# Integrated SET-Plan Action 7

## ~ Implementation Plan ~

## "Become competitive in the global battery sector to drive e-mobility and stationary storage forward"

## Executive Summary

The Implementation Plan of the Temporary Working Group (TWG) on Action 7 comes at a crucial moment for European Industry. Its scope is batteries for e-mobility and stationary energy storage applications. Batteries are a key enabling technology for both of these applications. It is imperative that European industry masters the development, manufacturing, application and recycling of advanced batteries to become competitive in the global battery sector. Already today, numerous aspects of European society are directly impacted by battery technology from education to economics, from knowledge to environment and from business to resource security.

Action 7 has been developed in the context of the overarching principles defined in the "Clean Energy for All Europeans" package which included legislative proposals and facilitating measures for accelerating of the necessary energy transition and in the "Delivering on low-emission mobility" Communication which announces legislative proposal for new CO2 limits for cars and calls for the creation of a pan-European and cross-sectoral battery ecosystem in Europe.

In this context, the proposals for Research and Innovation (R&I) activities issued by the TWG Action 7 are of high importance and can play a key role in a European strategy on batteries. The work presented in this Implementation Plan is proposed as an input to the R&I dimension of the European Battery Alliance, which in turn is a key political initiative by the Commission established in the context of the renewed impetus of industry engagement in the energy transition. A review of the R&I actions at national, European and International levels has revealed that Europe has a strong R&I base in some areas such as materials. However competition in this sector is high, leaving no room for complacency. Therefore augmented R&I is needed to keep up with the pace of battery development and uptake around the world. R&I activities needed to become competitive in the battery sector have been defined by the TWG applying a challenge based holistic approach. The main questions that guided the development of the plan were: What can we achieve together? Which challenges can we not solve alone?

The proposals have been developed by a group of expert stakeholders from industry, research and the Member States (including the SET-Plan countries). They represent stakeholders from all segments of the battery value chain – battery materials, cell and pack manufacturing, application, recycling and second use. R&I activities are proposed for e-mobility and stationary energy storage applications. High impact and high visibility R&I activities form Flagship activities which are directly or indirectly relevant to both applications - e-mobility and stationary energy storage. The TWG has also identified a number of issues related to market/market access and education/training/knowledge, which cannot be addressed by R&I alone but which nevertheless need to be addressed in a European initiative on batteries in order to meet the ambitious targets agreed in 2016 by key European players, including industry leaders, to become globally competitive in the battery sector.

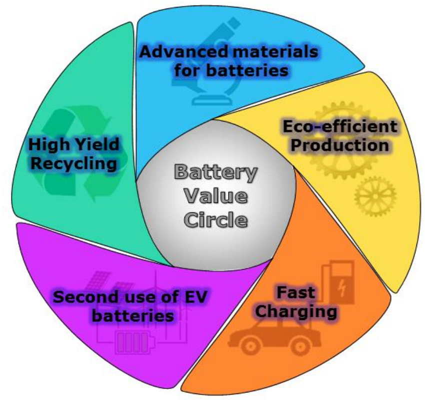
The R&I activities have defined objectives according to milestones. These milestones cover the period 2018 to 2030 and are structured around 3 focus areas:

1) Material/Chemistry/Design + Recycling
2) Manufacturing

3) Application and Integration

The TWG has identified five Flagship R&I initiatives. Flagships serve as projects illustrating how coordinated R&I, at national and EU level, can contribute to achievement of the agreed targets and entail activities of interest and visible to the public at large. Flagships are:

- MATERIALS FLAGSHIP - Advanced materials for batteries
- MANUFACTURING FLAGSHIP - Eco-efficient production
- FAST-CHARGE FLAGSHIP - Development of batteries with fast charging capability
- SECOND-USE FLAGSHIP - Second-use of EV batteries
- RECYCLING FLAGSHIP - High yield recycling




More than 40 experts have participated in the TWG to define the R&I activities needed to be competitive on the global market. The TWG considers the activities described in the Implementation Plan as the minimum required for achieving the targets agreed in 2016. The identified R&I activities and Flagships of this Implementation Plan represent key elements of a detailed technology roadmap for tailored future investments in battery technologies under the auspices of the European Battery Alliance.

# Content

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## 1. CONTEXT

Traditionally the European Union (EU) has been the economic block having the most ambitious energy and climate policy. This is illustrated in the "Clean Energy for All Europeans" package[1] which includes legislative proposals and facilitating measures for accelerating the necessary energy transition. At the same time EU climate and transport policy sets new $CO_2$ emissions targets for the EU fleet of new passenger cars and vans to accelerate the transition to low and zero emission vehicles[2]. In the drive to (i) accommodate more and more electric vehicles (EVs) in the transport sector and (ii) integrate ever growing volumes of variable renewables in the energy sector, batteries have been identified as a key technology to enable both these objectives. Accordingly, batteries are included as one of 10 key clean energy technology actions of the Strategic Energy Technology Plan (SET-Plan)[3], having potential to accelerate an energy system transformation through coordinated activities between SET-Plan countries, industry, research stakeholders and the European Commission[4].

In the context of the SET-Plan key action on batteries, ambitious targets to become competitive in the global battery sector were agreed between stakeholders and SET-Plan countries and are recorded in a Declaration of Intent (DoI)[5]. The targets are differentiated into performance, cost and manufacturing targets for lithium-ion batteries and future technologies[6] for use in automotive and stationary storage applications. The DoI also identifies a number of non-quantifiable targets (safety, reduction in the use of critical materials, reduced environmental impact etc.) which should also be considered. Following agreement on the targets, the relevant R&I activities required to deliver these targets were discussed and agreed between European stakeholder experts and their finding are reported in the current Implementation Plan on batteries.

Following the publication of the renewed Industrial Policy Strategy[7] in September 2017, a stakeholder meeting to kick-start industry-led initiatives for a full battery value chain in the EU and to help optimise possible public intervention was held on 11 October 2017 (meeting chaired by Commission Vice-President Šefčovič in charge of the Energy Union). This event led to the establishment of a European Battery Alliance which was tasked with preparing a comprehensive roadmap on the future of batteries in Europe, including aspects related to the supply chain, investment financing and engineering, trade issues, research and innovation, and others.

The work presented in this Battery Implementation Plan is proposed as an input to the research and innovation dimension of the European Battery Alliance.

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1 COM(2016) 860 final

2 COM(2017) 675 final

3 Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation, C(2015) 6317.

4 Recent Commission initiatives recognising batteries as a policy area deserving particular attention are summarised in Annexes C and I.

5 https://setis.ec.europa.eu/system/files/integrated.../action7_declaration_of_intent_0.pdf

6 The current state of the art of battery technologies and materials is described in the Annex E.

7 COM(2017) 479 final

## 2. BATTERY TEMPORARY WORKING GROUP

In March 2017 a Member State (MS) and industry-led Temporary Working Group (TWG) was formed. The TWG was assigned the task to prepare an Implementation Plan identifying the Research and Innovation (R&I) activities needed to achieve the battery targets agreed in the DoI for 2020 and 2030. More than 40 actors[8], representing the full battery value chain and consisting of representatives from industry, research and MS, have supported the work of the TWG[9].

The R&I needs identified by the TWG experts are presented in the current document, which forms the SET-Plan Battery Implementation Plan. The R&I activities proposed by the TWG cover both e-mobility and stationary energy storage sectors.

An overview of the necessary R&I activities is provided in Section 3, which is in particular focused on Flagship activities directly or indirectly relevant to both applications - e-mobility and stationary energy storage applications. The activities have been defined applying a challenge-based holistic approach. The TWG has also identified a number of issues related to market/market access and education/training/knowledge, which should complement R&I activities in a European initiative on batteries in order to meet the targets[10] set in the DoI and to be globally competitive. Where relevant, R&I aspects related to market/market access and education/training/knowledge are integrated in the R&I activities proposed in this IP to ensure that actions addressing market and education/training are fully integrated into the proposed European R&I eco-system. These and other non-R&I enablers are outlined in Section 4 describing cross-functional activities.

## 3. R&I ACTIVITIES AND BATTERY FLAGSHIPS

The R&I activities proposed as part of this battery IP are structured around three focus areas covering:

1) Material/Chemistry/Design + Recycling
2) Manufacturing
3) Application and Integration

The table below summarises ten R&I Activities proposed by the TWG. Each R&I Activity is described in detail in Annex A. Eight R&I activities are integrated and will contribute to a total of five Flagship initiatives which are described in the next sections.

| **R&I Activity** | ***Flagship*** |
|---|---|
| **Focus Area 1: Material/Chemistry/Design+ Recycling** | |
| 1.1 Advanced Lithium-Ion batteries for e-mobility | *Part of Materials Flagship* |
| 1.2 Influence of Fast/Hyper charging of Li ion batteries on materials and battery degradation | *Fast-charge Flagship* |
| 1.3 Advancement of batteries for stationary energy storage (ESS) | *Part of Materials Flagship* |
| 1.4 Beyond Li ion / Li based batteries for e-mobility | *Part of Materials Flagship* |
| 1.5 Develop circular economy and de-bottleneck availability of critical raw materials | *Recycling Flagship* |
| 1.6 Lithium recovery from European geothermal brines and sustainable beneficiation processes for indigenous hard rock occurrences of lithium | |
| **Focus Area 2: Manufacturing** | |
| 2.1 Foster development of materials processing techniques and components for fast industrialization compatible with present mass production lines | *Manufacturing Flagship* |
| 2.2 Foster development of cell and battery manufacturing equipment | |
| **Focus Area 3: Application and Integration** | |
| 3.1 Hybridisation of battery systems for stationary energy storage (ESS) | |
| 3.2 Second use and smart integration into the grid | *Second-use Flagship* |

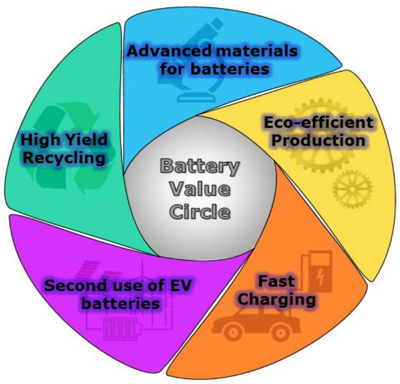
[8] See Annex B for a list of the TWG members

[9] The Approach and process for drafting IP and some key findings from the preparation of IP are described in Annexes F & G.

[10] The DoI targets are listed in Annex D.

## A. FLAGSHIP ACTIVITIES

The TWG has identified five Flagship R&I initiatives. The flagships serve as projects illustrating how coordinated R&I, at national and EU level, can contribute to achievement of the DoI targets and entail activities of interest and visible to the public at large. The flagships are designed to facilitate the exchange of knowledge and transfer of experimental results and technologies across all the value chain segments including materials, manufacturing, application, second-use and recycling. As such, the flagships comprise all the strategic elements necessary to establish a complete battery value circle in Europe, including a domestic large-scale battery cell manufacturing base which is compliant with the principles of the circular economy. More elaborate details (description, expected deliverables, timeline, indicative financing contribution, etc.) on each of the flagships are available in the relevant R&I fiche(s) in this document. These flagships will be used to monitor the achievement of KPIs compared to the targets sets in the DoI.




### MATERIALS FLAGSHIP

***Flagship on advanced materials for batteries.*** The scope of this flagship includes the development of battery materials and technologies for both automotive applications (advanced lithium-ion and post Li-ion) and for stationary energy storage applications (including but not limited to alternative ion based systems (Na, Mg or Al), redox flow batteries and high temperature batteries). The current performance of Li-ion batteries can be at least doubled. For this purpose a specific focus is to be placed on high voltage 4.5-5V Li-ion and all solid Li-ion systems with a differentiation made for energy orientated applications, such as passenger cars (BEVs), light electric vehicles (e.g. bikes, motorcycles), buses, trains and power orientated applications, such as heavy duty vehicles, maritime, (P)HEVs, etc. Higher performance needs the gradual introduction of new generation batteries (post Li-Ion) based on the development of a series of novel advanced materials. At this stage the promising technologies include Na-ion, Li-S and metal (Li, Fe or Zn)-air however issues related to poor cycle life, low power density, low efficiencies and limited safety need to be addressed through research.

For stationary energy storage there is a need for significantly more research, to optimize power applications, such as for frequency regulation, with a particular focus on lifetime. For energy applications, including home stationary systems, storage duration and cost should be improved. Both the optimisation of Li-ion batteries and the innovation and development of non-Li ion battery technologies (including molten-salt batteries, redox-flow batteries, metal-air, lithium-sulfur, new ion-based systems) specifically designed with high cycle life, long calendar life, optimised safety and low cost are considered.

### MANUFACTURING FLAGSHIP

***Flagship on eco-efficient production.*** *The* short-term focus of this flagship initiative is the <u>integration of close-to-market materials into mass production lines</u>. Intensive development is required in order to obtain new components which are compatible with today's production equipment. New electrode recipes and compatible process parameters will be investigated. Similarly, inactive materials need improvements for better manufacturing. Environmental friendly processes will be enabled such as water-based electrode coating. This aspect will support the early scaling-up of battery cell manufacturing factories in Europe.

In parallel, a longer-term focus on the development of <u>new equipment for present and future cell chemistries</u> should be progressive. It should enable product differentiation by addressing specific market trends: flexibility through equipment modularity, higher environmental standards, and cost reduction through better production efficiency. Research and development for equipment compatible with future technologies such as all-solid state batteries is also a focus. This aspect will support the medium-term scaling-up of cell manufacturing factories in Europe. Eco-design will be considered to advance battery recycling and second use; better knowledge on the design of batteries will improve their dismantling, repurposing and recycling.

## .FAST-CHARGE FLAGSHIP

***Flagship on the development of batteries with fast charging capability.*** The availability of high-power fast charging stations enables long-distance e-mobility and will convince more customers to opt for an electric vehicle. Fast charging facilities (superchargers 120 kW) are already installed by Tesla in a wide network. Moreover, European industry members have partnered to create a large electric vehicle fast-charging station network in Europe with ultra-fast chargers of 350 kW. To optimize batteries for fast charging, the effects of very high C-rates need to be studied, limiting factors determined, and eventually a complete overhaul of battery cell components (anodes, cathodes, current collectors, electrolytes and separator) and design will be needed for performance and safety improvements. Activities under this flagship will be coordinated with the Energy Systems SET-Plan working group, which is addressing the impact of fast charging on the grid.

## SECOND-USE FLAGSHIP

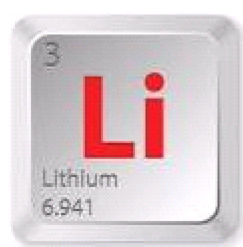
***Flagship on second-use of EV batteries.*** Facilitating a second-use for batteries, the performance of which have dropped below that required application has many advantages. Their total lifetime is increased which reduces the levelised cost of electricity of the battery. In addition its environmental impact is improved as its lifetime is extended before it is recycled. The main challenges for a sustainable market for "second-use" batteries concern provision of a reasonable guarantee of the continued performance of batteries when they are reused either for EVs or for Stationary Energy Storage Systems. This may be achieved through knowledge recorded on the battery during its first lifetime. More generally, an Intelligent Life Long Battery Management System is needed. Designing batteries which are optimised anticipating battery second-use would encourage a second lifetime for the battery. Determination of the type of tests necessary to assess battery reliability, safety and performance at the end of its first use will be an area for research. Different micro-markets for second-use could be developed depending on the level of performance in the batteries and corresponding needs for different application types. A market study on batteries as a service can be included in this flagship.

## .RECYCLING FLAGSHIP

***Flagship on High Yield Recycling.*** Li-ion battery recycling is not yet fully mature, despite the fact that recycling projects for such batteries have been ongoing for several years. R&I challenges include, but are not limited to: 1) reversed logistics including development of low cost packaging for safer and more efficient recycling, 2) development of an improved reversed logistics business model 3) Dismantling of industrial batteries, prior to recycling, i.e. removing 'easy to recycle parts' which reduces the needed recycling capacity and lowers the environmental footprint 4) Robust scaling up of metallurgical or chemical processes: Industrial and commercial processes already exist to recover Cu, Ni and Co (Co as a critical raw material is already fully recovered) but further improvements of current processes to increase the process efficiency and lower the environmental footprint are still possible, 5) Designing cells for ease of disassembly and recyclability. The performance of recycling will benefit from integration of this activity into the battery design and manufacturing processes.

### B. OTHER IMPORTANT R&I ACTIVITIES

**Eco-friendly lithium recovery from European geothermal brines and more environmentally sustainable beneficiation processes for indigenous hard rock occurrences of lithium**




In addition to R&I activities under the Flagship initiatives mentioned above, further R&I focused on the recovery of lithium for the anticipated high volumes of traction batteries is needed. Nowadays, to extract lithium from brines, suppliers mainly use a conventional process based on natural evaporation, which presents a number of disadvantages (important surface required for evaporation, significant evaporation time, solid waste production, low lithium recovery yield of about 50-60%) and will certainly not be feasible in Europe due to the climate. Other solutions are being developed such as extracting

lithium from brine or the utilization of membrane electrodialysis. These direct extraction processes are more environmentally friendly (less solid waste, smaller footprint, best yield leading to less brine pumping) and may result in a higher profitability.
Hard rock occurrences of lithium in Europe can also contribute to increasing EU's security of supply (especially as geothermal Li-containing brines are relatively scarce and their Li concentration is not high). Efforts should be concentrated on more environmentally sustainable beneficiation processes.

**Hybridisation of battery systems for stationary energy storage (ESS)**

Use of batteries for stationary energy storage facilitates the integration of increased volumes of renewable energy sources into Europe's energy system. Bearing this in mind, and acknowledging that batteries for grid connected stationary applications have somewhat different requirements than those for the automotive sector, specific R&I needs for development of batteries and hybridised systems for stationary applications were identified by the TWG. These R&I needs are in line with the intermediate findings of the BATSTORM[11] project, with focuses on stationary rechargeable batteries and which offers a ten-year roadmap on R&I and accompanying actions.

This Implementation Plan also covers hybridisation of battery systems for ESS since no single technology is able to serve all the high-energy and high-power needs. With increasing penetration of variable renewable electricity there is a need for highly efficient short term storage, where batteries will be of main importance, and long term (weeks-seasonal) storage where fuel and heat storage are required; storage technologies in the stationary-applications sector will be required to perform multiple or bundled functions, such as a combination of load levelling, frequency regulation, provision of backup power and providing hydrogen as fuel and as feedstock for chemical industries. The use of dual systems for energy storage applications can be advantageous in reducing cost, improving performance, capacity factors, and safety. Low cost batteries can be used to store large quantities of energy i.e. providing energy, while a high power in/output can be added, provided by systems such as Li-ion batteries or supercapacitors or non-electrochemical systems (e.g. flywheels). In addition, integration of a battery with an electrolyser (e.g. 'battolyser') makes use of the electrochemical similarities of these systems and can thus provide a hybrid double use system. Its improved battery performance provides short term hour/day/night storage and, when the battery capacity is full, produce hydrogen as storable fuel or feedstock for the chemical industry.
The development of advanced materials will enable optimal hybridisation of systems, their design, energy management, safety and demonstration. Also Cell and Stack design as well as Battery Management Systems will need to be adjusted to the needs of hybridisation.

The relevant work to be performed in energy storage related R&I activities will be coordinated with the Energy System SET-Plan working group.

## 4. CROSS FUNCTIONAL ACTIVITIES – NON-R&I ENABLERS

Europe cannot overcome all of the challenges it faces to become competitive in the global battery sector through R&I alone. While coordinated R&I activities are certainly essential to achieve the technological advancements necessary to bring competitive products to the market, non-technological challenges however also need to be considered in a European strategy to ensure they do not hinder competitiveness. In this section non-technological challenges are identified and mitigating strategies are proposed. These challenges are primarily related to market access and educational/knowledge aspects. When specific challenges requiring R&I on market and education issues were identified, corresponding R&I activities have been integrated in the R&I activities proposed in this IP to ensure that actions addressing market and education/training are fully integrated into the proposed European R&I eco-system.

[11] http://www.batstorm-project.eu/

## A. MARKET ACCESS

To address the DoI targets on manufacturing and recycling volumes, market access issues were widely discussed by the TWG. Where appropriate intermediate recommendations of the BASTORM project were taken into account. Key outcomes of the discussions are as follows:

**i) Access to finance for upscaling production and large scale advanced battery production and deployment.**

European competitiveness in the battery sector hinges on the need for urgent upscaling of cell production capacities based on the best currently available battery technologies. Current battery performance levels enable meeting present requirements for e-mobility and stationary applications. Hence current technologies permit to step into the market and get experience with mass production, while the research community and industry work to further improve performances.

It is necessary to ***quickly proceed with the first big plants using largely existing technology*****.** The following resources could be mobilised for this purpose: EIB loans together with EFSI guarantees, commercially-based investments and regional aid by Member States. The latter may also involve ERDF component, if investment takes place in eligible regions. To succeed with mass production in these large manufacturing plants, it is important for EU industry players to agree on a limited number of cell-standardised sizes. Similarly, the variety of cell chemistries needed for addressing power (W) and energy (Wh) requirements should not be too wide. Standardisation will play an important role here.

It is also important to ***join efforts to break through with manufacturing processes for more advanced technologies, based on the ambitious targets set in the SET-Plan batteries DoI***, possibly benefiting from flexible State aid provisions applicable to Important Projects of Common European Interest (IPCEIs). At EU level, H2020 financing could be mobilised, together with other existing support tools. Support through an IPCEI could be made conditional on improved recyclability, reduced carbon footprint of production and higher performance and safety of the products and the manufacturing process. Pilot platforms will help demonstrate the battery innovation at a scale representative of the final application and to test it in a real use and thus advance the TRL level.

In parallel, it is important to ***develop a strategy regarding intellectual property right issues*** and to propose support within the limits of EU State Aid rules, on how to hold process intellectual property.

***Product differentiation at system engineering level also needs support***. This concerns, in particular, Battery Management System (BMS) development (power electronics and software) to enhance system safety and/or cell capacity utilisation, thus ensuring optimum performance and increased operational life of the cells in their intended primary application. Even if the EU industry is stronger at BMS level than at battery cell production level, further R&I efforts are needed to keep pace with technological developments in this field. Advanced BMS will also improve the performance when the battery will be integrated in $2^{nd}$ use applications.

***Appropriate incentives are also needed to support deployment***. Notably, for stationary applications, it would seem appropriate to encourage incentive schemes for investments in intermittent renewable energy generation in a way conducive for storage development rather than proceeding with separate support schemes for intermittent renewables and for capacity adequacy. For e-mobility, support measures can include public procurement (CEV directive) and lower car registration fees and annual taxes for low emission vehicles. In this respect, development of business models for battery storage as a service should be further pursued inter alia within innovation projects related to grid integration (also projects financed under Horizon 2020).

**ii) Establish an enabling regulatory framework for competitiveness in the batteries field**

- ***Harmonisation of safety requirements*** is an important driver to further boost battery markets through increased customer acceptance. Furthermore real-life representative application-based ***duty cycle standards,***

***testing standards and performance certificates*** are to be developed and agreed upon. Currently there are no standardized tests for state of charge and state of health estimation. Work should be continued/intensified in relevant standardization fora. Test facilities would have to be developed.

- In the context of revision of the Batteries directive, it is important to aim at tightening recycling norms so that ***maximum recovery of critical raw materials*** is guaranteed (for example today lithium recovery in particular is hardly takes place as it is not economically attractive and is not necessary to meet regulatory requirements[12]). Possibilities of enforcing declaration of environmental impact of battery production for battery producers and importers should be considered.

- Harmonisation of the different ***regulations concerning the transportation of dangerous goods*** to facilitate second use of EV batteries.

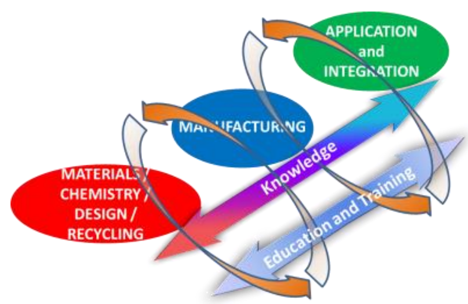

- Member States should consider removing barriers for storage expansion within the context of new rules resulting from the proposal for a new Electricity Market Directive and Regulation take effect. This notably concerns ***removal of double grid fees*** which are badly affecting expansion of battery-based storage. In addition, ***advantages of storage should be taken into account in grid planning*** and ***possibilities for curtailment of renewable electricity should be minimised***. Member States should also be encouraged to ***exempt from taxation energy losses from charging/discharging batteries when applying the Energy Taxation Directive*** at national level.

- ***Legislation on $CO_2$ emission limits*** should be used as a tool to encourage e-mobility uptake by consumers. Incentives to promote sustainable mobility through improved emissions standards and use of green public procurement can help e-mobility uptake. Enablers are needed at all levels (regional, national and European) including the ***widespread deployment of an alternative fuel infrastructure*** for charging (through national policy frameworks).

- ***Establishment of best practice for battery connection rules*** for providing different grid services would be desirable. Furthermore ***work should continue on interoperability*** issues at behind-the-meter level to facilitate deployment of batteries in the residential sector (by continuing present smart grid-related standardisation work within CEN/CENELEC/ETSI).

- Possibility of introducing ***$CO_2$ limits for "yellow machines"*** and other non-regulated sectors should be carefully considered.

## B. IMPROVED EDUCATION AND KNOWLEDGE THROUGHOUT THE ENTIRE VALUE CHAIN




The TWG stressed the need for improved education and knowledge throughout the entire value chain if the EU is to succeed in the battery sector. An ecosystem of cooperation between industry, research and academia should be built covering the whole value chain. A strong knowledge base is to be developed, on all TRL and MRL levels, to facilitate training of researchers, prototype developers, demonstrators and processes/products designers. Below there is a tentative list of measures needed to address the above-mentioned objective for a strong `Education, Research and Innovation` knowledge base (further details are provided in the

[12] It is enough to recover 50% of materials of Li-ion batteries in terms of weight and it can be done without recovering any lithium which is relatively cheap and light.

Annex H). A holistic approach is proposed for (a) the update of skills and training courses, (b) exchange of best practices between professionals, disciplines and institutions, (c) cooperation between relevant stakeholders in the market and (d) exchange of best practices on successful business models:

***a)*** **Training courses on batteries** such as basic electrochemistry courses, applied courses for batteries, courses on best practices in industry and laboratories, courses on safety and courses on modelling efforts. Also courses on business models dedicated to battery storage. These courses should be combined with research and training activities in appropriate education and training environments, including online training. The education can be provided for university students, students in a professional education, professionals and skilled workers in the battery field. Some of concrete proposals include:

**i.** **Design and implementation of master level programmes in the domain of energy storage.** The modules can be taken as online courses MOOCs[13] or SPOCs[14] and can lead to credits or micro-degrees if the student combines the online courses with projects and campus activities. The blended micro master also becomes accessible to professional learners from industries whom need to reskill or require training in energy storage technology and applications. On the longer term, the combination of 3 or more micro master modules and a project should lead to a new blended master programme in energy storage, including the possibility to being offered as a remote programme supported by remote campuses.

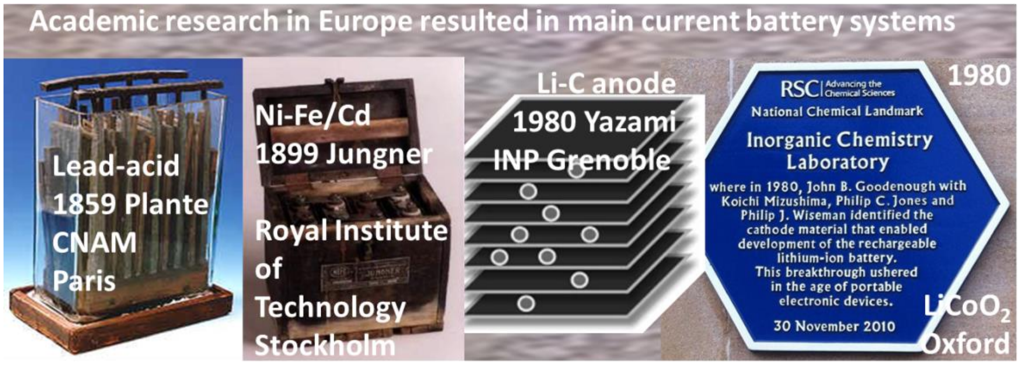
**ii.** **Professional online courses.** Increasing renewable energy generation, growing electricity trade and raising demands for stable energy supply from transmission and distribution networks require flexible solutions and battery storage can provide this flexibility. However, currently there is lack of knowledge on the potential of energy storage, availability of battery storage solutions, their applications and benefits for the grid. Additionally, there is a clear need for understanding of the economic viability of their installations and the legislation behind battery storage, the batteries' second life and recycling. This course will bring together well-known professionals and experts in the relevant fields, from both industry and academia, to deliver high-quality professional training.

***b)*** **Guidelines on multidisciplinary approaches** in higher education and research programmes (particularly in Master, Doctorate and Research Programmes) for renewable energy related programmes. These guidelines should become a reference point for the upgrade of existing programmes or the generation of new ones. An effective multidisciplinary approach should also include cooperation between faculties (e.g. chemistry, mechanical engineering, industrial design etc.)

***c)*** **Building an ecosystem of cooperation between academia and industry** for sharing knowledge and increasing skills of students and workers along the concept of "teaching factories" along the whole value chain. The approach should consider realistic settings (e.g. labs) and a holistic view of the batteries sector. Workshops could facilitate interactions between academia and industry. Dissemination activities to a wider public (e.g. citizens, professional categories such as firework, police, start-ups, SMEs etc.) should also be considered.

***d)*** **Analysis of existing, and proposals for new, business and contracting models, considering organisational, financial, legislative, social and technological barriers**. This activity would contribute to optimising the introduction of battery storage applications in electrical transport and in static renewable electricity storage. Cooperation with energy regulators is also key.

[13] Massive open online course
[14] Small private online course




## 5. MEMBER STATE SUPPORT TO R&I ACTIVITIES

Ten SET-Plan Member States participating in the work of the Action 7 TWG were requested to provide an indication of their intended support to the ten R&I Activities (through nationally funded research ' R', provision of State Aid ' S' or through a (bi/tri/n)lateral action (M) with other Member States). Eight Member States replied and their intended support and type of support for individual R&I activities is indicated in the Table below.

| ***Activity*** | **Tot** | Action planed (Y/N) | National Research (R) | (bi/tri/n)lateral action (M) | State Aid (S) | AT | BE | DE | ES | FR | IT | NO | SE | TR | UK |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Overall support** | | | | | | Y | | | | | | | | | |
| **Materials, Chemistry, Design and Recycling** | | | 0 | 0 | | | | | | | | | | | |
| Advanced Lithium-Ion batteries for e-mobility | 7 | 3 | 3 | 1 | 0 | | | Y | Y | M | R | R | R | Y | |
| Influence of Fast/Hyper charging of Li ion batteries on materials and battery degradation | 7 | 3 | 3 | 1 | 0 | | | Y | Y | M | R | R | R | Y | |
| Advancement of batteries for stationary energy storage (ESS) | 7 | 3 | 3 | 1 | 0 | | | Y | Y | M | R | R | R | Y | |
| Post Li ion for e- mobility | 7 | 3 | 3 | 1 | 0 | | | Y | Y | M | R | R | R | Y | |
| Recycling of batteries (Li ion and Post Li ion) | 7 | 3 | 3 | 1 | 0 | | | Y | Y | M | R | R | R | Y | |
| Lithium recovery from European geothermal brines to supply the battery market | 6 | 3 | 2 | 1 | 0 | | | Y | Y | M | R | | R | Y | |
| **Manufacturing** | | | 0 | | | | | | | | | | | | |
| Foster development of cell and battery manufacturing equipment | 6 | 3 | 1 | 0 | 2 | | | Y | Y | S | S | R | | Y | |
| Foster materials development for fast industrialization compatible with present mass production lines | 7 | 3 | 2 | 0 | 2 | | | Y | Y | S | S | R | R | Y | |
| **Application and Integration** | | | 0 | 0 | | | | | | | | | | | |
| Second use and smart integration into the Grid | 6 | 3 | 2 | 0 | 1 | | | Y | Y | S | R | | R | Y | |
| Hybridisation of battery systems for stationary energy storage (ESS) | 5 | 3 | 1 | 0 | 1 | | | Y | Y | S | R | | | Y | |

## 6. MEMBER STATE SUPPORT TO NON-R&I ACTIVITIES

Similarly the table below illustrates an overview of non-R&I activities identified by the TWG and the support indicated from MS related to (i) Market/Market Access and (ii) Education & knowledge value chain.

| Activity | Tot | Action planed (Y/N) | National Research (R) | (bi/tri/n)lateral action (M) | State Aid (S) | AT | BE | DE | ES | FR | IT | NO | SE | TR | UK |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Overall support | 1 | | | | | Y | | | | | | | | | |
| Market / Market Access | | | 0 | 0 | | | | | | | | | | | |
| Non technological needs (Aid) | 2 | 0 | 0 | 0 | 2 | | | | | S | | | S | | |
| Regulation and Standard | 5 | 2 | 1 | 2 | 0 | | | Y | Y | M | R | | M | | |
| Education & knowledge value chain | | | 0 | 0 | | | | | | | | | | | |
| Education & knowledge value chain | 4 | 2 | 1 | 1 | 0 | | | Y | Y | M | | | R | | |

At this point in time it is acknowledged that indication of support is indicative and does not represent a commitment to finance any specific activity. It is expected that such commitments from MS and industry will be furnished in the follow-up to this Implementation Plan.

## 7. INDUSTRIAL SUPPORT TO R&I ACTIVITIES

The table below illustrates the possible intentions and needs identified by some of the industrial stakeholders at this point in the definition of the activities. This is not a firm commitment, but is to be discussed and confirmed depending on projects content and partners.

| Activity | nb of participant | SOLVAY | BASF | LECLANCHE | LITHOPS | EDF | ENEL | VW | RENAULT | SCANIA | ERAMET | BLUE SOL. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Materials, Chemistry, Design and Recycling** | | | | | | | | | | | | |
| Advanced Lithium-Ion batteries for e-mobility | 9 | P | P/tbd/tbd | P/tbd/tbd | P/36/1.15 | P/36/0.6 | | P/36/0.3 | P/36/3 | P/tbd/tbd | P/24/tbd | |
| Influence of Fast/Hyper charging of Li ion batteries on materials and battery | 6 | P | P/tbd/tbd | P/tbd/tbd | | | | L/3Y/0.5 | P/60/5 | P/tbd/tbd | | |
| Advancement of batteries for stationary energy storage (ESS) | 8 | P | P/tbd/tbd | P/tbd/tbd | P/18/0.5 | P/tbd/tbd | | P/36/0.3 | | P/tbd/tbd | | P |
| Post Li ion for e- mobility | 9 | P | P/tbd/tbd | | P/2.5/36 | P/tbd/tbd | | P/36/0.3 | P/84/20 | P/tbd/tbd | P/24/tbd | P |
| Recycling of batteries (Li ion and Post Li ion) | 8 | P | | P/tbd/tbd | P/36/3 | | | P/36/0.3 | P/84/2 | P/tbd/tbd | P/12/tbd | P |
| Lithium recovery from European geothermal brines to supply the battery market | 2 | | | | | | | | | | L/36/8 | P |
| **Flagship MATERIALS** | 6 | P(B,A1-2) | | P / A1-6 | P/36/1.5 | P | | | P | P | | |
| **Flagship *FAST CHARGE*** | 4 | P(B,A1-2) | | P / A1-2 | | | | | P | P | | |
| **Flagship *RECYCLING*** | 0 | | | | | | | | | | tbd/tbd/tbd | |
| **Manufacturing** | 0 | | | | | | | | | | | |
| Foster development of cell and battery manufacturing equipment | 2 | | | P/tbd/tbd | P/24/1.5 | | | | | | | |
| Foster materials development for fast industrialization compatible with present mass production lines | 4 | P | | P/tbd/tbd | P/24/2 | | | | | | P/12/tbd | |
| **Flagship *MANUFACTURING*** | 0 | | | B(A4-5) | | | | | tbd | | | |
| **Application and Integration** | 0 | | | | | | | | | | | |
| Second use and smart integration into the Grid | 6 | | | P/tbd/tbd | P/36/0.2 | P/36/1 | P/tbd/tbd | | P/60/10 | | | P |
| Hybridisation of battery systems for stationary energy storage (ESS) | 3 | | | P/tbd/tbd | | P/324/0.3 | | | | | | P |
| **Flagship *SECOND USE*** | 2 | | | tbd | P/36/0.2 | | B(A6) | | P | | | |

This table indicates the efforts requested by the industrial stakeholders to complement any type of actions they have in-house or at regional and national level. The way to read the figures is defined by the key below:
For the activities in which the stakeholder indicated intent to participate:

- The role: L = Leader or P = Participant

- The duration for this action (months) and the effort (M€) needed to support the participation

For example: P as participant / 18 (duration in month) - 1.7 (the effort in M€).

When this concerns a Flagship, the rules are:
- Taking part in the Flagship is indicated by a P
- If the industrial already have an activity from which we can build the Flagship, this is indicated by a B
- Which activity from the list above is associated to the Flagship, by A1-2 for Activity A1 and A2

For several actors, it was not possible to complete this table due to time constraints. However they have indicated to provide this information in the context of the EU Battery Alliance.

## 8. NEXT STEPS

This IP and its associated R&I activities and flagship initiatives is the product of intense interactions and exchange of knowledge between key European industrial players, MS representatives and research entities. Expert opinions on battery R&I needs from stakeholders across the complete battery value chain were considered and have been used to prepare the elaborated R&I activities described in this document.

Key elements of the agreed R&I priorities have been consensually selected and integrated to create a conceptual circular structure of flagship initiatives. The ambition is to translate this concept into a sustainable and competitive EU battery value circle through which Europe will differentiate itself, not only through its performant and safe products but also through the safe and sustainable processes preparing, repurposing and recycling these products.

Based on this joint vision concrete pledges from European industry and Member States are urgently required. Europe needs to step up to the challenge as global competition is strong on battery production and competitors are heavily financing targeted R&I programs in the field of battery technology. This IP is a blueprint for Europe's battery R&I needs and can be considered and used, as a next step, by the newly formed European Battery Alliance for elaborating its R&I strategic roadmap.

The Battery Alliance initiative and this battery Implementation Plan are mutually reinforcing, and provide the battery sector with new opportunities and a powerful momentum. The Implementation Plan is in essence the research and innovation dimension of the Alliance; the identified research and innovation actions as well as the proposed Flagships of this Implementation Plan represent the key elements of a technology roadmap for tailored investments under the Battery Alliance. In its turn, the Alliance should provide detailed recommendations on and commitment to the strategy to follow, i.e. which R&I priorities to focus on, within which timeline, where to cooperate at international level, and how to finance the activities (industry, SET Plan countries, the European Commission and/or the European Investment Bank). This goes in particular for the 5 Flagship activities proposed in the Implementation Plan, as these are pivotal activities to achieving the targets of this SET-Plan action in a sustainable and competitive way.

The R&I work-stream of Battery Alliance established in the context of the Industrial Forum will play a key role in "operationalising" the battery R&I activities described in this Implementation Plan, *inter alia* by promoting firm joint commitments of Battery Alliance members to specific R&I actions. Strong involvement of the main SET-Plan actors will remain crucial for the successful implementation and monitoring of the activities.

## ANNEXES

# ANNEX A - Activity fiches

This section of the document describes the different fiches proposed by the Action7 TWG. The TWG considers the activities described in the Activity Fiches as the minimum required for achieving the targets agreed in the DoI. When relevant, interfaces with other TWGs are identified in the fiches. Cross-check of activities has also been realised with the TWG Action 4.

## Activities developed by the sub-group ***Advanced Materials, Chemistry, Design and Recycling***

## OVERVIEW

Activity 1.1: **Advanced Lithium-Ion batteries for e-mobility**

The specific focus is to be placed on the development of high voltage 4.5-5V Li-Ion and all solid Li-Ion with a differentiation made for energy orientated applications, such as passenger cars, LEV, buses, trains and power orientated applications, such as heavy duty vehicles , maritime, (P)HEVs, etc.

*Activity 1.1 has been identified as part of the Materials Flagship.*

Activity 1.2: **Influence of Fast/Hyper charging of Li ion batteries on materials and battery degradation**

The availability of high-power fast charging stations, enables long-distance e-mobility and will convince more and more customers to opt for an electric vehicle. Fast charging pools (superchargers 120 kW) are already installed by Tesla in a wide network. Moreover, large electric vehicle fast-charging station networks in Europe, have partnered to create new integrated alliances, and even partnerships have been made to install networks in Europe with ultra-fast chargers of 350 kW. To optimize batteries for hyper-charging, the effects of very high C-rate charge, need to be studied and eventually a complete overhaul of battery components (anodes, cathodes, current collectors, electrolytes and separator) and design will be needed for performance and safety, improvement.

*Activity 1.2 has been identified as a Fast-charge Flagship.*

Activity 1.3: **Advancement of batteries for stationary energy storage (ESS)**

Following 2020 and 2030 energy objectives of the EU, renewable energy generation will contribute to a growing share of the energy mix in Europe and will be central to the European energy supply. It is generally admitted, that RES successful deployment requires the integration of energy storage. There is a strong potential for the development of battery storage solutions for a variety of power ranges and energy storage capacities (in households as standalone systems or as utility grid connected assets). However, there remains a need for significantly more research, in order to optimize power applications with a particular focus on lifetime, and to improve storage times and cost for energy applications. For stationary energy storage both the optimisation of Li ion batteries and the innovation and development of non – Li ion battery technologies specifically designed with high cycle life, long calendar life, optimised safety and low cost are focused on.

*Activity 1.3 has been identified as part of the Materials Flagship.*

Activity 1.4: **Beyond Li ion / Li based batteries for e- mobility**

Current traction batteries are, to a large extent based on lithium-ion (Li-ion) chemistry but their maximum energy density will be limited to approximately 350- 400 Wh/kg. Higher performance needs the gradual introduction of new generation batteries (post Li Ion) based on the development of a series of novel Advanced Materials. At this stage the technologies probably offering the best chances for success are Na-Ion, Li- S and metal (Li or Fe or Zn)- air but depending on the system, performance issues generally include poor cycle life, low power, low efficiencies and limited safety and they need to be addressed, through research and solutions brought from TRL levels 4 to 7.

*Activity 1.4 has been identified as part of the Materials Flagship.*

Activity 1.**5: Develop circular economy and de-bottleneck availability of critical raw materials**

Li-ion battery recycling is not yet mature, despite the fact recycling projects for such batteries have been ongoing for several years. R&I Challenges include, but are not limited to: 1) reversed logistics including development of low cost packaging for safe reversed logistics and improved reversed logistics business model 2) Dismantling of industrial batteries, prior to recycling 3) Robust scaling of metallurgical or chemical processes: Industrial and commercial processes already exist recovering Cu, Ni and Co (Co as a critical raw material is already fully recovered) but improvements of current processes are still possible, 4) Design of new cells for ease of disassembly and recyclability.

*Activity 1.5 has been identified as a Recycling Flagship.*

Activity 1.6: **Lithium recovery from European geothermal brines and sustainable beneficiation processes for indigenous hard rock occurrences of lithium**

Nowadays, to extract lithium from brines, suppliers mainly use a conventional process mostly based on natural evaporation, which appears to be very long and presents major disadvantages (important surface required for evaporation, significant evaporation time, solid waste production, low lithium recovery yield of about 50-60% ) and will certainly not be feasible in Europe due to the climate. But, other solutions are being developed such as the utilization of a solid material to extract lithium from brine or the utilization of membrane electrolysis. These new processes of direct-extraction have, on one hand, the advantage to be environmentally friendlier (less solid waste, smaller footprint, best yield leading less brine pumping) and, on the other hand, to result in a higher profitability. Moreover, these processes are more versatile and much less dependent on evaporation than the conventional process implying that lithium can be extracted from many types of lithium brines under various climatic conditions. As many lithium resources are available in Europe (geothermal brines, oilfield brines), the use of these processes allow to foresee a possible exploitation of European brines and could contribute to securing of lithium supply for the battery market in Europe.

**Cross-functional activities and activities Advanced Materials, Chemistry, Design and Recycling**

In order to efficiently and consistently manage the activities regarding the overall goal it has been identified 2 cross-functional activities: Market and Education/Knowledge. Consistent indicators for technical progress, technical performance, knowledge development and education criteria specifically related to the activity Advanced Materials, Chemistry, Design and Recycling will be developed and used as monitoring mechanism.

# R&I Activity Fiche 1.1: Advanced lithium-ion batteries for e-mobility

**Activity Leader: Sub-Group Advanced Materials, Chemistry, Design and Recycling**

**PRIORITY: 1**

| **Targets: high voltage 4.5-5V Li-Ion and all solid Li-Ion**<br>**All e-mobility segments:**<br>**- Energy oriented (E): passenger cars, LEV, buses, trains, forklifts**<br>**- Power oriented (P): heavy duty, maritime, (P)HEV** | **Monitoring mechanism**:<br>**Proposed as part of the Materials Flagship**<br>- Flagships will be used to monitor the achievement of KPIs compared to the targets set in the DoI. |
|---|---|

**Description:**

One of the core priorities of the Energy Union strategy is to accelerate energy efficiency initiatives and decarbonisation of transport through Research and Innovation (R&I) in E-mobility. Traction batteries are considered a Key Enabling Technology in electric vehicle (EV) drive trains. Current traction batteries are, to a large extent, based on lithium-ion (Li-ion) chemistry which is expected to remain the technology of choice for many years come.

Current Li-ion batteries are not yet near their fundamental limits illustrated e.g. by their gravimetric & volumetric energy density, with current cell level state-of-the-art at 90-235 Wh/kg & 200-630 Wh/l and the expected fundamental limits at 350-400 Wh/kg & >750 Wh/l. Such drastic improvement of performance must be achieved by, development of Advanced Materials covering cathode, anode, binders, separators, electrolyte, current collectors and packaging materials to enable new Li-ion batteries, with a particular focus on high voltage systems (4.5 – 5.0 V), or high capacity systems, or all solid configurations preferentially combined with higher voltage or high specific capacity. Significant improvements in Advanced Materials are required, in order to move beyond the state-of the-art technologies currently used in commercial cells for electric vehicles. Such Advanced Materials could be based on, among others, 1) cathodes composed of high capacity nickel-rich or Li-rich NMC compounds, high voltage spinels or phosphates, 2) anodes based on graphite-silicon composites or silicon alloys or lithium alloy or even lithium metal, 3) new oxidation resistant electrolytes, which may include new polymer or ceramic / glassy materials, 4) ceramic coated membranes for the separator, or interface layers at the cathode/electrolyte or anode/electrolyte interfaces , 5) additives or materials modifications to improve safety, 6) electrode and cell design methods that maximise the active material content (energy density) in the cell without compromising power density, and 7) Zero-strain materials or other materials enabling high C-Rates (>6) for high power applications.

In the all-solid configuration, high ionic conductivity over a broad temperature range (especially for low temperature operation) is imperative, particularly for the key component - solid electrolyte which can be polymeric or inorganic by nature. Strategies and procedures for cost competitive manufacturing of solid state batteries suitable for EV must be developed.

All developed Advanced Materials should be investigated for phenomena and problems at the interfaces of the components of the battery cell, which are often not well understood; tailoring of the morphology and/or composition of such interfaces should be also considered. Special consideration should be given to safety issues (such as thermal runaway). Knowledge on the ageing processes to understand cycle and calendar life prospects, battery degradation and state-of-health, should also be given attention. Production aspects should be considered during the prototyping phase, and should be reflected in the choice of materials. Last, but not least, elements of circular economy (access to raw materials and recycling) should be incorporated into the development of the Advanced Materials.

All developed Advanced Materials should be demonstrated in a representative and optimised large cell design (10 Ah or more in the frame of the project). Output targets should be demonstrated at cell level in a

Consortium comprehending a European Battery Manufacturer and OEM in a 4-year research and innovation program. Potential for upscaling and recyclability must be addressed in the development.

**TRL:** Research and Innovation Actions: activities should start at TRL 3 and achieve TRL 7 at the end of the project (to be re-evaluated over time).

**Total budget required: 100 M€ to TRL 7, additionally 20M€ to TRL 9 (indicatively)**

| Activity # | Title | | TRL to be reached by | | Indicative budget (MEuro) to reach | |
|---|---|---|---|---|---|---|
| | | | TRL7 | TRL9 | TRL7 | TRL9 |
| 1 | Advanced Li-ion batteries for e-mobility*,** | 5 V track | 2023 | 2025 | 100 | 20 |
| | | Solid state track | 2028 | 2030 | | |

*Energy density: 350 Wh/kg
**20 MEuro is for advanced materials scale-up while Manufacturing Sub-Group should also evaluate needs for battery integration phase.

| Expected deliverables | Timeline |
|---|---|
| *DoI states:*<br>1. For (E) at cell level:<br>by 2020: 350 Wh/kg, 750 Wh/l<br>by 2030: > or = 400 Wh/kg, > 750 Wh/l<br>2000 cycles at 80% DoD<br>< 100 €/kWh<br>2. For (P) at cell level:<br>by 2020: 700 W/kg, 1500 W/l<br>by 2030: > 700 W/kg, >1500 W/l<br>< 100€/kWh, > 15000 cycles<br>More deliverables can further be added for instance characteristic of performance at low temperature (values to be determined) | *See above* |

| ***Parties / Partners***<br>*(countries / stakeholders / EU)*<br>Industry, RTO's, Academia/ Member states, EU | **Implementation financing / funding instruments** | **Indicative financing contribution** |
|---|---|---|
| A typical consortium might be composed of (non-exhaustive list):<br>- advanced materials EU producers<br>- EU battery producer<br>- EU OEM Tier 1 and 2<br>- EU RTO's and Universities | *EU MS* | 8 to 10 million € per project. About 8 Projects may be expected lead by Industrial Companies focussing for a) High voltage systems: |

| | | |
|---|---|---|
| | | development of generation 3b (fig.1 below)<br>b) all-solid-state Li batteries: development of generation 4 (fig.1 below) |

**Expected deliverables and impact :**

The KPI's for E-Mobility Li Ion batteries are based on the ones launched in the DoI: Key Action 7 E-Mobility from the European Commission: as an example by 2020 reach at cell level 350 Wh/kg and 750 Wh/l realized in a minimum 10 Ah cell configuration.

The impact upon achieving these KPI's would be a doubling of the EV driving range at equal cost for the same cell/pack weight or a 50% cell /pack weight halving the €/kWh cost, compared to today's values. Development of the required materials and cell designs would open strong manufacturing capabilities in Europe:

*At present, optimised LIB cells of generation-1 and -2a represent the core technology for xEVs and for ES. Given the lead time from R&D on battery materials to their actual incorporation in large scale production of cells, these generations – and incremental improvements to them – are expected to remain the chemistry of choice for at least the next 10 years. Because manufacturing capacity build-up for these chemistries is already ongoing in Asia – particularly in China – it does not seem effective to spend significant efforts to establish a mass production chain in Europe on cell chemistries up to and including generation-2a u. Efforts for establishing manufacturing capacity in Europe should hence primarily target LIB cells of generation-2b and beyond and should moreover focus on the operations in the production chain which are critical to quality of the end-product, as they represent areas where IP may confer competitive advantage. Furthermore, advantages gained in these production processes may be transferable to other end-applications and thereby offer increased market .-* **REF JRC-EU Competitiveness in Advanced Li-ion Batteries for E-Mobility and Stationary Storage Applications – Opportunities and Actions –** Steen, M., Lebedeva, N., Di Persio, F., Boon-Brett, L. 2017

| Cell generation | Cell chemistry | |
|---|---|---|
| Generation 5 | • Li/O₂ (lithium-air) | > 2025 ? |
| Generation 4 | • All-solid-state with lithium anode<br>• Conversion materials (primarily lithium-sulphur) | |
| Generation 3b | • Cathode: HE-NCM, HVS (high-voltage spinel)<br>• Anode: silicon/carbon | ~ 2025 |
| Generation 3a | • Cathode: NCM622 to NCM811<br>• Anode: carbon (graphite) + silicon component (5-10%) | ~ 2020 |
| Generation 2b | • Cathode: NCM523 to NCM622<br>• Anode: carbon | current |
| Generation 2a | • Cathode: NCM111<br>• Anode: 100% carbon | current |
| Generation 1 | • Cathode: LFP, NCA<br>• Anode: 100% carbon | current |

**Activity 1 focusses on generation 3b and 4 developments. (REF JRC-EU Competitiveness in Advanced Li-ion Batteries for E-Mobility and Stationary Storage Applications – Opportunities and Actions –** Steen, M., Lebedeva, N., Di Persio, F., Boon-Brett, L. 2017

**Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal**
**- so far only one large on-going project related H2020 "FiveVB"**
The vision of this FiveVB project is to push European's Lithium battery industry and academia to take over a leading role in the development and manufacturing of Lithium Ion cells and materials to provide cost and performance competitive Lithium Ion cells and batteries to European and Non-European Automotive Industry.
Partners: AVL List GmbH (AVL), Austria, 3M Germany GmbH (3M), Germany, Arkema France (ARK), France, Robert Bosch Gmbh (RB), Germany, UMICORE NV (UMI), Belgium, Kompetenzzentrum – Das virtuelle Fahrzeug Forschungsgesellschaft GmbH (ViF), Austria, Vrije Universiteit Brussels (VUB), Belgium, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), Germany, BMW Group (BMW), Germany, European Commission – DG JRC (JRC), The Netherlands. From 2015-05-01 to 2018-04-30, ongoing project, Total cost: EUR 5 927 428,75 EU contribution: EUR 5 673 272,50

- **MONBASA:** fabrication of high voltage all-solid state Li-ion batteries based on physical vapour deposition processing methods used in mass production for microelectronics and advanced glass industry.
From 2017-06-01 to 2018-05-31, ongoing project, Total cost: EUR 1 264 025, EU contribution: EUR 996 465,50
**- eCAIMAN:** Electrolyte, Cathode and Anode Improvements for Market-near Next-generation Lithium Ion Batteries, From 2015-05-01 to 2018-04-30, ongoing project, Total cost: EUR 6 126 698,75, EU contribution: EUR 5 807 244,50
- **SUPER-Lion:** Surface Promoted Enhanced Transport of Li-ions, From 2017-04-01 to 2018-11-30, ongoing project, Total cost: EUR 144 000, EU contribution: EUR 144 000
- **HS-GLASSion:** Highly stable glasses applied for lithium ion battery electrolytes, From 2015-08-01 to 2017-07-31, ongoing project, Total cost: EUR 172 800, EU contribution: EUR 172 800
**- IMAGE:** The vision of IMAGE proposal is to contribute to sustainably develop the European next-generation rechargeable lithium battery cell integration as well as manufacturing competence and capability by creating a competitive and powerful production-oriented research and development framework within Europe.
From 2017-10-01 to 2021-09-30, ongoing project, Total cost: EUR +/- 5.000.000, EU contribution: EUR +/- 5.000.000
**- Increase energy density:** Improvement of the energy density of batteries by R&D activities (BOSCH, Germany).
**- Reduce the cost of batteries:** Improvement of the cost situation of batteries in order to reduce the Total Cost of Ownership (TCO) of Battery Electric Vehicles (BOSCH, Germany).
**- SoLiK:** Li high conductivity ceramics for all solid state batteries. All-solid-state lithium ion batteries based on sputtered LLZO thin films (Salzburg University, Austria, EERA). From 2014 to 2017. Budget: EUR 701000.
**- DianaBatt:** Diagnostik zu Alterung, Sicherheit und Wiederverwertbarkeit von Li-Ionen-Batterien. Represent the electrochemical processes that take place to make improvements to the electrolyte and/or the material or combination (Technical University of Vienna, Austria, EERA). From 2016 to 2019. Budget: EUR: 227000.
**- HighEnd2:** Development of materials and processes for high-energy Lithium ion battery cells including new cathodes, solid state electrolyte materials as well as Silicon (RWTH Aachen, Germany, ISEA).
From 01.10.2016 to 31.08.2020. Budget: EUR 8200000.
**- Anodenalterung:** Analysis of anode (graphite) aging depending on SOC and cycle range to improve aging prediction and lifetime (RWTH Aachen, Germany, ISEA).
From 01.09.2013 to 31.08.2017. Budget: EUR 250000.
**- SiBEC:** Development of binders, electrolytes and cathodes for "industrial" Si materials for use as anode materials in Li-ion (including high-voltage Li-ion) batteries (IFE, Norway, EERA).
From 01.04.2016 to 01.04.2019. Budget: NOK 15 200 000.
**- Siproco Fobeliba:** Understanding and development of characterisation methods of Si-nanomaterials for Li-ion batteries (e.g. in-situ/in-operando structural and chemical characterisation) (IFE, Norway, EERA).
From 02.01.2016 to 01.01.2018. Budget: NOK 10 900 000.
**-MoZEES:** Mobility Zero Emission Energy Systems; Norwegian Research Center on Zero Emission Energy Systems

with focus on battery- and hydrogen technology for transport applications (IFE, Norway, FME).
From 01.01.2016 to 01.01.2026. Budget: NOK 120 000 000.
**-SafeLiLife:** Safety aspects on Li-ion batteries. Life and Safety for Li-ion batteries in Maritime conditions. An area associated to the automotive targets. Maritime battery systems have much in common with heavy road vehicles
From 01.08.2013 to 01.01.2017. Budget: EUR 2047632.
**-SICANODE:** Li ion batteries. The project aims to establish Elkem as a vendor of silicon for the battery industry. Focus on overcoming Li trapping mechanisms related to excessive surface electrolyte interface (SEI) formation. The SiCAnode project aims to reduce these mechanisms to a level where a full cell, not just half cell, can be cycled for >2000 cycles.
From 01.01.2016 to 01.01.2019. Budget: NOK 6 000 000.
**-OXIPATH:** Develop novel cathode materials and routes to prepare close to commercial electrodes for full cell battery demonstrators.
From 01.01.2017 to 01.01.2020. Budget: EUR 1175109.
**-Next generation of lithium ion batteries:** Dynatec has a patent protected production method for silicon nanoparticles with very interesting properties. Together with IFE they will produce powders with different surface area, morphology, surface charge and size distribution. Borregaard AS has a unique competence on biopolymers that can be adapted to the different silicon surfaces used (IFE, Norway, NFR).
From 2015 to 2017. Budget: NOK 6 800 000.
**-Metal hydrides for Li-ion battery anodes (**IFE, Norway, NFR**).**
From 2015 to 2018. Budget: NOK 9 500 000.
**-Product optimization of LFP/graphene composite cathode (**Graphene Batteries, Norway, NFR**).**
From 01.03.2015. Budget: EUR 600000.
**-Silicon product control for better Li-ion batteries (**IFE, Norway, NFR**).**
From 2016 to 2018. Budget: NOK 10 900 000.
**--Industrial scale silicon-carbon composites adapted to battery grade anode material (**Elkem, Norway, NFR**).**
From 2016 to 2018. Budget: NOK 600000.
**-Cenate:** Centrifuge Nano Technology: Silicon Anodes for Li-ion Batteries (Cenate AS, Norway, NFR).
From 2016 to 2017. Budget: NOK 9 500 000.
**-FELIZIA:** research on materials (sulfidic and oxidic solid state electrolytes) and cell concepts for All-Solid-State Batteries to increase energy density (BMW, Germany).
From 01.01.2016 to 01.12. 2018. Budget: EUR 12 600 000.
**-Effiform:** Li-ion: Process technologies to optimize formation process (BMW, Germany).
From 01.01.2016 to 01.12.2018. Budget: EUR 5000000.
**-Produkt:** Optimization of Si-anodes and development of structured current collectors (BMW, Germany).
From 01.01.2016 to 01.12.2018. Budget: EUR 4800000.

**- PT 2015-2017 AdP ENEA-MiSE** Definition of test procedures (ageing, second life, safety). Rechargeable batteries; predicting their degradation and failure whilst improving their durability and reliability, From October 2015 to September 2018, on-going project, total cost: not disclosed (meaning that this is a sub-project of the main project "Energy Storage Systems for the Electric System", the total cost of which is EUR 4.800.000), Ministry of Economic Development, Italy. (ENEA)

- **PT 2015-2017 AdP RSE-MiSE** New testing procedures specifically devoted to quantify performances and lifecycle of batteries for different applications, power or energy intensive. From March 2015 to February 2018 on-going project, total cost: not disclosed (meaning that this is a sub-project of a main project "Storage materials and technologies for the Electric System", the total cost of which is EUR 5.000.000), Ministry of Economic Development, Italy. (ENEA)

**- PT 2015-2017 AdP ENEA-MiSE** "Safety of Lithium Batteries". (during vehicle use and charging) when the redundant safety systems are in fault, behavior under crash and mechanical abuse, behavior in fire, the rescue analysis and the ways of operation in emergency conditions (fire extinguishment and evacuation). From October

2015 to September 2018, total cost: not disclosed (meaning that this is a sub-project of the main project "Electro Mobility", the total cost of which is EUR 4.700.000), Ministry of Economic Development, Italy. (ENEA)

| Name | Description | Timeline | Location/Party | Budget |
|---|---|---|---|---|
| **FiveVB**<br><br>**Others: see above for more details** | Most relevant EU project in TWG scope | From 2015-05-01 to 2018-04-30 | EU (see above) | 5.9 M€ |

**Gaps**:
Lack of knowledge; lack of tools
More in depth knowledge needed on materials ageing, thermal and safety properties, interfaces, upscaling, manufacturing

# R&I Activity Fiche 1.2 - Influence of fast/hyper charging of Li ion batteries on materials and battery degradation

**Activity Leader: Sub-Group Advanced Materials, Chemistry, Design and Recycling**

**PRIORITY: 2**

| | |
|---|---|
| **Present SET Plan KPI's for fast charging are 22 minutes by 2020 and 12 minutes by 2030. However, debate has started for hyper fast recharging in less than 5 minutes using newly developed 350 kW charging stations. Ratio fast / slow charging is further to be determined** | **Monitoring mechanism**: **Proposed as part of a Fast-charge Flagship -** Flagships will be used to monitor the achievement of KPIs compared to the targets set in the DoI. |

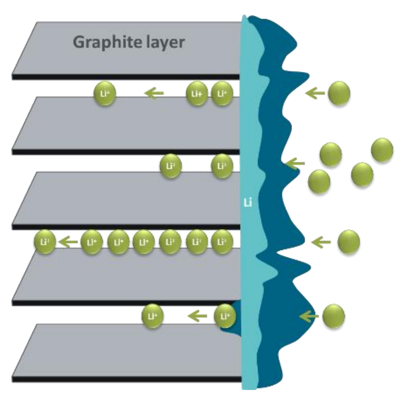
**Description**: Audi, BMW, Daimler, Ford, and Porsche plan to work together to create a European network of hyper fast charging stations (300+ kW) that can recharge batteries in minutes. An initial target of 400 sites has been set, and construction is expected to start in 2017. Sites will be chosen along highways and major transportation routes throughout the EU. The new network will use the Combined Charging System (CCS,) standard for battery charging, which is used in BMW, VW, GM, and newest electric vehicles.

**Safety and battery performance are the priority considerations in this activity.**

Depending on the battery capacity (24-90 kWh) this corresponds with recharge times <5 to 15 min and very high C-rates. To optimize batteries for hyper-charging, such effects of very high C-rate charge need to be studied and eventually a complete overhaul of battery components (anodes, cathodes, current collectors, electrolytes and separator) will be needed for performance, improvement of battery degradation and safety (less flammable). In addition, changes to the battery design and construction are expected to be necessary, to facilitate good heat dissipation.

This action presents cross-cutting issues and requires the fulfilment of tasks including development of

1. New battery materials design (electrodes, electrolytes, separators and current collectors) with excellent kinetic characteristics, high safety, strong chemical bonds and excellent thermal performance.




To save the energy density needed for BEV applications (>300 Wh/kg) and to achieve an acceptable fast charging behaviour, the design of the electrodes especially of the anode has to be modified. For the high energy density, the thickness and the loading are very important, therefore a thinner anode leads to a better fast charging behaviour but to a lower energy density. The key for fast charging is the limiting Li-Ion transport through the anode and SEI. To higher Li-Ion transport for fast charging thick electrodes (80-100µm) can be adjusted with higher porosity, optimized pore structure (high tortuosity) or by another graphite particle and additives for a better Li-Ion conductivity. Another parameter for improving the Li-Ion transport is the improvement of the Li-conductivity of the SEI. This can be done with additives.

In the first step, the overall performance of "fast charging cells" can be simulated. The theoretical borders can be determined depending on material parameters. For example, max. C-rate depending on thickness and energy density.

2. Control of battery interfaces that will allow fast kinetics and heat dissipation.

3. New cell design, module and pack design with inbuilt optimized thermal management and safety mechanisms.

4. Design of suitable charging stations including charge cables and power electronics, which will be actively cooled through liquid cooling.

**This is also a research topic of the GV-1-2018 call.**

**KPI levels expected**

| Activity # | Title | TRL to be reached by | |
|---|---|---|---|
| | | TRL7 | TRL9 |
| 2 | Fast/Hyper charging of Li-ion battery | 2020* | 2022 |
| | | 2025** | 2030 |
| | | 2030*** | 2035 |

Lead KPI; Charging time: *22 min, **12 min and ***5 min.

**Total budget required: 40M€ to reach TRL 7, additionally 10M€ for TRL 9 covering only materials activities (indicatively)**

| Activity # | Title | TRL to be reached by | | Indicative budget (MEuro) to reach | |
|---|---|---|---|---|---|
| | | TRL7 | TRL9 | TRL7 | TRL9 |
| 2 | Fast/Hyper charging of Li-ion battery | 2020* | 2022 | 40 | 10 |
| | | 2025** | 2030 | | |
| | | 2030*** | 2035 | | |

| Expected deliverables | Timeline |
|---|---|
| - Understand and measure effect of high C charge (up to 10C) on current and advanced Li Ion cells<br>- Evaluate progress on fast/hyper chargers: from existing 120 kW to future +300 kW<br>- Propose measures to mitigate cell degradation: material changes, thermal management.<br>- Benchmark with international studies | *See above* |

| **Parties / Partners** (countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
|---|---|---|

| | | |
|---|---|---|
| A typical consortium might be composed of (in a non-exhaustive list):<br>- advanced materials EU producers<br>- EU battery producer<br>- EU OEM Tier 1 and 2<br>- Charger producer<br>- EU RTO's and Universities | *EU/ MS* | *6 to 8 million € per project* |

**Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal: very little on-going related research in EU**

**- CONCEPT:** CONductive fast Charge system for Electric buses in Public Transport - From 2016-08-01 to 2018-07-31, ongoing project Total cost: EUR 2 115 297,50 EU contribution: EUR 1 480 708,25

- **LASER4SURF:** laser nano- and micro- structuration of current collector for rechargeable batteries with enhanced electrode adhesion, current-rate capability and lifetime. From 2017-10-01 to 2020-09-30, ongoing project, Total cost: EUR 4,077,750.00, EU contribution: EUR 4,077,750.00.

**- Mobicus:** Development of innovative systems for the management of electric vehicle batteries and intelligent charging stations with the objective of prolonging the lifetime of the batteries (EDF, France). MOdeling of Batteries Including the coupling between Calendar and USage ageing. Financial support of Conseil Général des Yvelines, CR Nord Pas de Calais, BPI France. Budget: EUR 4 300 000.

**-Organic Redox Flow Battery:** Project's objective is to develop high energy density flow batteries for potential use in electric vehicles with fast recharge by electrolyte swapping (IMDEA Energy Institute, Spain, EERA). From 2016 to 2018. Budget: EUR 500 000.

**PT 2015-2017 AdP ENEA-MiSE** "Safety of Lithium Batteries". (during vehicle use and charging) when the redundant safety systems are in fault, the behavior under crash and mechanical abuse, the behavior in fire conditions, the rescue analysis and the ways of operation in emergency conditions (fire extinguishment and evacuation). From October 2015 to September 2018, total cost: not disclosed (meaning that this is a sub-project of the main project "Electro Mobility", the total cost of which is EUR 4.700.000), Ministry of Economic Development, Italy.

| Name | Description | Timeline | Location/Party | Budget |
|---|---|---|---|---|
| Mobicus | Most relevant project to the scope of TWG activity 2 | 2014-2017 | 16 partners, Renault, EDF… | 4.3 M€ |

**Gaps**: real fast charging impact on battery materials, battery safety and battery life has not been studied thoroughly yet.

## R&I Activity Fiche 1.3: Advancement of batteries for stationary energy storage

**Activity Leader: Sub-Group Advanced Materials, Chemistry, Design and Recycling**

**PRIORITY: 2**

| **Targets:**<br>**- optimise Li Ion battery for ESS**<br>**- develop and optimise other battery chemistries for same target**<br><br>**(focus on cycle and calendar life, cycle cost and volumetric energy density, power density)** | **Monitoring mechanism**:<br>**Proposed as part of the Materials Flagship -** Flagships will be used to monitor the achievement of KPIs compared to the targets set in the DoI. |
|---|---|

**Optimization of Li-ion batteries** for low cost, high safety and long cycle life stationary energy storage requires the development of Advanced Materials for electrodes (cathode, anode, current collectors), electrolytes, binders and optimized packaging materials. These Advanced Materials shall lead to improved stationary Li-ion batteries with well specified KPIs for energy and power density, extended lifetime and significantly improved cost (target cycle cost below 0.05 €/kWh/cycle) while offering full safety. Solid-state developments by polymer or solid electrolytes may lead to higher safety levels. A particular focus for stationary energy storage by Li Ion batteries is to prolong the cycle and calendar life of the systems, which beyond the materials properties will also be strongly driven by the attainment of stable interfaces. Ageing characteristics of the materials need to be determined and improved. Modeling activities are to be included

**Innovation in non-Li ion battery technologies** deals with the creation and advancement of new storage solutions compared to the current systems. The wide range of new candidate systems covers among others metal-air, lithium-sulfur, new ion-based systems (Na, Mg or Al), redox flow batteries (including Vanadium free systems), high temperature batteries ($Na-NiCl_2$, Solid-oxide Fe-air, liquid metal batteries), advanced lead acid batteries. Advanced Materials developed herein can cover cathodes, anodes, current collectors, catalysts, electrolytes, separators that are obtained from abundant low cost and widely distributed sources. Similar cycle cost KPI is targeted as < 0.05€/kWh/cycle. Safety and ageing characteristics of the materials need to be determined and improved. Modeling activities are to be included.

The cell development needs to be accompanied by appropriated sensing, monitoring, thermal management and safety systems. Output targets should be demonstrated at cell level in a Consortium comprehending a European Battery Manufacturer and OEM in a 4-year research and innovation program. Potential for upscaling and recyclability must be addressed in the development.

**SET Plan Action 4 "Increase the resilience and security of the energy system"/TWG 4 will propose a broader research activity on storage, including non-battery technologies. Specific focus will be on intra-week and seasonal modulation needs. Contact will be kept to ensure complementarity and avoid overlaps.**

**TRL:** Research and Innovation Actions: activities should start at TRL 3 and achieve TRL 7 at the end of the project.

**Total budget required: 50 M€ to reach TRL 7, additionally 15 M€ for TRL 9 (indicatively)**

1) **Li Ion: development novel materials and 10Ah cell design with focus on >10000 cycles and <0.05€/kWh/cycle**
2) **Non Li Ion: choices to be made on an initial assessment how the critical KPI's are proposed to be met.**

| Activity # | Title | TRL to be reached by | | Indicative budget (MEuro) to reach | |
|---|---|---|---|---|---|
| | | TRL7 | TRL9 | TRL7 | TRL9 |
| 3 | Batteries for ESS | 2020* | 2022 | 50 | 15 |
| | | 2025** | 2028 | | |

Lead KPI; # cycles: *5 000 and **10 000.

| Expected deliverables | Timeline |
|---|---|
| **By 2020:** 3000-5000 cycles, 15 years, cost 0.1 €/kWh/cycle, 750 Wh/l<br>**By 2030:** 10.000 cycles, 20 years, cost 0.05 €/kWh/cycle, >750 Wh/l | *See above* |

| **Parties / Partners** (countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
|---|---|---|
| typical consortium might be composed of (in a non-exhaustive list):<br>- advanced materials EU producers<br>- EU battery producer<br>- EU grid operators, TSO and DSO<br>- EU RTO's and Universities | *EU/MS* | *6 to 8 million € per project* |

**Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal**

- **ALION:** HIGH SPECIFIC ENERGY ALUMINIUM-ION RECHARGEABLE DECENTRALIZED ELECTRICITY GENERATION SOURCES- **From** 2015-06-01 **to** 2019-05-31, ongoing project, Total cost: EUR 7 223 551,25, EU contribution: EUR 7 223 551,25
- **HiPerBat:** Hunting for high performance energy storage in batteries, From 2013-01-01 to 2017-12-31, ongoing project, Total cost: EUR 1 497 838, EU contribution: EUR 1 497 838
- **ZAS:** Zinc Air Secondary innovative nanotech based batteries for efficient energy storage, From 2015-06-01 to 2018-05-31, ongoing project, Total cost: EUR 6 614 553,75, EU contribution: EUR 6 614 553,75
-**HELIS:** High energy lithium sulphur cells and batteries, From 2015-06-01 to 2019-05-31, ongoing project, Total cost: EUR 7 974 352, EU contribution: EUR 7 974 352
- **NAIADES:** Na-Ion Battery Demonstration for Electric Storage, From 2015-01-01 to 2018-12-31, ongoing project, Total cost: EUR 6 492 262, 50 EU contribution: EUR 6 492 262
- **ALISE**: Advanced Lithium Sulphur battery for EV from 2015-06-01 to 2019-05-31, ongoing project, total cost EUR 6 899 233, EU contribution EUR 6 899 233, -**ZnR** Batteries – Development of a rechargeable zinc-air module, From 2016 – 2018 ongoing project. Total cost: Not disclosed. Industry project EDF, France

-**Eair** – Development of advanced materials for reversible air electrodes for metal-air batteries, from 2014-2017 ongoing project., Total cost: 1,923 391 Co-funded from ANR
- **Flowbox** - Novel Cost Effective Energy Storage Solution for Renewable Integration and Infrastructure Deferral. Development et demonstration of a novel flow battery storage –Total cost: Not disclosed. Industry project EDF and partners.
- **Energy Keeper** (flow battery) –H2020 -http://www.energykeeper.eu/ - the project is focussed on designing, developing and testing a novel, scalable, sustainable and cost competitive flow battery based on

organic redox active materials. A 100kW redox flow battery with a capacity of 350 kWh will be constructed and equipped with an interoperable Battery Management System enabling plug and play integration into a Smart Grid.
- **BAOBAB** (acid-base battery) -H2020 - https://ec.europa.eu/inea/en/horizon-2020/projects/h2020-energy/storage/baobab. The goal of the BAoBab project is to develop a novel, environmentally-friendly acid/base battery for storing energy.
- **PT 2015-2017 AdP CNR-MiSE**: The project is focused on the tests of lithium ion battery for renewable energy storage applications. From 2017 – 2019 ongoing project, Total cost: 2,400 000, Ministry of Economic Development, Italy
- **PT 2015-2017 AdP CNR-MiSE** The project foresees the development of materials, device research and prototype of Low Temperature Metal-air (Fe-air) batteries. From 2017 – 2019 ongoing project, Total cost: Not disclosed, Ministry of Economic Development, Italy
**Batteries2020:** The project aims to improve performance, lifetime and total cost of ownership of batteries for EVs by the simultaneous development of high-performing and durable cells, reliable lifetime prediction, understanding ageing phenomena and assessment of second life in renewable energy applications. **From 2013 to 2016. Total cost: 8 398 727€, EU contribution : 5 866 847€**
**SIRBATT:** the project studies the importance of the stability of interfaces in the life of batteries, focused mainly on stationary applications. **From 2013 –2016. Total cost: 4 415 236€, EU contribution: 3 144 717€**
**-New Energy Storage System:** For utility scale grid storage and maritime propulsion systems (Wartsila Norway AS, Norway, NFR). Budget: EUR 1 500 000.
**-PT 2015-2017 AdP CNR-MiSE:** The project foresees the development of materials, device research and prototype of Low Temperature Metal-air (Fe-air) batteries (Ministry of Economic Development, Italy, EERA). From 2017 to 2019. Budget: Under negotiation.
**-PT 2015-2017 AdP CNR-MiSE:** The project foresees the development of materials, device research and prototype of high temperature solid oxide Metal-air (Fe-air) batteries (Ministry of Economic Development, Italy, EERA). From 2017 to 2019. Budget: Under negotiation.

**-PT 2015-2017 AdP CNR-MiSE:** The project foresees the development of materials, device research and prototype of materials, device research and prototype of Zebra batteries (Ministry of Economic Development, Italy, EERA). From 2017 to 2019. Budget: Under negotiation.
**Low Cost Vanadium Redox Flow Battery:** Project's objective is to provide stationary energy storage at low cost, long duration and high recyclability (IMDEA Energy Institute, Spain, EERA).
From 2015 to 2018. Budget EUR 1 000 000.
**ADMIRE:** Advanced Materials for Mg-ion Rechargeable Batteries (SINTEF, Norway, NFR).
Focus: Cathode materials and electrolyte" From 2016 to 2019. Budget: NOK 9 100 000.
**-Liquid Metal Battery:** Liquid Metal Battery. New concept low cost membrane free liquid metal battery for large scale stationary energy storage (SINTEF, Norway). From 2014 to 2018. Budget: EUR 873 516.
**-Membrane free liquid metal batteries for grid scale energy storage** (NTNU, NFR).
From 2014 to 2018. Budget: EUR 900 000.
- **PT 2015-2017 AdP CNR-MiSE** CNR's activities on stationary storage: (i) development and prototype new vanadium redox flow battery (VRFB) technologies; (ii) development and prototype Low Temperature Metal-air (Fe-air) batteries; (iii) tests of lithium ion battery for renewable ESS. From 2016 to 2018 on-going activities, total cost: not discovered (meaning that these activities are sub-projects of the main project "Sistemi elettrochimici per l'accumulo di energia", the total cost of which is: EUR 2,400 000), Ministry of Economic Development, Italy.

- **PT 2015-2017 AdP RSE-MiSE**, Prototype of a BMS for Lithium batteries, with the objective of an optimal charge balance among cells, increasing the overall battery performance. From March 2015 to February 2018 - On-going project, total cost: not disclosed (meaning that this is a sub-project of a main project "Development and operation of distribution networks", the total cost of which is +/- EUR 20.000.000), Ministry of Economic Development, Italy.

**- PT 2015-2017 AdP RSE-MiSE** RSE's activities on stationary storage: (i) anodic materials development for Sodium Ion batteries, with high specific capacity and long lifetime, (ii) new, planar configuration electrochemical cells for Sodium-Nickel Chloride batteries, in order to increase power density, (iii) innovative solid electrolytes formulations for Nickel Chloride batteries, with the objective to decrease internal resistance, by improving ionic conduction, increasing mechanical strength and decreasing thickness, (iv) preliminary studies on Liquid metal batteries for stationary applications, (v) new testing procedures devoted to quantify performances and lifecycle of distinct batteries for different applications, power or energy intensive. March 2015 to February 2018 - On-going activities, total cost: not discovered (meaning that these activities are sub-projects of the main project "Storage materials and technologies for the Electric System", the total cost of which is +/- EUR 5.000.000), Ministry of Economic Development, Italy.

- **PT 2015-2017 AdP RSE-MiSE** Development of innovative equipment for Vehicle To Home (V2H) applications. The equipment will allow to exploit a battery pack both for vehicle operation and for smart storage in domestic applications. From March 2015 to February 2018 - On-going project, total cost: not disclosed (meaning that this is a sub-project of a main project "Electric mobility", the total cost of which is EUR 6.000.000), Ministry of Economic Development.

- **Enel "Large Scale Energy Storage" projects** in Southern Italy, where 3 storage systems has been installed to mitigate intermittency in renewable energy production and to study a new centralized/decentralized solution for voltage regulation and increase of the hosting capacity. From to, on-going project, total cost: not discovered, Enel Italy. (to be confirmed by Enel).

**- Enel "Storage system Ventotene"** A storage system with lithium batteries has been installed at Ventotene island, not connected to the national grid, for the purpose of optimizing the operation of the ICE's (oil fueled), taking the control of frequency and voltage during low-load hours. From to, on-going project, total cost: not discovered, Enel Italy. (to be confirmed by Enel).

**- PT 2015-2017 AdP ENEA-MISE** ENEA's activities on stationary storage: (i) R&D on lithium-sulphur, sulphur-ion, sodium-ion, industrial pre-series cells/stack on pilot production lines for lithium-ion batteries; (ii) Definition of test procedures (ageing, second life, safety), studies on storage systems integrated with energy production and or consumption systems. October 2015 to September 2018, on-going activities, total cost: not discovered (meaning that these activities are sub-projects of the main project "Energy Storage Systems for the Electric System", the total cost of which is EUR 4.800.000), Ministry of Economic Development, Italy.

**BALANCE** (Increasing penetration of renewable power, alternative fuels and grid flexibility by cross-vector electrochemical processes), Grant 731224, ongoing ECRIA project 1/12/2016-30/11/2019, 2.86M€ project with 2.5M€ EC funding.

| Name | Description | Timeline | Location/Party | Budget |
|---|---|---|---|---|
| Several projects (see above) | By far largest part devoted to non- Li Ion battery technologies but their breakthrough is not yet realized mainly because of technical shortcomings | several | several | ++M€ |

**Gaps**:
Lack of fundamental knowledge; lack of tools
Stable interfaces

# R&I Activity Fiche 1.4: Post Li ion for e- mobility

**Activity Leader: Sub-Group Advanced Materials, Chemistry, Design and Recycling**

**PRIORITY: 2**

| All e-mobility segments: | Monitoring mechanism: |
| --- | --- |
| **- Energy oriented (E): passenger cars, LEV, buses, trains, forklifts**<br>**Power oriented (P): heavy duty, maritime, (P)HEV…** | **Proposed as part of the Materials Flagship -** Flagships will be used to monitor the achievement of KPIs compared to the targets set in the DoI. |

One of the core priorities of the Energy Union strategy is to speed up energy efficiency and decarbonisation of transport through Research and Innovation (R&I) in E-mobility. Traction batteries are considered a Key Enabling Technology in electric vehicle (EV) drive trains. Current traction batteries are to a large extent based on lithium-ion (Li-ion) chemistry which is expected to remain the technology of choice for still many years but their maximum energy density will be limited to approximately 350- 400 Wh/kg. **Higher performance needs the gradual introduction of new generation batteries (post Li Ion) based on the development of a series of novel Advanced Materials.**

The wide range of new candidate systems covers among others metal-air, lithium-sulphur, new ion-based systems (Na, Mg or Al). Advanced Materials developed herein shall cover cathodes, anodes, electrolytes, separators, binders and packaging materials. Manufacturing for such Advanced Materials should be developed and their scaling-up in environmental processes. E-Mobility covers the wide range of applications: passenger cars, buses, trains, heavy duty, forklifts, maritime, etc.

At this stage, the technologies offering the best chances of success are Na-Ion, Li- S and metal (Li or Fe or Zn)-air, but depending on the system, performance issues including poor cycle life, low power, low efficiencies and limited safety need to be addressed and solutions brought from TRL levels 3 to 7. Research activities are dependent on the particular system addressed, but typically could include; - for Na-ion, new cathode and anode advanced materials; for Li-S, electrode materials migration and dissolution of the polysulphides, as well as stable, high-capacity anodes (like Li-metal or Si); for Metal-Air, improved electrolyte/separator combinations to reduce dendrite growth for Li (or Zn) metal anodes, porous cathode, use of catalysts, energy gap reduction. In general, research and innovation will be needed for advanced material coatings and the development of new ceramic/ polymer/ hybrid structures with high conductivity and low impedance and non-flammable, stable and conductive electrolytes. Methodologies for large-scale new materials manufacturing processes, environmentally friendly, need to be developed to reduce the battery system cost. Taking into account the rather fundamental character of most of the technical drawbacks of the post-Li ion systems, a good understanding of the cell reactions (cathode, anode...) is required. The cell development needs to be accompanied by appropriated sensing, monitoring, thermal management and safety systems.

Output targets should be demonstrated at cell level in a Consortium comprehending a European Battery Manufacturer and OEM in a 4-year research and innovation program. Potential for upscaling and recyclability must be addressed in the development.

**Interactions possible with Action 4/TWG 4 Smart energy system- Storage and with Green Vehicles 2018**

**TRL:** Research and Innovation Actions: activities should start at TRL 3 and achieve TRL 7 at the end of the project.

**Total budget required:**
**40 M€ to reach TRL 7, additionally 15 M€ for TRL 9 (indicatively)**

| Activity # | Title | TRL to be reached by | | Indicative budget (MEuro) to reach | |
|---|---|---|---|---|---|
| | | TRL7 | TRL9 | TRL7 | TRL9 |
| 4 | Beyond Li-ion based batteries for e-mobility#,* | 2030 | 2035 | 40 | 15 |

#Propose a selection of promising candidates.
*Energy density: 400 Wh/kg.

| Expected deliverables | Timeline |
|---|---|
| 1. For (E) at cell level: by 2030: > or = 400 Wh/kg, > 750 Wh/l, 2000 cycles at 80% DoD, < 100 €/kWh<br>2. For (P) at cell level: by 2030: > 700 W/kg, >1500 W/l | *See above* |

| **Parties / Partners** (countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
|---|---|---|
| A typical consortium might be composed of<br>- advanced materials EU producers<br>- EU battery producer<br>- EU OEM Tier 1 and 2<br>- EU RTO's and Universities | *EU/MS* | *6-8 million € per project* |

**Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal**

- **FunLAB:** Fundamental breakthroughs in Lithium-Air Batteries, From 2014-04-25 to 2018-04-24, ongoing project,
Total cost: EUR 100 000 EU contribution: EUR 100 000

- **ALISE**: Advanced Lithium Sulphur battery for xEV, From 2015-06-01 to 2019-05-31, ongoing project, Total cost:
EUR 6 899 233, EU contribution: EUR 6 899 233

-**HELIS:** High energy lithium sulphur cells and batteries, From 2015-06-01 to 2019-05-31, ongoing project, Total cost: EUR 7 974 352 EU contribution: EUR 7 974 352

-
- **Image Horizon2020 can be added as well**
-

**- PT 2015-2017 AdP ENEA-MISE** Research and development of lithium-sulphur, sulphur-ion, sodium-ion, realization of industrial pre-series cells/stack on pilot production lines for lithium-ion batteries. October 2015 to September 2018, on-going project, total cost: not discovered (meaning that this is a sub-project of the main project "Energy Storage Systems for the Electric System", the total cost of which is EUR 4.800.000), Ministry of Economic Development, Italy.

**- PT 2015-2017 AdP RSE-MiSE** RSE's activities on cell active materials: (i) anodic materials development for Sodium Ion batteries, with high specific capacity and long lifetime, (ii) innovative solid electrolytes formulations for Nickel Chloride batteries, with the objective to decrease internal resistance, by improving ionic conduction, increasing mechanical strength and decreasing thickness. From March 2015 to February 2018 - On-going activities, total cost: not discovered (meaning that these activities are sub-projects of the main project “Storage materials and technologies for the Electric System”, the total cost of which is +/- EUR 5.000.000), Ministry of Economic Development, Italy.

| **Name** | **Description** | **Timeline** | **Location/Party** | **Budget** |
|---|---|---|---|---|
| See above | Beyond Li Ion technologies are mostly studied for ESS and not yet for e-mobility | several | several | ++ M€ |

**Gaps**:
Lack of knowledge; lack of tools
Lead KPI’s are far from realized for e-mobility

# R&I Activity Fiche 1.5: Recycling of batteries (Li-ion and Post Li-ion)

**Activity Leader: Sub-Group Advanced Materials**

**PRIORITY: 2**

| | |
|---|---|
| **Develop circular economy and de-bottleneck availability of critical raw materials** | **Monitoring mechanism**: **Proposed as a Recycling Flagship -** Flagships will be used to monitor the achievement of KPIs compared to the targets set in the DoI. |

According to the EU batteries directive (BD), collected batteries have to be recycled. The BD makes a distinction between portable batteries and industrial batteries. For portable batteries, a collection target of 45% has been put forward. For industrial batteries (including xEV batteries), no collection target is set, but industrial batteries may not be landfilled nor incinerated and hence the only end-of-life option (after possible $2^{nd}$ use) is recycling.

1. **Recycling of current battery configurations particularly for Li ion:**
   Although recycling projects for Li-ion batteries have been ongoing for several years, Li-ion battery recycling is not mature. R&I Challenges include but are not limited to:

**Reverse logistics:** Today, due to the small volumes of EoL industrial batteries, reversed logistics is expensive. In addition, safety and regulatory issues increase costs (adapted packaging, shipping companies being reluctant to ship used batteries). Related research topics include both the development of Low cost packaging for safe reversed logistics and Improved reversed logistics business model.

**Dismantling:** Large batteries cannot put into a metallurgical process as such. Dismantling (removing 'easy to recycle parts' and size reduction in order to feed the metallurgical process) reduces the needed metallurgical recycling capacity and has a lower environmental footprint. Dismantling of industrial batteries, prior to metallurgical recycling can be improved. Dismantling is not just 'reversed assembling', because there are large volumes of a broad variety of industrial batteries.
Recycling of new pack materials (carbon reinforced synthetic fibres) is a challenge. The BD requires a recycling efficiency of 50 % (ration between recycled battery materials and input materials). As the casing is considered as part of the battery, the weight of the casing and the recycled casing materials are included in the calculation.

**Robust scaling of metallurgical or chemical processes:** The metallurgical or chemical recycling processes of mobility batteries is currently operational on a relatively small scale (from 100's of kg to a few 1000's ton). With the worldwide extensive transition to e-mobility, upscaling recycling to economically more viable capacity will be essential. 1 million EV's equals ± 500 000 tons of batteries to be recycled; 100 000 electric buses equals ± 400 000 tons of batteries. To cope with these volumes, existing battery recycling processes will have to be re-engineered and automated.
The upscaling will also have to take into account the EHS aspects.

a. Volatile organic carbons: in combination with halogenated compounds (Cl and F), risks on dioxin formation. Efficient gas treatment and fire risk control is needed
b. Final (waste) fraction: how to deal with final waste fractions (waste to landfill, slag).

Evolving battery chemistry is less an issue. In the medium term, recyclers may expect Si and Li as anode material (maybe also some Ti). These elements can be handled in actual flowsheets. For the foreseeable future, the cathode materials will be combinations of Co, Ni, Mn, Al: all elements that are already present in today's batteries. Industrial and commercial processes already exist recovering Cu, Ni and Co (Co as a critical raw material is already fully recovered) but improvements of current processes are still possible. Alternative recovery methods which could compete with existing technology may still be developed.

**2. Design of new cells for ease of disassembly and recyclability**

Next generation batteries will have Li-metal anode. Although Li-metal can be recycled in existing processes, Li-metal poses specific safety issues (fire). Focus should be put on **design and reference**: dimension standards (less than 5 dimensions) and references can be advantageous in reducing costs. Development of bar codes linked to the type of batteries and raw materials included should be developed for an optimized recycling approach. The final cost of recycling will depend on the process developed and the value of constituents of the battery.

**TRL:** Research and Innovation Actions: activities should start at TRL 5 and achieve TRL 7 at the end of the project.

**Total budget required:**
**75 M€ for TRL 7 (Li Ion and post Li Ion), additionally 25 M€ for TRL 9 (indicatively)**
*Li-ion
**Post Li-ion

| Activity # | Title | TRL to be reached by | | Indicative budget (MEuro) to reach | |
|---|---|---|---|---|---|
| | | TRL7 | TRL9 | TRL7 | TRL9 |
| 5 | Recycling | 2025* / 2030** | 2030 | 50 / 25 | 25 |

*Li-ion
**Post Li-ion

| Expected deliverables | Timeline |
|---|---|
| 2020: Collection rate70%, recycling efficiency 50%, economically breakeven<br>2030: Collection rate 85%, recycling efficiency 50%, economically viable | *See above* |

| Parties / Partners | Implementation financing / funding instruments | Indicative financing contribution |
|---|---|---|
| (countries / stakeholders / EU)<br>A typical consortium might be composed of (in a non-exhaustive list):<br>- EU battery recyclers<br>- EU battery producer<br>- EU OEM Tier 1 and 2<br>- EU RTO's and Universities | EU/MS | 6 to 8 M€ per project |
| | | |

**Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal**

**-CloseWEEE:** Integrated solutions for pre-processing electronic equipment, closing the loop of postconsumer high-grade plastics, and advanced recovery of critical raw materials antimony and graphite

From 2014-12-01 to 2018-11-30, ongoing project, Total cost: EUR 5 919 277,50 EU contribution: EUR 5 890 660

- **REE-CYCLE:** Rare Earth Element reCYCLing with Low Harmful Emissions, From 2013-07-01 to 2018-06-30, ongoing project, Total cost: EUR 2 255 515, EU contribution: EUR 2 255 515

- **REE4EU:** integrated high temperature electrolysis (HTE) and Ion Liquid Extraction (ILE) for a strong and independent European Rare Earth Elements Supply Chain, From 2015-10-01 to 2019-09-30, ongoing project, EUR 9 063 772,50, EU contribution: EUR 7 522 490,63

- **ProSUM:** Prospecting Secondary raw materials in the Urban mine and Mining waste, From 2015-01-01 to 2017-12-31, ongoing project, Total cost: EUR 3 704 327,57, EU contribution: EUR 3 051 577,57

| Name | Description | Timeline | Location/Party | Budget |
|---|---|---|---|---|
| | See list of relevant projects provided above | | | |

**Gaps**:

*Reversed logistics, scaling of robust processes, new designs..*

## R&I Activity Fiche 1.6: Lithium recovery from European geothermal brines and sustainable beneficiation processes for indigenous hard rock occurrences of lithium

**Activity Leader: Sub-Group Advanced Materials, Chemistry, Design and Recycling**

**PRIORITY: 3**

| **Targets:** | **Monitoring mechanism**: |
|---|---|
| - **Supply the European battery market with lithium recovered from European brines**<br>- **Using direct extraction processes implemented on existing wells to avoid opening of new mines** | to be agreed |

**Description:**

Lithium is a strategic metal especially for batteries manufacturing for electric vehicles, for which the worldwide demand is constantly increasing. The major part of lithium is currently recovered from brines in the *Lithium Triangle* located in South America. Europe does not produce lithium from brines but many projects are being developed and European geothermal resources represent a significant potential for lithium extraction.

Nowadays, to extract lithium from brines, suppliers mainly use a conventional process mostly based on natural evaporation which appears to be very long and presents major disadvantages (important surface required for evaporation, significant evaporation time, solid waste production, low lithium recovery yield of about 50-60% …) and will certainly not be feasible in Europe due to the climate. But, other solutions are being developed such as the utilization of a solid material to extract lithium from brine or the utilization of membrane electrolysis. These new processes of direct-extraction have, on one hand, the advantage to be environmentally friendlier (less solid waste, smaller footprint, best yield leading less brine pumping) and, on the other hand, to result in a higher profitability. Moreover, these processes are more versatile and much less dependent on evaporation than the conventional process implying that lithium can be extracted from many types of lithium brines under various climatic conditions. As many lithium resources are available in Europe (geothermal brines, oilfield brines), the use of these processes allow to foresee a possible exploitation of European brines and could contribute to securing of lithium supply for the battery market in Europe.

In addition hard rock occurrences of lithium in Europe can also contribute to increasing EU's security of supply (especially as geothermal Li-containing brines are relatively scarce and their Li concentration is not high). Efforts should be concentrated on more environmentally sustainable beneficiation processes.

**TRL:** *Research and Innovation Actions: activities should start at TRL 3 and achieve TRL 6-7 at the end of the project (to be re-evaluated over time).*

The concept of direct extraction to recover lithium from brines is currently implemented by some European industrials on *salars* in South America. But European brines are very different from other ones in terms of pressure and temperature mainly. Studies need to be performed to adapt these new processes and technologies to European brines (from TRL 3 to reach TRL 5). Trials at pilot scales are then necessary to implement processes and technologies on existing wells on the European soil (from TRL 5 to TRL 7).

**Total budget required:** 10-20 M€ (tbc) to develop new direct extraction processes and technologies and to test these processes on experimental or industrial existing wells in Europe.

| **Expected deliverables** | **Timeline** |
| --- | --- |
| • Mapping and identification of interesting European geothermal resources in terms of lithium content<br>• Adaptation of direct extraction processes and technologies to European brines<br>• Up-scaling: trials at demonstrator scale on existing geothermal wells to extract lithium from brine<br><br>More deliverables can further be added. | *2018-2020*<br>*Projects needs to be implemented before 2025 to not be too late.* |

| **Parties / Partners** | **Implementation financing / funding instruments** | **Indicative financing contribution** |
| --- | --- | --- |
| ERAMET (French mining and metallurgical company), BRGM (French RTO/Institutional), Gent University (Belgium), Swedish Environmental Research Institute (IVL), Storengy (French company), … | Possibly:<br>- EIT-Raw Materials (*the European Institute of Technology on Raw Materials*)<br>- H2020 programs<br>- ERA-MIN<br>- Other national or European call for commitments | ~90% of the total budget (max 5M€)<br>70% to 100% of the total budget (max 10M€)<br>30% to 50% of the budget (max 300K€) |

**Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal**

Several European companies such as ERAMET have already developed direct extraction processes to extract lithium from brines in Argentina. But none of them are currently adapted to European brines, very different in Argentina than in France or Germany for instance, in terms of pressure and temperature. Processes must be adapted to each specific geothermal resource. It will also be necessary to study hydrogeology on reservoirs of fractured rocks. This is indeed very important since this technique allows estimating the real potential of extraction of lithium from geothermal brines.

The lithium demand and supply being critical and very high on the European political agenda, R&D projects are being developed such as the WATER+Li project and the EuGeLi projects submitted respectively to the EIT Raw Materials and the ERA-MIN 2 call for commitment. Results are expected in the coming months.

Europe has now the opportunity to become a supplier in lithium and to secure its own supply, mainly for the battery market but, in order to reach this goal, more R&D has to be performed.

To illustrate the fact that these topics are new and there is still a need for technology developments, several European start-ups are now on the market, proposing business models based on lithium recovery from European brines:

- Geolith
- Adionics
- Ajelis.

The Lithium extraction from geothermal brines is already actively developed in the US by Californian Companies such as Simbol and EnergySource Minerals: experience shows that Li levels in the pumped brines need to show concentrations >200 ppm. In the UK activity is deployed by Cornish Lithium Limited.

| Name | Description | Timeline | Location/Party | Budget |
|---|---|---|---|---|
| | So far no on-going H2020 project on this topic. | | | |

**Gaps**:

The technology needs to be further developed at EU scale as outlined in project’s deliverables and starting with the assessment of Li concentrations in existing geothermal installations: candidates for such assessment are locations in a.o France, Italy, Germany and Belgium.

## Activities developed by the sub-group ***Manufacturing***

# OVERVIEW

Activity 2.1: **Foster development of materials processing techniques and components for fast industrialization compatible with present mass production lines**

This activity has a short-term objective: it focusses on the integration of close-to-market materials into mass production lines. Intensive development must be done to **obtain new components which are compatible with today's production equipment**. New electrode recipes and compatible process parameters will be searched. It also considers inactive materials not mentioned in the activities of the Materials sub-group. One important objective is to enable environmental friendlier processes such as water-based coating. This activity will overall support the early scaling-up of factories in Europe.

Activity 2.2: F**oster development of cell and battery manufacturing equipment**

By contrast, this fiche focusses on developing new equipment for present and future cell chemistries. Its main objective is to enable differentiation by addressing specific market trends: flexibility by equipment modularity, higher environmental standards, and cost reduction through better production efficiency. Research and development for equipment compatible with future technologies such as all-solid state is also a focus. This activity will overall support the medium-term scaling-up of factories in Europe.

*Eco-efficient production through Activities 2.1 and 2.2 has been identified as a Manufacturing Flagship topic.*

**Cross-functional activities and activities Manufacturing**

In order to efficiently and consistently manage the activities regarding the overall goal it has been identified 2 cross-functional activities: Market and Education/Knowledge. Consistent indicators for technical progress, technical performance, knowledge development and education criteria specifically related to the activity Manufacturing will be developed and used as monitoring mechanism.

## R&I Activity Fiche 2.1: Foster development of materials processing techniques and components for fast industrialization compatible with present mass production lines

**Activity Leader: Sub-Group Manufacturing**

**PRIORITY: 1**

| Targets | Monitoring mechanism |
|---|---|
| **Targets: a1 to a6, b1 & b2, c1 & c2**<br>**By 2022:**<br>**Production: Reach > 5GWh/a in Europe**<br>Energy: targets from Issue paper<br>Mix: 500 – 1500 W/kg‡ (1/5 at -20°C), 10 years‡ (>4000cycles) , EUCAR level ≤ 4‡<br>Power: >120Wh/kg, 1000 – 2000 W/kg‡ (1/5 at -20°C), 1500 W/l, 10C, 8 years‡ (>15000 cycles @10C charge), 200€/kWh, EUCAR level ≤ 4‡<br>Stationary: 0.05€/kWh/cycle, P/E>10<br>†: NPE Roadmap (2016)<br>‡: VDMA Battery production Roadmap (2016) | **Monitoring mechanism**:<br>**Proposed as part of the Manufacturing Flagship -**<br>Flagships will be used to monitor the achievement of KPIs compared to the targets set in the DoI.<br>Monitor if the 3 milestones are reached on time. |

**Description:**

Quickly reaching mass production (>>GWh/a) of performant Li-ion cells and solid state batteries in Europe, following Circular Economy principles, is of paramount importance to push the industry forward. As stated in the renewed EU Industrial Policy Strategy (COM(2017) 479 final), for the EU to remain competitive in the e-mobility field "it will be necessary to fill missing links in relevant value chains. This is why investment in batteries is of strategic importance". This fiche thence focusses on short-term activities having a direct impact on current pilot and production lines **by 2022.** The deadline is postponed from 2020 to 2022 as R&I projects run at least 3 years. The projects responding to this activity fiche will require financial support for scaling-up beyond R&I. The consortia shall receive support to approach private and public financing solutions, such as IPCEI.

A focus on short-term targets requires investigating **processing of close-to-market materials** and **cell components** as well as non-Li-ion materials **compatible with typical cell assembly lines**. Unlike the fiches “Advanced Li-ion batteries for e-mobility” and “advancement of batteries for stationary energy storage (ESS)” targeting electrochemical performance, this fiche concerns materials improvement for **processability**, new **recipes** and non-active components not listed in the other fiches.

Regarding toxicity and legislation, it should also take into consideration NMP-free electrode manufacturing, i.e. with water-based slurry mixing. Water during the mixing process has a non-negligible influence on active and inactive materials.

As stated in the introduction of this implementation plan, the DoI of Action 7 considers KPIs only for energy-oriented applications. Considering the SET-Plan Roadmap on Materials, it is necessary to consider the market in its whole diversity, i.e. energy-intensive and power-intensive applications where electrochemical energy storage can be a solution. For this reason, this fiche considers both energy-intensive (e.g. 2.a) as well as power-intensive materials (e.g. 2.b). As described in the DoI, reaching all KPI targets concurrently is hard to achieve. There should be a diversity of projects, not only focusing on energy density, so that all scenarios are addressed.

This activity should focus on the following topics, but not limited to:

1. Improvement of active and inactive materials to better manufacturing:

   a. Surface modification of active materials for water-based processing: e.g. High-Nickel NMC materials (811, 622 or 532), 5V materials (lithium cobalt phosphate, LiNMO) as cathode materials
   b. Development of current collectors' materials which are either cheaper, lighter, with higher adherence properties, or with higher conduction properties. This includes surface modification or doping of standard Al/Cu foils. The collectors must have mechanical properties compatible with today's lines.
   c. Development of reliable water-compatible binders, such as modified PVdF, SBR-based, Acrylic-based, Alginates, CMC-based or any other solution. Considering recyclability of the future batteries is of advantage, e.g. enabling easy dissolving of the used electrodes.
   d. High voltage electrolytes (no gassing) and electrolytes for silicon-graphite composite electrodes with good wettability properties and no toxic additives (e.g. no Propane Sultone). Electrolytes for lithium metal working at room temperature.
   e. Quasi solid-state electrolyte which can be coated with today's coating lines. This type of electrolyte can increase safety. Consider up-scalability of the process with marginal machine change.
2. Recipes development:
   a. Scalable recipes of Graphite/Silicon blending as anode material for high energy cells providing adequate cycle stability
   b. Scalable recipes of new anode materials for high power cells, e.g. zero-strain materials like Titanium dioxide ($TiO_2$).
   c. Scalable recipes using Cobalt-free cathode materials such as multi-metal lithium phosphates and spinel structures to reduce dependency to raw materials
   d. Recipes for higher loading (thick electrodes, or loading > 3.5 $mAh/cm^2$) without loss in power performance.
   e. High-safety separators which are thinner (< 15µm) and cheaper enabling EUCAR-level ≤ 4. The separator foil must have mechanical properties compatible with today's lines.
3. Cell design innovation compatible with today's lines:
   a. Increase safety by design enabling EUCAR-level ≤ 4 +
   b. increase recyclability without endangering integrity.

For all activities (1, 2 and 3), non-Li-ion chemistries compatible with today's line can also be considered such as:

- Recipes with Na-ion based active materials compatible with today's prod lines.
- Recipes of Lithium Metal Polymer based cells compatible with today's prod lines.
- Recipes of Li-S or Li-ion – S based cells compatible with today's prod lines.

It is suggested to invest in 5 large consortia where all actors of the value chain are participating and where at least one member has a pilot line for materials synthesis (sub-activity 1) or for cell assembly (sub-activities 2 and 3). The pilot line should be scalable in order to reach MRL8.
New IP and recipe know-how produced by this Action must be quickly exploitable yet only within the EU. Access to the pool of knowledge (licensing) should be available to all companies investing in a manufacturing line within the EU and associated countries, with prime access to members of the consortia. After a delay of [X] years, licensing is opened for all.

**TRL:** As the important target is manufacturing, we will use Manufacturing Readiness Levels.
Development should focus on materials compatible with today's line, hence today's line techniques should reach MRL 10 by 2020; while materials MRL should all reach 8 by 2022 (7 is pilot line, 8 is low rate production).
All materials must be above TRL6 today and reach TRL9 by 2022.
<u>Cell assembling equipment:</u> MRL 9 today, MRL 10 by 2022 (already available today at equipment manufacturers)
<u>Materials development:</u> MRL 5 today, to MRL 8 by 2022 (pilot production at materials manufacturer)
<u>Recipe development:</u> MRL 5 to 7 today, to MRL 8 by 2022 (pilot production at cell manufacturer)
<u>Cell design:</u> TRL6 today, TRL9 by 2022 (pilot production at cell manufacturer)

**Total budget required 50M€ (4-year projects, 5 projects)**
***Stakeholders:***
***materials and components manufacturers + associated RTOs (for synthesis process & pilot lines) 80%***
***Cell assemblers + associated RTOs (recipe & assembly process) 15%***
***System assemblers + associated RTOs (testing and demonstration) 5%***

| **Expected deliverables** | **Timeline** |
|---|---|
| 1. *Reach TRL8 (recipes tested and demonstrated)*<br>2. *Reach MRL7 (pilot line)*<br>3. *Reach MRL8 (low rate production)* | *Project Month (start = project Month 0)*<br>*M12*<br>*M24*<br>*M48* |

| **Parties / Partners** (countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
|---|---|---|
| Materials and components manufacturers<br>Cell assemblers<br>Module/System assemblers<br>OEMs & utilities<br>RTOs | TBD | TBD |
| TBD | | |

**Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal**

***Sintbat (H2020):*** Silicon based materials and new processing technologies for improved lithium-ion batteries http://www.sintbat.eu/project.html **From** 2016-03-01 **to** 2020-02-29, ongoing project, Total cost: EUR 9 755 886,25 EU contribution: EUR 8 334 786,25 (*high energy materials coated with aqueous process)*

**eCAIMAN:** Electrolyte, Cathode and Anode Improvements for Market-near Next-generation Lithium Ion Batteries, From 2015-05-01 to 2018-04-30, ongoing project, Total cost: EUR 6 126 698,75, EU contribution: EUR 5 807 244,50

***FiveVB*** *(H2020): 5V materials/electrolyte.* From 2015-05-01 to 2018-04-30, ongoing project, Total cost: EUR 5 927 428,75 EU contribution: EUR 5 673 272,50

| **Name** | **Description** | **Timeline** | **Location/Party** | **Budget** |
|---|---|---|---|---|
| | A list of relevant projects is provided above | | | |

**Gaps**:

*Lack of awareness; lack of knowledge; lack of tools*

## R&I Activity Fiche 2.2: foster development of cell and battery manufacturing equipment

**Activity Leader: Sub-Group Manufacturing**

**PRIORITY: 2**

| | |
|---|---|
| **Targets: b1 & b2, c1 & c2**<br>Reduce manufacturing cost<br>Meet market demand<br>2022: 5GWh/a (MRL8)<br>2030: 50GWh/a (MRL9) | **Monitoring mechanism**:<br>**Proposed as part of the Manufacturing Flagship -**<br>Flagships will be used to monitor the achievement of KPIs compared to the targets set in the DoI.<br>Monitor if the 3 milestones are reached on time. |

**Description:**

Materials are the biggest cost factor. Mass-scaling production is a vital step to reduce this cost share by increasing the order book. Improvements of production machines and techniques can be a significant solution for growth by addressing different needs of the market in the dimension of applicability of the cells (mobility, stationary, other), environment and cost itself. As stated in the renewed EU Industrial Policy Strategy (COM(2017) 479 final), for the EU to remain competitive in the e-mobility field "it will be necessary to fill missing links in relevant value chains. This is why investment in batteries is of strategic importance". While the fiche titled *"Foster development of materials processing techniques and components for fast industrialization compatible with present mass production lines"* focusses on short-term development of recipes and chemical processes, this fiche considers **equipment** development for a longer period: from 2022 to 2030. It is essential to develop equipment for next-generation chemistries using less critical materials but also for enabling recyclability. Technological advancement and standardization will also need to be addressed after 2030, so projects extending beyond this point are welcome.

Market requirements are the following:

1. Application: Flexible cell design (dimensions) and cell chemistry (performance)
2. Environment: Free from toxic materials, in particular NMP, to stay resistant to present and future EU environmental regulations.
3. Cost: reduce it by increasing production speed, and reducing rejects and energy consumption.

Activities to address this issue are hereafter listed. Some of them are inspired by VDMA Battery production roadmap and KLIB proposal for funding programmes. They were then enhanced by TWG members. Note no deadline is set for 2020 as it is too early. Earliest deadlines are set for 2022.

1. Differentiation potential to respond to market (automotive and stationary) needs:
    a. from notching to cell assembling, accept different cell designs (similar to paper production with ISO 216). Modularity with 3 cell sizes, constant cost ➔ 2025
    b. from mixing to cell assembling, accept different materials for flexible cell performance (changing foil+ coating thickness, cost effectiveness for change from high power to high energy materials). Modularity with 4 cell compositions, constant cost ➔ 2025
    c. From powder to cell: pilot line for all-solid-state production using inorganic electrolyte (oxide, phosphate class). All-solid-state will both increase energy density and safety (could impact charging rate). ➔ 2025

Work addressing this sub-activity must consider sub-activities relating to all-solid-state cells from other fiches.

   d. Intelligent housing productions: increase production speed, safety and energy density with new cell+module design produced in-line. > 100 housings / min + new safety functions ➔ 2022
   e. Production of cells with minimum global warming potential (GWP), cumulative energy demand (CED), eutrophication potential (EP) and other LCA measures. This sub-activity is directly linked to sub-activities 4.d and 4.f. Other solutions are welcome.

2. Reduce cost by accelerating electrode manufacturing:
   a. Enable double-sided coating in one process step for all electrodes while keeping good adherence. ➔ 2022
   b. Improve mixing methods and/or machines to halve mixing time (semi-continuous to consider). ➔ 2022; Establish, improve and optimize continues and highly viscose electrode paste production technologies
   c. Improve coating dyes to enable high homogeneity and high production throughput (foils of large width up to 2 m or more to be coated with multiple stripes of 0,5-0,75 m each). Variance in thickness << 0.5 µm ➔ 2022
   d. Improve coating machines/methods to accept thin sheet and thick coatings (e.g. extrusion coating). Current collectors between 6 to 10µm ➔ 2022
   e. Minimum solvent content formulation (based on paste extrusion and extrusion drying; machine development) and dry coating of electrodes, such as with electrostatic deposition and thermal fusion, development of dry blending and structuring of active material, binder and functional additives.
3. Reduce cost, improve quality with efficient cell assembly:
   a. Cutting/slitting/notching with lasers with no contamination. This will reduce investment, allow for modularity, potentially reduce waste. ➔ 2022
   b. Accelerate stacking/winding via new process approaches. > 600 layers/min ➔ 2022
   c. Enable stacking/coating of gel-like electrolyte in-line. In addition, polymer-electrolyte membrane can be directly prepared onto electrode surfaces. ➔ 2025
   d. Pouch cell housing sealing: increase mechanical stability, no leakage while enable easier recycling by design. ➔ 2022
   e. Improve electrolyte filling methods or machines: increase speed while keeping 100% wetting of the cell. < 5sec ➔ 2025
   f. Improve and accelerate formation (material and process approaches), ageing, sorting with new methods. Formation+sorting< 2 hours. Halving ageing time. ➔ 2030
   g. Better contact bonds (tab welding) for higher currents ➔ 2022
   h. Development of new investigation methods to improve cell quality (e.g. in-situ characterisation methods for electrolyte filling)
4. Increase overall quality of the cells and cell production:
   a. International standards for quality control methods on powder, suspension, electrode and cell level for mechanical, structural, electrical
   b. Increase robustness as well as defect prevention and, therefore, decrease overall costs due to a deep knowledge of parameter influence in each process step and their interdependency. Directly linked to sub-activity 4.e
   c. Long-term forecasting with simple quality tests; correlation of physical properties of intermediates with functional/electrochemical cell performance parameters. Guaranteed service life ➔ 2025
   d. Improving $CO_2$-footprint and overall ecological balance (e.g. by reducing/eliminating the need of clean rooms and drying rooms, with water-based processing or closed assembly lines (mini environments)). ➔ 2022
   e. Standardization for digitalization of equipment across the whole production chain (Industry 4.0) to increase quality and reduce rejects. standards and smart data; incl. identification of key-parameters and tracking strategies for failures identification across the production chain with

high impact on electrochemical cell properties → 2025

f. Intra-European/International standards for environmental regulation of cell production and use. Suggest a new legal framework for cell acquisition and recycling within Europe considering these standards.

Each funded project should involve all actors of the value chain, of which one member plans to host a scalable pilot line to demonstrate the new technologies.
At least one project should consider future technologies (e.g. solid-state) and at least one project should consider current technology (e.g. liquid electrolyte, coating).

**TRL:**
Cell assembling equipment:
In all case, TRL7 should be reached for the **production process.**

**Total budget required 60M€ (4-year projects, 6 projects)**
***Stakeholders:***
***materials and components manufacturers + associated RTOs (materials compatibility with new production) 17 %***
***Manufacturers of battery production equipment + associated RTOs 60%***
***Cell assemblers + associated RTOs (assembly process) 20%***
***System assemblers + associated RTOs (testing and demonstration) 3%***

| **Expected deliverables** | **Timeline** |
|---|---|
| • Production process demonstrated individually in laboratory (TRL4)<br>• Finished pilot line to test new technologies in near-real conditions (TRL5 to 6)<br>• All production process demonstrated together in operational environment (TRL7) | *Project Month (start = project Month 0)*<br>*1. M18*<br>*2. M36*<br>*3. M42* |

| **Parties / Partners** (countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
|---|---|---|
| Materials and component manufacturers<br>Equipment manufacturers<br>Electrode & cell manufacturers<br>System (battery) manufacturers<br>End users (OEMs & utilities)<br>RTOs | TBD | TBD |

**Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal**

Mars-EV project (EU funding: FP7 Theme GC.NMP.2013-1 (2013-2017))**: integration of "gel-like" polymer-electrolyte in the cell assembling process.**

***Image Manufacturing of beyond li-ion batteries, From 2017-11-01 to 2021-04-30, ongoing project, Total cost: EUR 4,948,026.25 EU contribution: EUR 4,948,026.25***

| Name | Description | Timeline | Location/Party | Budget |
|---|---|---|---|---|
| | A list of two relevant projects is provided above | | | |

**Gaps**:

*Lack of awareness; lack of knowledge; lack of tools*

## Activities developed by the sub-group ***Application and Integration***

## OVERVIEW

Activity 3.1: **Hybridisation of battery systems for stationary energy storage (ESS**) aims to develop the optimal battery system based on hybridisation. This is strongly linked with the activities related to materials and chemistry. Based on the battolyser concept, this activity will have a strong focus on integration of and electrochemical system next to the battery. Key challenges are on the design of the cell and stack, and the development of the Battery Management System.

Activity 3.2: **Second use and smart integration into the Grid** aims to optimise the reuse of a battery in its 2$^{nd}$ life thanks to a better knowledge about its previous lifetime. Such better guarantee of performance will be also made possible thanks to a design of batteries that consider from the beginning the case of 2$^{nd}$ life. For this activity the development of an advanced BMS will ensure the capitalisation of the knowledge on the battery all along its life.

*Activity 3.2 has been identified as a Second-use Flagship.*

**Cross-functional activities and activities Application and Integration**

In order to efficiently and consistently manage the activities regarding the overall goal it has been identified 2 cross-functional activities: Market and Education/Knowledge. Consistent indicators for technical progress, technical performance, knowledge development and education criteria specifically related to the activity Application and Integration will be developed and used as monitoring mechanism.

## R&I Activity Fiche 3.1: Hybridisation of battery systems for stationary energy storage (ESS):

**Activity Leader: Sub-Group Application & Integration**

**PRIORITY: 3**

| | |
|---|---|
| Optimisation of power/energy requirements in a stationary energy storage system by the combination of different technologies. | **Monitoring mechanism**: |

No single technology is able to serve all the high-energy and high-power needs. High-energy applications require storage devices to discharge their energy at rated power for longer than one hour and high-power applications often need storage to discharge all their energy within an hour, or often a much shorter time. In addition, storage technologies in the stationary-applications sector will be required to perform multiple or bundled applications, such as a combination of load levelling, frequency regulation and backup power.

**This topic should be developed in coordination with Action 4 of the SET Plan dealing with Energy System.**

The use of dual systems for energy storage applications can be advantageous in reducing cost, improving performance, capacity factors, and safety. Low cost batteries can be used to store large quantities of energy i.e. providing energy, while a high power in/output can be added provided by systems such as Li ion batteries or supercapacitors (EC) or non- electrochemical systems (e.g. flywheels). In addition integration of a Ni-Fe battery with an alkaline electrolyser ('battolyser') can provide a hybrid double use system with improved battery performance and, when the battery capacity is full, with competitive and switchable electrolyser to produce hydrogen as storable fuel or feedstock for chemical industry.

Two approaches may be developed to this:

**Twinning of two distinct systems:** Such as by two electrochemical systems e.g. batteries and supercapacitors combined or such as by an electrochemical system with another energy storage technology (higher level of complexity)

**Internal hybrids (materials challenge and cell design issues):** open to novel concepts from the materials challenge, and the cell and stack point of view. The battolyser concept is such internal hybrid: all of the battery electrode material becomes water splitting catalyst, providing both spontaneous overcharge protection and high efficiency electrolysis surface.

In the scope of actions we can envisage with the SET-Plan point of view, different focus have to be made in order to offer solutions on the market:

**Focus has to be put on the development of Advanced Materials** to enable optimal hybridisation of systems, their design, energy management, safety and demonstration. The development of new Advanced Materials for the battery system has been sufficiently dealt with in the Activities proposed on Material/Chemistry/Design. Advanced materials developments in the context of hybridisation aim to address new Advanced Materials for including a second electrochemical system next to the battery; the study of non-electrochemical systems is out of scope. Internal hybrids (e.g. hybrid Li Ion capacitors – Li Ion and EC, battery and electrolyser) may also be developed based on the use of novel materials.

**Focus has to be put on the development of Cell and Stack design** since the hybrid characteristics require a modified electrode layout that accommodates the necessary charge transports. For instance a hybrid battery and super capacitor will require different dimensioning of the battery and capacitor materials sections of the electrodes. A hybrid alkaline battery and electrolyser also requires alternative battery electrode, electrolyte and gas separation when compared to a normal battery and alkaline electrolyser.

**Focus has to be put on the development of Advanced Battery Management Systems** since the hybrid system will have different high power capabilities and potential limits during use. For instance a hybrid capacitor and battery will have much higher power handling capabilities that need to be accommodated than normal batteries. A battolyser has different power, thermal management, and applied potential demands than a normal battery since e.g. overcharge with higher applied cell potentials is allowed (electrolysis) and also higher temperatures are allowed without thermal runaway or unwanted electrolyte decomposition risks.

**KPI's by 2020,2025 and 2030 respectively as follows:**

| Advanced materials for Li C supercapacitors | | | |
|---|---|---|---|
| Gravimetric energy density | 35 Wh / kg | 40 Wh / kg | 50 Wh / kg |
| Power density | 10 kW / kg | 12 kW / kg | 15 kW / kg |
| Cycle life | 1M cycles | 1.5M cycles | 2M cycles |
| Temperature window | - 20 °C, + 70 °C | - 40 °C, + 90 °C | - 40 °C, + 90 °C |

| Battolyser, a hybrid battery and electrolyser | | | |
|---|---|---|---|
| **Volumetric energy density** | 120 Wh/L | 180 Wh/L | 250 Wh/L |
| **Power density** | 40 W/L | 90 W/L | 125 W/L |
| **Cycle life** | 10000 | 15000 | 20000 |
| **Temperature window** | 0 °C, 60 °C | 0 °C, 70 °C | 0 °C, 80 °C |
| **Pilot/demo/TRL-8 price targets** | 5000Eu per 5kWh and 1.5kW (pilot) | 1000Eu per 5kWh and 1.75kW (demo) | 400Eu per 5kWh and 2.5kW (TRL-8) |

*The activity will produce several deliverables:*

- *Study of new materials for hybridisation of systems*
- *Study of components and system design specific to hybrid systems*
- *Study of the Advanced BMS for hybrid systems*

**TRL:** Research and Innovation Actions: activities should start at TRL 3 and achieve TRL 7 at the end of the project.

**Total budget required 25 M€**

| Expected deliverables | Timeline |
|---|---|
| ***Studies and components***<br>• *Study of new materials for hybridisation of systems (each 2 product families being developed in parallel)*<br>*2018 for 1st elements, then incremental study up to 2027 in line with the KPI based roadmap*<br>• *Study of components and system design specific to hybrid systems (each 2 product families being developed in parallel)*<br>*2018 for overall system design and incremental development up to 2030*<br>• *Study of the Advanced BMS for hybrid systems*<br>*From 2019, development of model and component of a generic BMS for hybrid systems*<br><br>***Large demo scale in 2023 (500MWh/175MW)***<br>*Timing depends mostly on availability of sufficient renewables of which curtailment should be prevented; this drives the large scale storage market (according to industry).* | |

| **Parties / Partners**<br>(countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
|---|---|---|
| *Note: during the working sessions a strong focus was made on the Battolyser as case of hybridisation. Nevertheless other hybrid systems will be investigated in order to satisfy the different needs.* | | |

| | | |
|---|---|---|
| *Parties that will implement Battolyser:*<br>*- Utilities and renewable power providers requiring short term (seconds-hours) stationary storage as well as seasonal storage in hydrogen fuel; providing better grid stability, the reduction of curtailment (loss of 1GEu last year in Germany, source: EWEA ), and the ability to guarantee security of renewable power supply.*<br>*- Automotive sector requires stationary batteries next to EV fast charge stations as well as hydrogen electrolysers for (hybrid) hydrogen transport.*<br>*- Chemical industries that need $CO_2$ emission reduction via electrification and clean hydrogen as feedstock, or for chemical processes.* | *National science organisations, local government organisations, EU funding from e.g. Fast Track to Innovation, H2020 funds for large demonstrations. Companies of the different sectors indicated.* | *Battolyser:*<br>*- 25MEu for R&D*<br>*- 5MEu for each 5MWh/1.5MW pilot near EV fast charge stations or small chemical plant.*<br>*- 100 MEu for first 500 MWh/175 MW demonstration near wind/solar park and chemical plant. (going down to 40 MEu for 50th 500 MWh/250 MW battolyser plant)* |

**Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal**

ONLINE project: hybrid system development using supercapacitors and NAS batteries

SULTAN project: Supercaps / NaNiCl2…

**PT 2015-2017 AdP ENEA-MiSE** Studies on hybrid storage systems.
From October 2015 to September 2018, on-going project, total cost: not disclosed (meaning that this is a sub-project of the main project “Energy Storage Systems for the Electric System”, the total cost of which is EUR 4.800.000), Ministry of Economic Development, Italy.

SMILES project - simulation technologies to model and simulated Batteries, Grid, RES, HEAT and other power sources.

Battolyser project, 2017-2022. Dutch Science Foundation (NWO/TTW), TU Delft and industrial partners in electricity, energy, chemistry, and automotive sectors.

| Name | Description | Timeline | Location/Party | Budget |
|---|---|---|---|---|
| | A list of relevant projects is provided above | | | |

**Gaps**:
*Lack of awareness; lack of knowledge; lack of tools*

# R&I Activity Fiche 3.2: Second use and smart integration into the Grid

**Activity Leader: Sub-Group Application & Integration**

**PRIORITY: 2**

| **Targets:** | **Monitoring mechanism**: |
| --- | --- |
| Reduce the Levelised Cost of Stored Energy (LCOE) of EV batteries by enabling their 2nd use | **Proposed as Second-use Flagship -** Flagships will be used to monitor the achievement of KPIs compared to the targets set in the DoI. |

**Description:**

Facilitating a second life for aged batteries once their performances have dropped below that required by their initial application has many advantages: their total lifetime is increased which reduces the LCOE of the battery and its environmental impact is improved since its lifetime is increased before it is recycled or simply buried. The main challenges for a sustainable market of the "2nd Use" are to offer a reasonable guarantee of the future performance of batteries when they are reused either for EV or for Stationary Storage Systems. This can be done through knowledge recorded on the battery during its first lifetime. Designing batteries which are also optimised for a 2nd Use would also help to encourage a second lifetime for the battery. OEMs will then be able to determine the right level of performance he can offer for this 2nd life with a certain level of guarantee. A new market for used batteries can therefore be envisaged if sufficient guarantees on their future performance can be obtained. Perhaps different micro-market could be developed depending on the level of performance in the batteries and corresponding needs for different application types.

Today, the performance of the battery at its end of life in its 1st life is not sufficiently established/documented and a high level of risk needs to be accepted when the battery is reused in its second application. We can also imagine that depending on the reuse application (e.g.: frequency regulation, peak shifting, lower range EV, etc.), different levels of performance will be required. Depending on the application of the 2nd use, it can be imagined that the battery module is either used as is or that it is reconditioned.

The case of 2nd use could also be the opportunity to define specific regulations that will encourage their reuse or efficient recycling.

Topics for this activity are:

- Market and battery performance characterisation for the 2nd use
- 1st life of batteries and interconnection to the electricity grid (V2G)
- Application of 2nd life batteries to Stationary Market
- Intelligent Life Long Battery Management System

**<u>Market and battery performance characterisation for the 2nd use</u>**

**- Benchmark : Commercial Li-ion cells and batteries :**

The activity suggest a paper study of commercial Li-ion cells, regarding their production, their design (size vs capacity, voltage,…), their chemistry, and their price.

**- A preliminary technico-economic study to better quantify second life criteria:**

A preliminary technico-economic study should take place to still envision the interest to use Li-ion battery for a second life, regarding the Li-ion battery price, the expected disassembly cost, the expected performances.

This preliminary study will help to determine the 2nd battery life criteria (cells or modules level disassembly, minimum performances, price, pack modification…). Determination of the type of tests necessary to assess battery reliability, safety and performance at end of its first use will be an area for research.

A chapter of this study will be related to the use of the batteries in 2nd life without any modification.

In this specific case, from the results of projects, it appears the economy done on disassembly is counterbalanced by the necessity to develop specific power convertors and power management systems to dialog with the existing BMS of the battery. The advantage of such solution (apart from the lower price) is to benefit of the high level of safety of the EV Battery. Removing the regulatory barriers to promote the use of second life batteries is an important issue an example, evolution of the different regulations concerning the transportation of dangerous material will be necessary (the battery moving in the car is not considered as a dangerous material but the same battery carried in a truck comes under the ADR regulation with high cost of transfer). This point will be addressed by the study.

In this study, it will be interesting to have a feedback of second life existing battery demonstrators like the ELSA H2020 project. Elsa Project identifies 6 energy storage markets and 6 pilot installations in Europe resemble all important use cases for small and medium storage solutions. A simple modular concept for buildings or grid applications is used, based on EV second life batteries whose price is ½ of a new battery.. Other important assessments on second life are reported in the papers „Sustainability Assessment of Second Use Application of Automotive Batteries: Ageing of Li-Ion Battery Cells in Automotive and Grid-scale Applications" and „Economic Viability of Second Life Applications of Lithium-ion Traction Batteries „ exhibited during the 30th Electric Vehicle Symposium from 9 to 11 October 2017 in Stuttgart, Germany.

An analysis with the key stakeholders in the value chain will be developed in order to find the business oriented criteria (like reduction of total cost of ownership), Key stakeholders are car manufacturers, electricity utility companies, recyclers, etc.

The study will have to clearly define the context for standardisation related to 2nd life (interface, evaluation criteria, design, traceability, handling, etc.), which should be included in the initial production of the battery.

**- Most promising batteries : comparison of the first and the second life, regarding applications :**

Tests protocols: Protocols will be established, depending on the final 2$^{nd}$ use application. It will be interesting to have quick tests protocol. The objective will be to determine criteria to select as soon as possible the most promising batteries (several levels of expected performances, depending on the application).

Aging tests (including calendar one to anticipate the intermediate storage) will be performed on most promising batteries: Electrochemical and abusive tests will be coupled with post-mortem analysis to correlate Li-ion batteries degradations with electrical performances.

Models will be developed to better understand and anticipate Li-ion battery performances regarding today and next generation Li-ion batteries.

**<u>1$^{st}$ life of batteries and interconnection to the electricity grid (V2G)</u>**

During long time parking, vehicle batteries (1$^{st}$ use) could be used to "back" supply the electric distribution grid in well identified points and times for contributing to the grid balancing ("smart charging" concept). Due to the low power and time required, these V2G services would be a sort of "soft training" for the batteries, without significant effects on battery life and vehicle range. On the contrary, they should bring an income for the vehicle's owner.

Challenge is in today set of applicable standards that are in force for the 2 sectors. A study will have for objective to identify a convergence roadmap from the current situation. Different barriers prevent for the use of batteries of EV in electricity networks.

Proposals for either update and/or creation of a shared set of standard will be developed. If necessary evolutions of existing standards will be proposed.

**Application of 2nd life batteries to Stationary Market**

In energy storage applications lithium-ion batteries have not fully realized the same economies of scale as for EV applications due to the lower degree of vertical integration along the production chain. Second use could help energy storage operators to achieve a positive business case.

To get more knowledge and experience from the use of such battery for the stationary market, a set of demonstration or lighthouse projects will be proposed. Demonstration of relevance for this use will help the different categories of actors (energy providers, cell manufacturers, energy consumers, citizens, etc) to assess the interest for such application.

**Intelligent Life Long Battery Management System**

Get characteristics and better knowledge about the battery and its components will improve not only its performance but also its efficiency when integrated and used, when reused, when de-manufactured/recycling. The development of a standard platform (functional architecture, generic interfaces, generic services, models) will be developed.

**TRL:**
*…Demonstration and Market uptake*

*Products are at TRL 7 to 9 and system is starting at TRL 6 and end at TRL8*

**Total budget required**
15 MEu

| **Expected deliverables** | **Timeline** |
| --- | --- |
| *Fill in one line per deliverable*<br><br>TBD | *Project Month (start = project Month 0)*<br><br>TBD |

| **Parties / Partners**<br>(countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
| --- | --- | --- |
| Equipment manufacturers<br>System (battery) manufacturers<br>End users (OEMs & utilities)<br>RTOs | | |

**Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal**

- Project **UEX2** (ADEME, SNAM, CEA-INES, CEA-Grenoble)
- Project **B2T** (Région Midi-Pyrénées, SNAM, CEA-Midi-Pyrénées, CEA-INES)
- ***PT 2015-2017 AdP ENEA-MiSE*** *Definition of test procedures (ageing, second life, safety). Project steps: (i) definition of battery cells pick-up criteria from the 1st application (automotive), (ii) development of procedures for the characterization of the residual performances, (iii) electrical and thermal characterization of Li-ion battery cells, (iv) experimental valuation of second life based on charge/discharge profiles which are typical of stationary applications, (v) models to estimate battery life and/or optimal dimensioning for second life applications, realization of a demonstrator battery module built with selected cells. From October 2015 to September 2018, on-going project, total cost: not disclosed (meaning that this is a sub-project of the main project "Energy Storage Systems for the Electric System", the total cost of which is EUR 4.800.000), Ministry of Economic Development, Italy (ENEA)*
- ***AdP RSE-MiSE***
- ***ENEL, COBAT, CLASS-ONLUS, ITIA-CNR*** *agreement to define the feasibility of an optimized process for the up-cycling of end-life accumulators coming from electric and hybrid vehicles. Project scope: (i) definition of the best practice for a safe storage of the exhausted batteries and the recovery of the residual energy, (ii) planning of an automated line for the de-manufacturing of end-life batteries and re-manufacturing of second life batteries for storage applications, (iii) planning of the treatment of the unused cells. On-going project, total cost non disclosed (confidential project).*

***Possible flagship*** :

- ✓ ***Flagship on second-use of EV batteries*** - Optimum re-use of end-of-first-life xEV batteries or of materials recycled from them

The main target/product of the flagship is the realization of an experimental facility in pilot scale (capacity: 1 battery/day, 4 MWhe/year) which, included in a pre-selection step (object itself of research and development in this Project), allows the re-manufacturing of automotive batteries or their re-use (as it is) in stationary applications. Through the development of an on-board and non-intrusive monitoring system, able to be used on any type of electric vehicle, and of not destructive, highly automated analysis techniques to check battery packs and single cells when the pack is decommissioned, the flagship is aimed to support the re-use of "exhausted" battery systems in stationary applications, such as:

- V2G (Vehicle To Grid) systems, in parking and/or public-private interchange areas, through the realization of power/energy buffer to release the grid from input/output load fluctuations due to the charging stations.
- Ultra fast charging stations and head-lines of local public transport services, which need very high power (many hundred kW).
- Home storage products.
- Industrial applications.

Second-use flagship is aimed to demonstrate the technical-economic feasibility of the topic "second life" for auto motive batteries by the means of:

- The analysis and definition of innovative business models (the fact that a lot of used EV batteries exist doesn't guarantee that people will want to buy them) that take into account new markets and/or paradigms. E.g. second life storage developers aren't selling a commodity so much as a service.
- The development and implementation of ITS hardware and software technologies, with relevant impact on smart and efficient managing of the combined system between battery, vehicle and battery maintenance/substitution service, on "open" platforms, to on-line valuate functional safety, reliability

and life of automotive battery systems.

- The development of “off-board” testing procedures, highly automated, for “exhaust” batteries, to classify and address them to re-use (as it is) or re-manufacturing or re-cycling of components and materials.
- The realization of the prototype of a testing bench with capacity of 1 battery/day for the characterization of exhausted batteries.

The flagship will include the lab demonstration of “second life” for batteries, which will be firstly aged through typical cycles of fast charge realized with “accelerated” procedures and then tested through stationary cycles until the end-of-life condition.

The flagship is 4 years long, including a first significant experimental step; in addition to ENEA (PCU Division, STMA and SPCT Laboratories), Lithops, RSE (Research on Energetic System) and University of Pisa (and others) will be involved.

Enel (the main Italian utility), COBAT (the main Italian consortium for collecting and recycling exhausted batteries), Class-Onlus (a no-profit environmentalist association), ITIA-CNR (the Institute for Industrial Technology and Automation of the National Research Center) and the Department of Mechanical Engineering of the Politecnico di Milano declare their interest in this project, considering their on-going activity (see above) to design an automated line to re-manufacture EV batteries and reuse them repacked for other specific purposes.

Toyota Italia has also been consulted. It confirms a strong interest and attention on second life: Toyota already deals with it relating to hybrid and electric vehicles of its own fleet, mostly fueled by NiMH batteries and, to a lesser extent, lithium batteries. The matter is under Toyota Europe’s management.

*Total budget required*: 12 M€ (4 years)

| Name | Description | Timeline | Location/Party | Budget |
|---|---|---|---|---|
| | A list of relevant projects is provided above | | | |

**Gaps**:

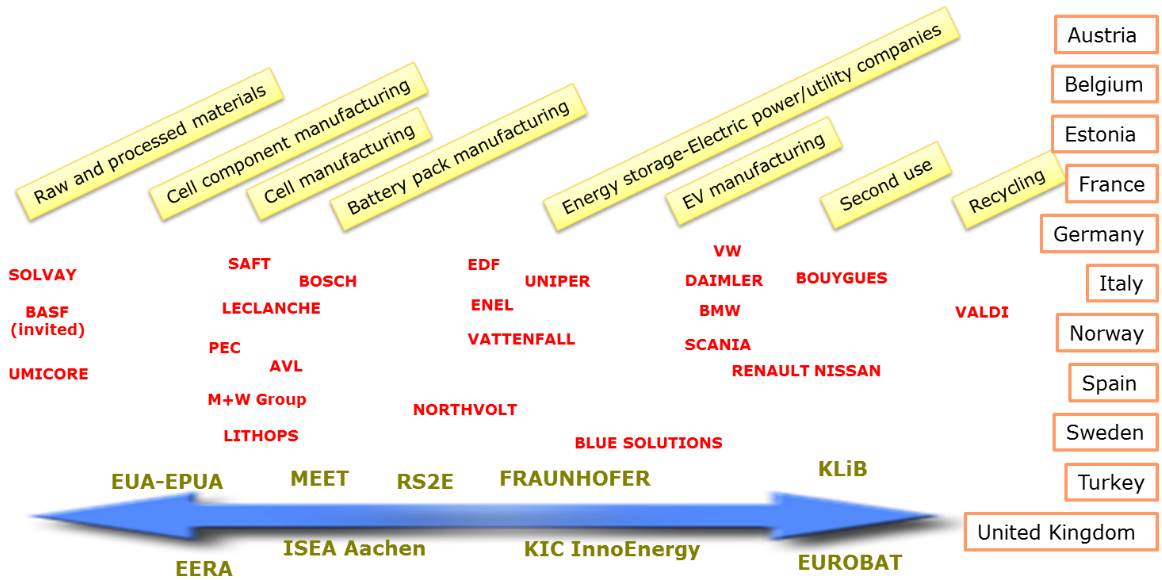
*Lack of knowledge on products.*

# ANNEX B - Members of the TWG

The TWG is composed of a set of members representative of the battery value chain, considering the recommendations of the SET-Plan as maximum number of members.

From a set of 20 Industrials + Research + 10 Member States, thanks to the dissemination efforts, new members have participated to the TWG.

France, Umicore[15] through EMIRI (Energy Materials Industrial Research Initiative), European energy Research Alliance (especially SINTEF), battery producer Leclanché and European Platform of Universities in Energy Research & Education accepted to offer a special effort in elaborating proposals and consolidating stakeholder and MS contributions.




# ANNEX C - Policy context leading to Action 7 of the Integrated Set-Plan

As one of the European priorities, the Energy Union Strategy[16] is built on the ambition to achieve a fundamental cost-effective transformation of Europe's energy system. The energy system transition will be achieved by moving to more flexible, more decentralized, more integrated and therefore smarter, more sustainable, secure and competitive ways of delivering energy to European citizens and companies.

The Energy Union Strategy recognises that an innovation-driven transition to a low carbon economy requires technological leadership and development of industrial production capabilities/technology supply chains across Europe and that this transition offers great opportunities for growth and job creation. The Strategy's fifth dimension puts Research and Innovation (R&I) and Competitiveness at the heart of the Energy Union in order to increase energy efficiency, decarbonise transport and develop energy storage solutions for increased integration of renewables.

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15 global materials technology and recycling group

16 A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy, COM(2015) 80.

In 2015 the Commission adopted the Communication for an Integrated Strategic Energy Technology Plan[17]. The Integrated SET-Plan is the first R&I deliverable on which the fifth dimension of the Energy Union will be built to accelerate Europe's energy system transformation. The Communication defines the European research and innovation strategy for the coming years and highlights areas where the EU needs to strengthen cooperation with SET Plan countries and stakeholders to bring new, efficient and cost-competitive low-carbon technologies to the market faster. Ten key actions are identified with potential to accelerate the energy system transformation through coordinated or joint investments between SET-Plan countries, industry and research stakeholders and the European Commission. These key actions were selected based on an assessment of the energy system's needs, their importance for the energy system transformation and their potential to create growth and jobs in the EU. Among these 10 key actions, Action 7 has the objective to ***Become competitive in the global battery sector to drive e-mobility and energy storage forward***.

### Activities under Action 7

In a first phase, a Commission-led process resulted in the identification of ambitious targets deemed necessary to become competitive in the battery sector. These targets were subsequently agreed between stakeholders and SET-Plan countries in a consultative process and are recorded in the Action 7 Declaration of Intent[18] (DoI) published in July 2016. The targets are differentiated into performance, cost and manufacturing targets for lithium-ion batteries and future technologies specifically for use in automotive and stationary storage applications. The DoI also identifies a number of non-quantifiable targets (safety, reduction in the use of critical materials, reduced environmental impact etc.) which should be considered as well. The DoI further expresses the agreement between Action 7 stakeholders to put forward their best efforts in a coordinated way between public and private sectors, and to jointly address all relevant issues to attain the agreed targets.

In March 2017 a Member State (MS) and industry-led Temporary Working Group (TWG) was formed and assigned the task of identifying the R&I activities needed to achieve the targets outlined in the DoI bearing in mind potentialities for joint and/or coordinated actions and ways in which the EU and national research and innovation programs could be leveraged. The TWG was also asked to identify the contributions of the private sector, research organizations, and universities and to identify all issues of a technological, socio-economic, regulatory or other nature that may be of relevance in achieving the targets.

The Action 7 TWG comprises more than 40 actors[19], representing the full value chain of batteries and battery production systems and consisting of representatives from industry, research and MS. The members of the TWG have shared their vision and proposals on how to develop a competitive European battery manufacturing ecosystem. The findings of the TWG are summarised in this document which forms an Implementation Plan to address current technical and non-technical barriers to competitiveness and contains proposals for specific R&I activities (including flagships) to be carried out by private stakeholders and Member States to achieve the targets stipulated in the DoI.

### Recent battery-related policy developments in the EU and the role of Action 7

As important as they are, evolutionary and/or disruptive technology improvements achieved through R&I, are not sufficient to drive EU competitiveness in the battery sector. Competitiveness in this sector also hinges on having a stable and secure battery manufacturing base. The global market potential is huge and definitely justifies efforts to establish and safeguard a competitive position for EU industry to serve both domestic and export markets. The lack of a domestic cell manufacturing base makes the EU dependent on the supply of foreign battery technology, but also prevents EU industry from gaining a share in the quickly expanding global market for batteries in transport and stationary storage applications. And, over time, the current EU capabilities in high-quality R&I at worldwide level will decline and compromise the ability for Europe to compete for and catch the market of the next generation of batteries.

[17] Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation, C(2015) 6317.

[18] https://setis.ec.europa.eu/system/files/integrated.../action7_declaration_of_intent_0.pdf

[19] See Annex B for details.

The November 2016 Clean Energy for All Europeans Communication[20] lays out a comprehensive strategy for the EU to boost private investment in clean energy innovation. In the Accelerating Clean Energy Innovation Communication[21], published at the same time, the Commission announced its intention to focus future funding available under Horizon 2020 on four interconnected strategic priorities. The Action 7 TWG has defined activities that contribute directly to three of them, namely:

1. Electro-mobility: the rapid development and deployment of the next-generation electric vehicles based on advanced battery designs and new powertrains, associated with innovative recharging infrastructures and associated business models and services are key elements of future low-carbon mobility
2. Developing affordable and integrated energy storage solutions: EU needs to accelerate the full integration of storage devices into the energy system, at domestic, commercial and grid scale.
3. Decarbonising the EU building stock by 2050: buildings represent 40% of the energy demand, and once renovated and upgraded accordingly, they can ensure a key energy storage capacity.

Moreover, as part of its Mobility Package Communication[22] from May 2017, the Commission confirms batteries as a key-enabling technology for electric mobility and for achieving Energy Union objectives. Furthermore the absence of a complete domestic battery value chain (in particular a mass battery cell production capacity) in the EU is recognised. Accordingly, and given the growing strategic interest in batteries, the Commission expressed its intention to support industry-led initiatives to develop a full battery value chain in the EU for batteries for mobility and non-mobility applications (energy storage). To this end the Commission committed to step up its work with stakeholders (including the work under the Strategic Energy Technology Plan) to support an industry-led initiative and develop support measures for research, development and manufacturing of the next generation of battery cells and battery packs in the EU. The Commission also pledged promotion of an integrated European battery eco-system in support of electric mobility and energy storage addressing the issue of scarce resources and battery recycling, which will help facilitate the emergence of new circular economy business models for the automotive industry.

Most recently in the renewed Industrial Policy Strategy[23], published in September 2017, the Commission announced the strategic importance of investment in batteries and the intention to hold a stakeholder meeting to kick-start industry-led initiatives for a full battery value chain in the EU and to help optimise possible public intervention. During the subsequent stakeholder meeting, chaired by Commission vice-president Šefčovič in charge of the Energy Union, the urgency for concerted European action was emphasized and a European Battery Alliance was established, tasked with preparing a comprehensive roadmap on the future of batteries in Europe, including aspects related to the supply chain, investment financing and engineering, trade issues, research and innovation, and others. The work of Action 7 TWG was identified as a potential input to the research and innovation aspect.

### Coordination and financing of battery R&I activities in the Implementation Plan

To support the competitiveness of the European battery sector, the Action 7 IP encourages investments at all stages of the battery innovation chain. Such investments should be done in a coordinated way to leverage European public and private investments, to cover the expected high cost of R&I and the cost of upscaling of manufacturing processes to mass production scale for Li-ion and future non Li-ion based batteries. From the Commission side, strong coordination between the instruments dealing with R&I has been setup, and R&I programmes for the remainder of Horizon 2020 have been revised and updated. In addition, the Commission has suggested investigating the appropriateness of the Projects of Common European Interest (IPCEI) tool for supporting certain R&I activities identified in this IP to gather public support for large, innovative projects which contribute to European economic growth, jobs and competitiveness.

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[20] "Clean Energy for all Europeans" COM(2016) 860 final

[21] "Accelerating transition to a low-carbon competitive economy", COM(2016) 763

[22] An agenda for a socially fair transition towards clean, competitive and connected mobility for all, SWD(2017) 177

[23] "Investing in a smart, innovative and sustainable Industry" COM(2017) 479 final

# ANNEX D - Targets and priorities (from the Declaration of Intent)

### *a) Performance targets*

Successful deployment of batteries for automotive applications requires meeting a number of performance criteria. It is acknowledged that it may be difficult to achieve some targets concurrently, e.g. gravimetric versus volumetric energy density, gravimetric energy density versus fast charge time or energy versus power demand at cell level). Furthermore, some performance parameters are affected by use conditions (e.g. battery cycle life may strongly be strongly affected by the frequency of fast recharge). Such interdependencies need to be considered.

**Table a**

| | | Current (2014/ 2015) | 2020 | *2030 |
|---|---|---|---|---|
| **Performance targets for automotive applications unless otherwise indicated** | | | | |
| **1** | Gravimetric energy density [Wh/kg] | | | |
| | pack level | 85-135 | 235 | > 250 |
| | cell level | 90-235 | 350 | > 400 |
| **2** | Volumetric energy density [Wh/l] | | | |
| | pack level | 95-220 | 500 | > 500 |
| | cell level | 200-630 | 750 | > 750 |
| **3** | Gravimetric power density [W/kg] | | | |
| | pack level | 330-400 | 470 | > 470 |
| | cell level | | 700 | > 700 |
| **4** | Volumetric power density [W/l] | | | |
| | pack level | 350-550 | 1.000 | > 1.000 |
| | **cell level | | 1.500 | > 1.500 |
| **5** | Fast recharge time [min] (70-80% ΔSOC) | 30 | 22 | 12 |
| **6** | Battery life time (at normal ambient temperature) | | | |
| | Cycle life for BEV*** to 80% DOD [cycles] | | 1.000 | 2000 |
| | Cycle life for Stationary to 80% DOD [cycles] | 1000-3000 | 3000-5000 | 10000 |
| | Calendar life [years] | 8-10 | 15 | 20 |

*: Post-Lithium ion technologies are assumed relevant in this time frame
**: May also be relevant to stationary applications
*** Cycle life for PHEV must be bigger

### *b) Cost targets*

The medium term target date for cost targets is set to 2022 (as opposed to 2020) to allow more time for these targets to be met.

**Table b**

| TARGETS | | Current (2014/ 2015) | 2022 | 2030 |
|---|---|---|---|---|
| **Cost target** | | | | |
| **1** | Battery pack cost for automotive applications [€/kWh] | 180-285 | 90 | 75 |
| **2** | Cost for stationary applications requiring deep discharge cycle [€/kWh/cycle] | | 0,1 | 0,05 |

### *c) Manufacturing targets*

**Table c**

| TARGETS | | Current (2014/ 2015) | 2020 | 2030 |
|---|---|---|---|---|
| **Manufacturing targets** | | | | |
| **1** | Automotive (Li-ion and next generation post-lithium) battery cell production in EU [GWh/year][24] (% supporting EU PHEV+BEV production) | 0,15 – 0,20[25] | 5<br>(50% of the 0.5 M EVs with 20 kWh) | 50<br>(50% of the 2 M EVs with 50 kWh) |
| **2** | *Utility Storage (Li-ion and next generation post-lithium) battery cell production in EU [GWh/year] | 0,07 – 0,10[2] | 2.2 | 10 |
| **3** | Recycling | | | |
| | **Battery collection/take back rate | 45% (Sept 2016) | 70% | 85% |

[24] Two assumptions were made when defining this target value, based on projected global sales for PHEV+BEV in 2020 and 2030 of 2.5M and 10 M vehicles respectively: (a) the percentage for EU OEMs production of PHEV+BEVs is assumed to be maintained at the current level of 20% for both 2020 (with an average energy capacity of 20 kWh) and 2030 (with an average energy capacity of 50 kWh); (b) EU battery manufacturers will supply half of the cells needed for the PHEVs+BEVs produced by EU OEMs.

[25] Figures provided by Saft Group SA

| | | | | |
|---|---|---|---|---|
| | Recycling efficiency (by average weight) | 50% | 50% | 50% |
| | Economy of recycling | Not economically viable | Break even | Economically viable |
| 4 | Second Life | Not developed | Developed | Fully established |

* The energy storage capacity in GWh depends strongly on the implementation rate of intermittent renewable electricity sources and market models behind those.

** These targets are based on numbers defined in Directive 2006/66/EC. This Directive is being revised and targets should be consistent with the revised Directive.

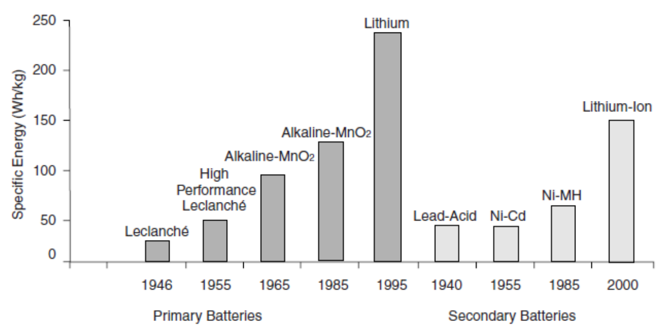
In addition to the targets above, there are other requirements for which it is more difficult to set SMART targets. Such requirements include enhanced safety through risk mitigation as well as increased efficiency, reduction in the use of critical materials, reduced environmental impact and implementation of Eco-design (energy savings and solvent reduction) for advanced battery materials/components manufacturing processes. Furthermore, interoperability, system integration at pack level, standardization, regulations, workforce and education are important.

# ANNEX E - State of the art

Known as an energy storage device thanks to high energy density and low self-discharge, a battery is considered a device which directly transforms the chemical energy inside the active materials to electric energy through a redox reaction between anode and cathode electrodes. The anode is always a reducing agent with high coulombic capacity (Ah/g) presenting a good conductivity, ease of production and low cost. The cathode uses an oxidizing agent (commonly metallic oxides) which is stable in electrolyte medium. The batteries are classified into two families: primary batteries (non-rechargeable) and secondary battery (rechargeable).

The first class of batteries are commonly used when the applications require a lightweight power source or a freedom of utility power such as utility metering, measure equipment, medical devices, military light system for soldiers, data loggers and a wide variety of other applications.

The energy densities of secondary batteries are generally lower than the primary ones, however the secondary batteries can be charged, discharged in to a load and recharged many times. In this family, Li-ion batteries have certain advantages over other chemistries thanks to their high gravimetric and volumetric energy density, low self-discharge rate and the absence of memory effect.




*Advances in battery performance for portable applications.* (Linden et al., 2001)

## Li-ion batteries in their context

Li-ion batteries are characterized by rapid technological advances, in particular in materials, cell designs, and system architectures. Nowadays, large attention is being paid to the development of batteries for the automobile industry to reduce the environmental impact associated to energy used for mobility. The automotive industry is one of the most important economic sectors in Europe, representing 10% of European employment in manufacturing. The electric vehicle (EV) market development is accelerating, driven by stricter emission regulations and lower battery cost. The value in EV supply is dominated by the battery pack, which accounts for about 40% of the EV cost. Furthermore, battery cell materials and battery cell manufacturing represent together about half of the battery pack cost. Therefore, battery materials, cells and packs play a major role in the EV value chain.

Europe can still forge its place in the battery world, considering the complete and strong European battery value chain, from R&D laboratories, pilot platforms, to major industrial materials providers, battery manufacturers, OEMs: The only way to maintain its leadership in the automotive industry is to develop an industrial ecosystem covering the whole EV value chain (from battery materials to battery cells, battery packs and EVs). European companies in the EV value chain will be able to innovate and gain a competitive edge only if the full industrial ecosystem is localized in Europe. While there are strong European industrial companies in the upstream (battery material manufacturing) and downstream (car manufacturing) of the value chain, there is today no European player positioned in the large-scale manufacturing of battery cells for EV applications. This is a serious disadvantage for the entire European automotive industry, in particular if compared to the current situation in Asia.

Battery technology also plays a major role in other strategic industrial sectors, notably energy storage systems (ESS). The emergence of a world-leading European battery cell industry will positively affect the competitiveness of energy storage service providers in Europe. There are strong synergies in terms of battery cell technology between the EV and ESS applications, which can lead to cost reduction by benefiting from economy of scale.

## A focus on LIB technologies:

- **The cell level**

Today commercial Li-ion cells: five active cathode materials are commonly used in commercial Li-ion cells. LCO (LiCoO2) is the historical active cathode material. This high energy material can be unstable and is often used for portable applications. NMC (Li[NixMnyCoz]O2) is the successor of LCO with nickel and manganese substituting cobalt to lower the cost. More and more applications are replacing LCO by this versatile material. NCA (Li[NixMnCoyAlz]O2) offers the highest energy density for a lamellar material, but its safety is lower than that of NMC. LMO (LiMn2O4) is a cheap active material, but offers lower energy density than NMC and is often blended with it to improve performance. LFP (LiFePO4) is the "Chinese" material, its electrochemical stability is very interesting for safety, but the energy density is quite very low (the lowest). Chinese automakers are changing their strategy and move to higher energy density batteries (to improve the vehicle autonomy).As negative active material, graphite is mainly used. This historical material allows high energy density, and even high power applications. $Li_4Ti_5O_{12}$ is suitable for high power applications but its energy density is very low.

**Next generation Li-ion cells, post-Li-ion and post Li cells: For Short-term 2020,** Li-rich (***Li-rich =*** $Li_{1+x}M_{1-x}O_2$ (0<x<1/3 ; M = Mn, Ni,…) materials are currently one of the best solution for the cathode, whereas silicon based materials represent the best solution for the anode. Li-metal anode should also be considered again (even though suitable method(s) to mitigate hazardous reactions at the Li-metal/electrolyte interface need to be developed). On the long term (> 5-10 years) the availability and price of cobalt will be a major issue and research and development will enable a technology change towards materials with lower Co content in that timeframe. This will affect the cathode materials first, on the long run alternative technologies need to be developed with more sustainable compositions and systems which can replace lithium based batteries in certain markets to relieve pressure also from the Li availability situation.

The Na-ion technology is similar to Li-ion (the Li+ ion is replaced by a Na+ ion), improving safety, reducing cost, and could replace Li-ion for high power application (stationary storage and hybrid cars). Long-term 2030, conventional Li-ion could be substituted by lithium-sulfur offering 5 to 7 times the energy density. Unfortunately problems concerning the electrolyte, mechanical changes on the sulfur cathode material remain still unsolved. The Na-ion technology is similar to Li-ion (the Li+ ion is replaced by a Na+ ion), improving safety, reducing cost, and could replace Li-ion for high power application (stationary storage and hybrid cars). Long-term 2030, conventional Li-ion could be substituted by lithium-sulfur offering 5 to 7 times the energy density. Unfortunately problems concerning the electrolyte, mechanical changes on the sulfur cathode material and cycle life remain still unsolved. By 2040, lithium-air could theoretically reach the energy density of gasoline but there is still a long way to go to proof of concept

Other cells technologies are in different states of maturity. While Na-ion batteries have reached prototype cell fabrication, the first Mg batteries have been announced for commercialization in 2018 (HONDA), and first prototypic Mg-S pouch cells with 20 Ah format are currently developed in Germany. Reversible Zn air and Al- and Ca-ion cells offer a sustainable chemistry and very high theoretical energy densities but are still new, at low TRL levels and need to be further developed.

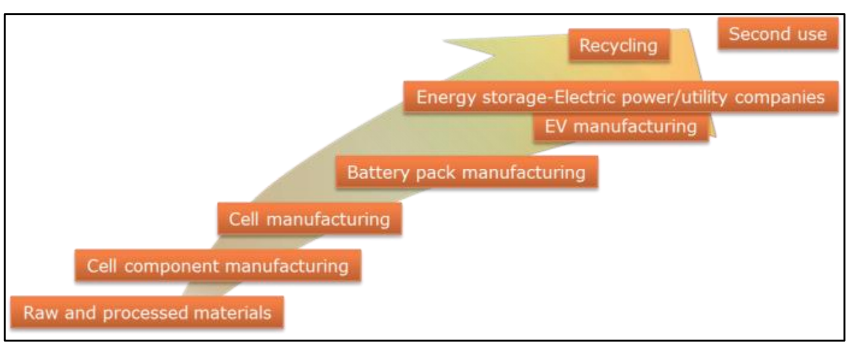
- **The battery system level**

A battery system consists of an assembly of cells connected in series and/or parallel to obtain the capacity and the voltage needed for the application. The cells and the system have a specific design to optimise heat dissipation. To control the whole battery system, a battery management system (BMS) monitors and limits voltage, current, and temperature, whereas the overall architecture (a cooling system can be used) offers the best environment for high performance and high safety. For a given cell chemistry and format, operational performance improvement measures target the overall mechanical, thermal and electrical architecture.

# ANNEX F - Approach and process for drafting the Implementation Plan

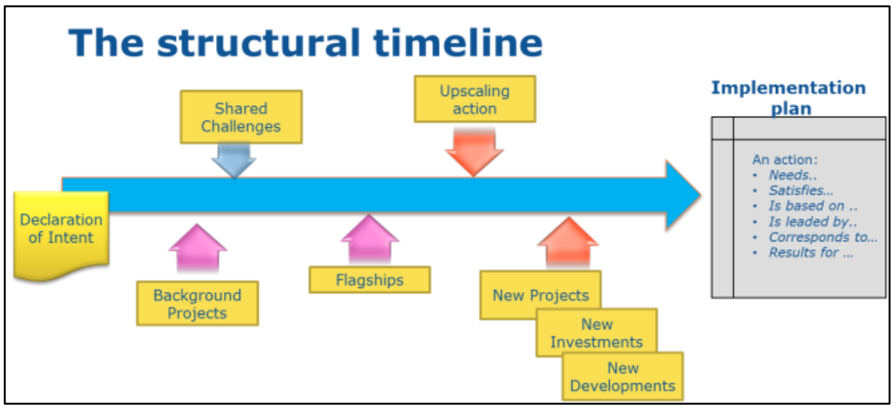
In discussing the scope of the IP, it was agreed from the outset to focus on challenges that could be best addressed and solved by exploiting and benefitting from the European context. In this respect, the need for establishing synergies between R&I actors along the full battery value chain to establish a strong European battery ecosystem covering battery development, battery production systems and battery recycling serves as the guiding principle for the IP and for establishing TWG membership.

Complying with this guiding principle, the TWG members involved in the development of the IP represent key actors in all segments of the overall battery value chain (see Annex A).



In line with the argumentation that led to the identification of the targets in the DoI, TWG members noted that Europe today already has a sustainable development and production of lead-based batteries, covering the entire value chain. It also has a strong position in developing/producing specific nickel, sodium and lithium based batteries for specific niche markets. Current European battery manufacturing industry is strong in developing tailored batteries based on specifications from customers and project developers, in a multitude of existing stationary, motive power and automotive markets. In full agreement with the DoI, the IP therefore targets lithium-ion and beyond lithium-ion battery chemistries for e-mobility and stationary storage applications.

The figure Structural Timeline highlights the main milestones in the IP drafting process. Important was the identification during the kick-off of shared challenges, as 'something that cannot be done alone'. These challenges have been continuously revisited during the IP drafting process and form the roots for the identification of the activities described further below.




As a necessary starting point for developing the Action 7 IP the TWG has made an inventory of existing battery initiatives - from individual, local, national to European level - covering Research & Innovation as well as the development of industrial infrastructures, with the aim to identify and develop activities which are mutually complementary and enhance existing ones. Analysis of these actions compiled by Member States and industry actors has revealed the following key opportunities for Europe:

- to organise through a shared roadmap the actions to be realised by the actors subscribing to the TWG and its follow-up, duly considering the need for direct collaboration between actors of adjacent segments (i.e. levels L-1 and L+1) of the value chain
- to develop an Education and Knowledge Value Chain as an overlay to the above network: education, permanent training, open teaching factories and skill management could represent a strong advantage compared to other regions of the word and a large pool of readily accessible competencies.

To check the soundness of activities for exploiting them as foundations for establishing a European value chain, a survey has been addressed to the Member States representatives and to the key actors along the battery value chain aimed at identifying ongoing and planned R&I activities or pilot lines eligible to become strategic building blocks and potential flagships for the IP.

A permanent monitoring of the proposed activities against the content of the DoI has been used throughout as quality check for the process.

Given the wide range of R&I topics to be considered for e-mobility and stationary storage, in order to streamline and accelerate the process, individual sub-groups have been tasked with the drafting of Activity Fiches for 3 focus areas: 1) **Material / Chemistry / Design + Recycling**; 2) **Means / manufacturing**; 3) **Application and integration**; in addition to identifying cross functional activities related to **Market / Market Access** and **Education and knowledge value chain**.

In addition to 3 in-person meetings in Brussels, webinars each 2 weeks allowed discussion of progress and to get reactions from the overall group of experts. When needed, telephone meetings were organised between the core team of chair, co-chair and the members of the Commission services involved. In the final stages of the drafting of the IP, the content of the proposed activity fiches has been quality-checked by the core team using a pre-defined set of indicators, and sub-group leaders have been requested to address the identified outstanding issues in the fiche descriptions.

# ANNEX G - Key findings from the preparation of the Implementation Plan

The following elements from the shared vision that has emerged during the discussions between TWG members have guided the formulation of the Implementation Plan:

- Holistic cooperation in R&I along the value chain is the only feasible way forward, including optimisation of the use of critical raw materials, of recycling and second use, and of cell design and manufacturing. In particular attention has to be paid on enhancing links between the R&I community and cell manufacturers.

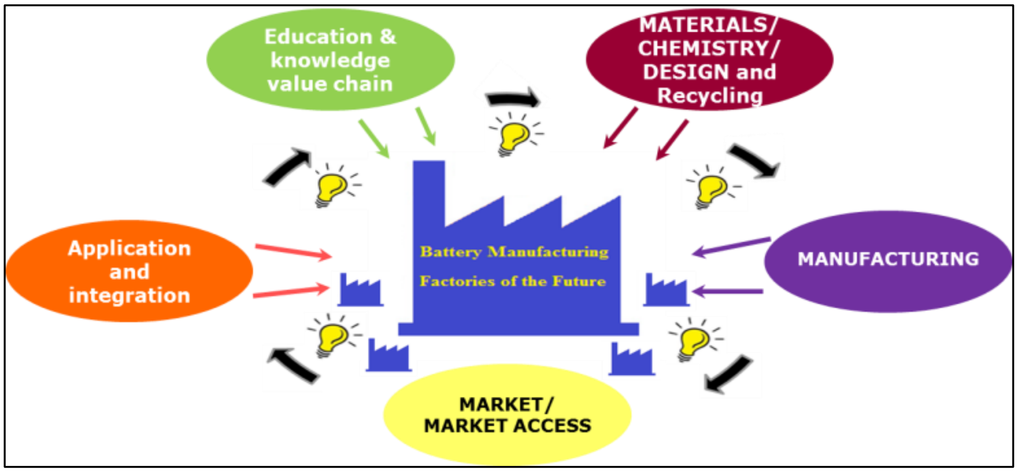
  *This allows addressing simultaneously and consistently the product (i.e. the battery), its components, as well as the process and the market. Only through such an approach, facilitated by an agile process involving key actors working actively together, can Europe become competitive in the battery sector.*

- It is necessary to cover mobility as well as stationary storage: with the uptake of electro-mobility, more renewable energy will be needed. Therefore, storage and balancing capacity should be reinforced on electric grids or at production plants. Batteries are a competitive and flexible alternative to grid extension in the EU.

  *Li-ion batteries (including so-called advanced lithium-ion batteries such as solid-state batteries) are projected to remain the dominant technology for EV applications for at least one decade. While stationary storage will benefit from technology developments driven by EV applications this does not preclude the development of alternative technologies for stationary applications when the performance characteristics better meet the needs of the application. This can be achieved through a specific technology or by hybridisation.*

- Support from EC and MS is a key success factor, *inter alia* through provision of financial support, and regulation (battery transportation, battery qualification for e-mobility and consequent safety regulation, etc).
- There is a need for development and sustained support to high-risk R&I activities (in order not to miss opportunities offered by emerging and potentially disruptive battery technologies)
- A tight coupling needs to be established between Research, Innovation and Education
- To succeed in the short term, all possible resources, from private and regional to European, should be mobilized.
- To not compromise the EU competitive position in the global market, due attention must be paid to appropriate management of IPR generated from the Implementation Plan activities.

The present Implementation Plan, containing activities in 5 focus areas as identified above (see figure below), fully reflects the conviction of TWG members that Member States, Associations and individual industry and research actors supported by the European Commission, can contribute to and indeed trigger the emergence of a world-leading battery cell industry in Europe through joint R&I efforts. TWG members realise that this can only be achieved by increasing and clustering cooperative European battery R&I efforts over the full value chain to achieve not only the quantitative targets but also the non-quantitative targets outlined in the DoI.




# ANNEX H - Statement on improving technological, economic, behavioural and social knowledge; training, capacity building and dissemination

During its working sessions, the TWG, and particularly EUA-EPUE, has identified the need to consider the following points as key differentiator for the EU battery Community:

- The ability to build an ecosystem of cooperation between research and academia covering the whole value chain.
- The ability to develop a strong knowledge base on all TRL levels in order to facilitate training of researchers, prototype developers, demonstration and factory designers.
- The ability to create a research and development environment which enables the identification of challenges in the area of materials performance and durability, of battery operating conditions and applications, of manufacturability, of safety, and of economic factors by performing fundamental and applied research, as well as implementation on all TRL levels.

The recommendations below will be organised as cross-functional activities developed into each activity and managed consistently.

The TWG emphasises that this cross-functional activities on "Improving technological, economic, behavioural and social knowledge; training, capacity building and dissemination" is essential for a successful and effective energy transition which cuts across all systems and technologies. In this sense, it is recommended that for a successful holistic approach on the battery value chain, the activities are devised in close collaboration with the activities, namely Materials, chemistry, design and recycling; Manufacturing; Application and integration. Similarly, it is emphasised that other SET-Plan Implementation Plans are developing similar Activities Fiches which intend to build knowledge, increase skills and capacity building26.

[26] *The SET-Plan TWG on Action 6 "Energy Efficiency in Industry" also includes an activity fiche dealing with "Improving exchange of technological, economic, behavioural and social knowledge; training, capacity building and dissemination" in its Implementation Plan which was adopted during the SET-Plan Steering Group meeting of 27 September 2017. Furthermore, the SET-Plan TWG on Action 3.2 "Smart Cities and Communities" is developing a fiche on "Capacity building and education – trainings and curricula that build future knowledge base".*

This is developed taking into consideration some of the main developments of the SET-Plan and the Energy Union with the objective of ensuring a coherent link with past and existing European initiatives in the field of Education, Research and Innovation. EUA-EPUE has for instance been engaging in several initiatives at the European level, aiming to support and inform political decision-making in the domain of energy (research) policy, including:

- the SET-Plan Education and Training Roadmap (2013)[27] and the SET-Plan Integrated Roadmap and Action Plan (2014)[28];
- the consultation process on the Energy Union Research & Innovation priorities and SET-Plan Key Actions (2015-ongoing);[29]
- the Public Consultation on the Development of an integrated Energy Union Research, Innovation and Competitiveness Strategy (2016).[30]

Specifically, the main focus of this cross-functional activity is on the importance of increasing skills in the battery sector as well as fostering collaboration between key stakeholders in view of replicability of success stories.

Specific cross-functional activities on how to concretely implement the goals are described by the deliverables below in the text.

### Skilled workers and researchers to increase competitiveness in the EU

The battery field is a very active area of research worldwide. For the EU to become competitive in the global battery sector, there should be a priority for educating European workers and researchers in the area.

In order to educate workers and researchers there needs to be at university level research in advanced types of battery systems for Electric Vehicle (EV), and also in static batteries that can be applied near fast charge stations. Competence necessary for advanced Battery Management Systems (BMS) is also extremely important.

Research should include to a greater extent than today the construction materials on cell and pack level, electric connectors etc. In addition, activities in the field of battery technology must be targeted towards scalable and low cost technologies, including abundant, environmentally friendly materials. Furthermore, knowledge about cell design is important. Cell developments must target designs that are recyclable.

To identify the potential impacts and opportunities of the growing market for automotive lithium-ion batteries, research could be devoted for instance to:

a) Conducting studies to identify the greenest, most economical mining, beneficiation and recycling processes;
b) Investigating recycling practices to determine how much of which materials could be recovered with current or improved methods;
c) Quantifying the environmental impacts of both battery production and recycling processes through sound life-cycle analyses;
d) Determining the material compositions needed to perform sound Life Cycle Assessments (LCAs) on different Li-ion battery chemistries.

### Collaboration between universities, institutes and industry; Dissemination and replicability of results:

In accordance with the principles of a circular economy, building an ecosystem of cooperation between academia and industry for sharing knowledge and increasing skills of students and workers is key. During scale up and long term testing, it is important to identify training and research opportunities to be performed in collaboration between industry, universities and institutes. The successful scale up of projects will lead to start-up of battery

27 https://setis.ec.europa.eu/setis-output/education-training-roadmap
28 https://setis.ec.europa.eu/set-plan-process/integrated-roadmap-and-action-plan
29 https://setis.ec.europa.eu/; http://uni-set.eu/index.php/resources/set-plan-input
30 http://uni-set.eu/images/uniset/Documents/EuaEpueEurics.pdf

businesses. Dissemination and training activities to a wider public (e.g. citizens, professional categories such as firework, police etc.) should become an integral part of the overall effort.

In terms of replicability of results, in regions where EV is already rolled out, and/or where renewable energy is implemented at significant scale of renewable electricity supply, business cases for battery storage will be more profitable. This battery storage may first involve implementation of smart EV charging solutions, using renewable electricity peaks, and it may involve a fast charge stationary battery network that will play a role in stabilising the grid and alleviate grid costs.

Impact will be measured in terms of successful results based on a monitoring mechanism. Furthermore, a positive impact can be observed when the actions detailed in section "Expected deliverables" contribute to targets in the Declaration of Intent, as for instance:

1) Performance targets: through increased provision of skills and improved energy culture
2) Reduced costs: through better business models; see in particular Deliverable 4
3) Improved manufacturing targets (e.g. storage, recycling, second life): through provision of skills and improved energy culture

This cross-functional activity foresees the following deliverables:

***1)*** **Training courses on batteries:**
   *a)* Development of courses such as: Basic electrochemistry courses, applied courses for batteries, courses on best practices in industry and laboratories, courses on modelling efforts. Also courses on business models dedicated to battery storage.

   These courses should be combined with research and training activities in appropriate education and training environments. The education can be provided for university students, students in a professional education, professionals and skilled workers in the battery field.

   *b)* Development of online training courses for battery.

***2)*** **Guidelines on multidisciplinary approaches** in higher education and research programmes (particularly in Master, Doctorate and Research Programmes) for renewable energy related programmes.
   a) These guidelines should become a reference point for the upgrade of existing programmes or the generation of new ones.
   b) An effective multidisciplinary approach should also include cooperation between faculties (e.g. chemistry, mechanical engineering, industrial design etc.)

***3)*** **Cooperation and dissemination activities:**
   a) Network of "teaching factories" along the whole value chain: Building an ecosystem of cooperation between academia and industry for sharing knowledge and increasing skills of students and workers. The approach should take into account realistic settings (e.g. labs) and a holistic view of the batteries sector.
   b) Workshops to facilitate interactions between academia and industry.
   c) Dissemination activities to a wider public (e.g. citizens, professional categories such as firework, police, start-ups, SMEs etc.)

***4)*** **Analysis of existing, and proposals for new, business and contracting models, taking into account organisational, financial, legislative, social and technological barriers.**
   a) This activity would contribute to optimising the introduction of battery storage applications in electrical transport and in static renewable electricity storage.

Stakeholders to be involved include:

- Universities and professional educations across the EU for the implementation of new educations and for providing R&I projects that train students, PhD students that will find subsequently jobs in industry.

- Industries involved in market development and implementation. They will build up the track records of best practices, safety aspects, commercial aspects, R,D&I of battery technologies. They employ educated workers, provide internships and research questions from the professional field.
- Research institutes that perform research and independent product quality checks and advise industries, governments on battery products, their characteristics, safety aspects etc.

# ANNEX I – Recent Commission activities on batteries

The Commission recognises batteries as a policy area which deserves particular attention, and has addressed the relevant policy challenges in a number of recent studies and publications.

The **Projects for Policy** (P4P) report[31] *'Batteries – a Major Opportunity for a Sustainable Society'* provides an overview of the portfolio of EU-funded projects, followed by an analysis of the impacts and results of EU funding in terms of the added value of research and innovation (R&I) investments and achievements. The report stipulates that strengthening competitiveness, promoting the circular economy and recycling, as well as reducing dependency on imported raw materials are the main policy challenges relevant to the batteries value chain. These three challenges are prominently addressed in the Implementation Plan for SET-Plan action N°7.

The **JRC Science for Policy Report**[32] *'EU Competitiveness in Advanced Li-ion Batteries for E-Mobility and Stationary Storage Applications –Opportunities and Actions'* focuses on competitiveness aspects related to batteries as a key enabling technology for electric mobility and stationary storage. The report identifies the conditions that have to be fulfilled for establishing a globally competitive LIB cell manufacturing chain in the EU, additional factors that can support the business case, and suggests measures that the Commission can take to support their realisation and thereby enable EU industry to take its share in a globally booming market. The report identifies two major conditions for domestic LIB cell manufacturing by European companies to be globally competitive: the risk for private investors has to be reduced and realising economies of scale must be made possible. The report recommends prioritising access to financing for the establishment of first-of-a-kind and pilot production lines based on the latest and best available technology. This report is a follow-up to another report *'Lithium ion battery value chain and related opportunities for Europe*' which provides an outline of the automotive Li-ion battery value chain identifying current market volumes, leaders and the status of the EU industry. The report indicates that EU industry is far from being self-sufficient in all segments of the value chain and that R&I investments are essential to respond to new opportunities presented by the EV market.[33]

Financial engineering is indeed a crucial element to implement the activities in the Implementation Plan for SET-Plan action N°7. In this context it is worth mentioning that under Horizon 2020, the **InnovFin EDP** (Energy Demonstration Projects) provides loans, loan guarantees or equity-type financing typically between EUR 7.5 million and EUR 75 million to innovative demonstration projects in the fields of energy system transformation, including batteries for both e-mobility and stationary storage, helping them to bridge the gap from demonstration to commercialisation. The product is deployed directly by the EIB.

As part of the Commission proposal on the revision of the EU emissions trading system (ETS) for the period after 2020, an **Innovation Fund** should support first-of-a-kind investments in renewable energy, carbon capture and storage (CCS) and low-carbon innovation in energy intensive industry. The European Parliament and Council proposed to enlarge the scope to include funding for **energy storage technologies**. On November 9th 2017, the European Parliament and Council reached a provisional agreement on the revised ETS. Once officially endorsed by both co-legislators, the revised EU ETS Directive will be published in the Official Journal of the Union and enters into force 20 days after publication.

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

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

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