotive Battery Systems", Roland Berger, presentation at Batteries, 15 November 2012. Available online: http://www.google.be/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=0ahUKEwjgwtiUoKnMAhWjOsAKHdzeAEoQFggoMAE&url=http%3A%2F%2Fonlinelibrary.wiley.com%2Fdoi%2F10.1002%2Fese3.47%2Ffull&usg=AFQjCNHD3n6z4jToxWqg-6RUg26G8Y3xfQ&sig2=EEc2-Zmg_hfA83FrSSKGHA

[SAPB] https://eur-lex.europa.eu/resource.html?uri=cellar:0e8b694e-59b5-11e8-ab41-01aa75ed71a1.0003.02/DOC_3&format=PDF

[SET] https://ec.europa.eu/energy/en/topics/technology-and-innovation/strategic-energy-technology-plan

[SETIS] https://setis.ec.europa.eu/

[TWG4-IP] https://setis.ec.europa.eu/system/files/set_plan_esystem_implementation_plan.pdf

[TWG7-IP] https://setis.ec.europa.eu/sites/default/files/set_plan_batteries_implementation_plan.pdf

[Zakeri] Behnam Zakeri, Sanna Syri, “Electrical energy storage systems: A comparative life cycle cost analysis”, Renewable and Sustainable Energy Reviews, Volume 42, February 2015, Pages 569-596, ISSN 1364-0321. Available online: http://dx.doi.org/10.1016/j.rser.2014.10.011