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Solid-state-lithium-ion-batteries for electric vehicles



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Table of contents

Table of contents
Section 1.....
1. Background and objectives of the report.....	4
1.1 Background of this product report	4
1.2 Objectives of this report	7
Section 2.....
2. Value chain analysis	8
2.1 Value chain structure	8
2.2 Key actors in the value chain	9
2.3 Linkages along the value chain	20
Section 3.....
3. Analysis of EU competitive positioning.....	21
3.1 Strengths	23
3.2 Opportunities	23
3.3 Risks.....	24
3.4 Challenges	25
Section 4.....
4. Conclusion & Outlook	26
4.1 Conclusions	26
4.2 Outlook.....	27
4.3 COVID-19 and impact on solid-state-batteries	27
Section 5.....
5. Annexes	29
5.1. List of interviewees.....	29
5.2 Bibliography.....	29
About the 'Advanced Technologies for Industry' project	32

Section 1

1. Background and objectives of the report

Background

The Product Watch Reports have been developed in the framework of the 'Advanced Technologies for Industry' project and serve to identify and analyse 15 promising advanced technology (AT)-based products and their value chains, with an assessment of the strengths and weaknesses of the EU positioning.

Promising AT-based products can be defined as *"enabling products for the development of goods and services enhancing their overall commercial and social value; embedded by constituent parts that are based on AR/VR, Big Data & Analytics, Blockchain, Cloud, Artificial Intelligence, the Internet of Things (IoT), Mobility, Robotics, Security & Connectivity, Nanotechnology, Micro-nanoelectronics, Industrial Biotechnology, Advanced Materials and/or Photonics; and, but not limited to, produced by Advanced Manufacturing Technologies"*.

1.1 Background of this product report

Since the global demand for high-energy and high-power energy storage devices increased, lithium-ion (li-ion) batteries have emerged as the dominating energy storage solution for portable electronics and electric vehicles¹. With the objective of realising the green mobility transition and overcoming concerns about electric vehicles, e.g. with regards to their range, new technologies for lithium-ion-batteries are developed. Among these advanced battery technologies, is the solid-state-lithium-ion battery (SSB) as one of the most relevant approaches, promising greater security and performance.

Why choosing SSB among the different emerging battery technologies?

Significant research effort is dedicated world-wide to several future cell chemistries with the potential to outperform contemporary li-ion cells used in conventional batteries and to address their weak points².

A significant improvement in performance might be the introduction of pure li-anodes, which could be the mid- to long-term goal and might require the deployment of solid electrolytes³. On experimental scale, such batteries with pure-li-anodes and solid electrolytes already reach impressive energy densities, which make them very attractive for their use in cars.

Furthermore, solid-state-li-ion-batteries have the potential to address some of the major limitations of conventional li-ion-cells, especially their safety aspect. The liquid electrolyte used in conventional li-ion batteries, is flammable and corrosive, having led to several dangerous hazards in the past.

Definition of the product

In contrast to conventional li-ion-batteries, solid-state li-ion batteries are characterised by a solid not flammable electrolyte which also acts as separator. This allows for down-scaling to certain components by reducing passive components and to create cells with higher energy capacity per unit weight and volume. The solid-electrolytes are more tolerant to changes in temperature, physical damages, as well as to overcharging and deep discharging. In fact, they promise to be safer and more long-lasting compared to the conventional li-ion⁴. The major objectives for developing SSBs are improved safety, better performance and lower costs⁵. This could be achieved through improving the battery cell (higher energy density), the battery pack (focus on safety/ optimum cell integration) and the manufacturing equipment and processes (high throughput, reliability, safety).

The focus of this report will be on "bulk" solid-state batteries which can be operated at room temperature and are currently under development in the research and development (R&D) and pre-commercialisation phase. Instead, we do include thin-film solid-state batteries (micro batteries) only in those cases, where

¹ Qing Zhang, 2019

² European Commission, 2016

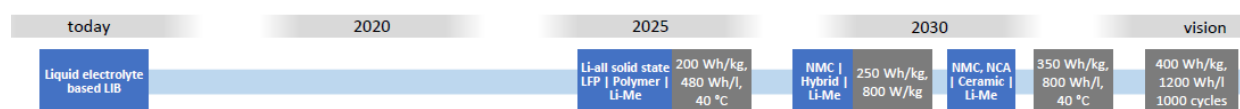
³ Thielmann, et al., 2020

⁴ YOLE, 2018

⁵ YOLE, 2018

new emerging approaches are conducted, and exclude those that are already commercially available e.g. for mobile devices.

Figure 1: Roadmap for High Energy Batteries 2030+



Source: Thielmann & Neef, 2019

Figure 1 shows the development towards high safety all-solid-state batteries as potential enabler for Li-metal anodes and the vision for their performance characteristics. SPE (Solid-polymer-electrolyte) SSBs have been demonstrated and produced on small scale (Technological Readiness Level (TRL): 7-8). Market introduction with competitive performance indicators might be possible by 2025+. Hybrid solid electrolytes and SCE (Solid-ceramic-electrolytes) are in applied research or basic research stage (TRL 5-6 and TRL 4 respectively)⁶.

Although there are still considerable R&D challenges, SSBs are on the roadmaps of most major li-ion-battery producers, but especially of original equipment manufacturers (OEMs). The target of SSB development is the enabling of li-metal anodes (dendrite suppression) resulting in very high energy density batteries with good safety properties. The target is to ultimately achieve energy densities of 400 Wh/kg, 1200 Wh/l with a cyclability of 1000 full cycles⁷.

Drivers for SSBs and relevant application fields

The **main technological drivers** for this emerging kind of li-ion-battery are higher energy density, greater safety and cost reduction, which in sum create the potential for greater added-value differentiation compared to competitors for potential users of solid-state-batteries. **Application areas** are currently most probable in the automotive sector in electric or hybrid vehicles. In the long-term applications in other areas such as aerospace, space and consumer electronics are possible, especially for wearables or drones⁸.

The **main market drivers** for the development of batteries are the regulations for emission control, the rising renewable energy generation and the need to create alternatives to fossil-fuel based energy. Especially for the mobility sector, which still represents a quarter of Europe's greenhouse gas emissions and presents a main cause of air pollution in cities, a transition towards sustainable electric mobility solutions is pushed forward by political actors⁹.

But even with increasing interest in hybrid and electric vehicles (EV), there are still consumer concerns regarding too short driving range and long charging time, which are supposed to be addressed by the potential use of SSBs.

This may be why SSBs are on the roadmap of many battery producers and OEMs. Their theoretical key performance indicators (KPIs)¹⁰ are very well suitable for electric mobility¹¹. EV-makers decide on mass commercialisation of SSB and will be the decisive element for the organisation of the supply chain, as they pose the requirements and make strategic decisions¹². Even though preliminary types of solid-state batteries with lithium-polymer materials (LMP-technology) are on the market since 2011 and used in electric buses, SSBs with hybrid or ceramic solid electrolytes, especially suitable for electric vehicles (EVs), are in the level of basic to applied research at the moment.

These drivers explain the focus of this report on the application of SSB in EVs.

⁶ Thielmann & Neef, 2019

⁷ Thielmann & Neef, 2019

⁸ IDTechEx, 2019

⁹ European Commission, 2020

¹⁰ volumetric and gravimetric energy density above 300Wh/kg and 500 Wh/l and respective power density

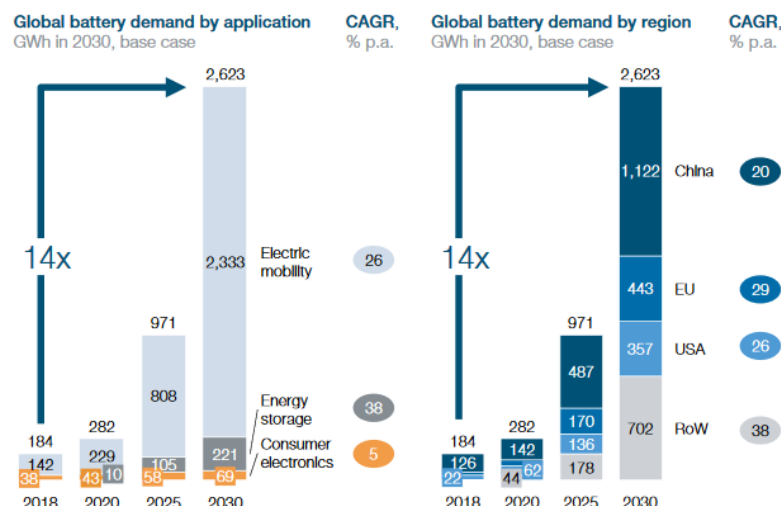
¹¹ Neef & Thielmann, 2019

¹² YOLE, 2018

Market volume for SSB

When considering the market for batteries in general, we can see that the battery demand by application will grow until 2030 to 2.6 Terrawatt hours (TWh), from which about 2.3 TWh will be for the EV-mobility sector. This is equivalent to a compound annual growth of the battery demand of 26% Compound Annual Growth Rate (CAGR)¹³.

Figure 2: Global Battery demand by application from 2018 to 2030



Source: World Economic Forum, 2019

For the part of solid-state-batteries in this market, it is still difficult to make projections to the future, although it will be significantly smaller, as SSBs will enter the market probably from 2025 on. IdTechEx Research forecasts the solid-state electrolyte industry to reach a market size over \$25 billion (€22.96 billion¹⁴) in 2029.¹⁵ Based on the hypothesis that the main technological barriers will be solved, the prospected demand for solid-state-batteries in electric vehicles will rise from 200 Megawatt hours in 2022 to 2 Gigawatt hours in 2025, which is equivalent to a CAGR of 118%¹⁶. However, this scenario is doubtful, when considering other sources, which see mass commercialisation of solid-state-batteries not before 2025, based on the observation of the efforts of relevant industrial and scientific actors¹⁷.

Still there remain severe technological challenges, as well as cost and supply chains issues. Leading players, developing SSB cell prototypes and testing initial batteries are forming supply chain partnerships to bring efforts together and accelerate the development and commercialisation, with especially growing interest from automotive companies. The increasing number of R&D-partnerships and large consortia has created a big momentum for SSB-technology, pulled by mobility applications¹⁸. Even if a lot of technical issues still have to be solved, there are recent commercialisation developments - e.g. the eCitaro bus by Daimler/Mercedes-Benz with a solid-state-li-ion-battery by Blue Solutions. However, the performance indicators still have to be proven in real-world practice.

Potential impacts and political efforts

For the input side of the value chain, especially the chemical sector, but also the mining sector will be affected. For the throughput-side of the value chain the development of SSBs will mainly affect the batteries industry, but also the mechanical engineering industry as a supplier of specific machinery as well as technology enabler. New processes for SSBs have first to be established in cooperation between these industries. On the output-side, for the industries in which solid state batteries will be applied, especially the automotive sector will be impacted.

¹³ World Economic Forum, 2019

¹⁴ equivalent to €22 962 625 000, when considering the exchange rate of 1\$ = 0,92€ from 20.04.20

¹⁵ IdTechEx, 2019

¹⁶ still representing only less than 1% of the total EV/HEV lithium-ion battery demand. Source: (YOLE, 2018).

¹⁷ Thielmann, et al., 2020

¹⁸ YOLE, 2018



As the World Economic Forum (WEF) states, "*batteries are a key technology to achieve the Paris Agreement and support the UN SDGs*"¹⁹. The European Union targets to have 20% of EVs in total vehicle sales by 2025. Some European governments and cities have announced that they intend to ban the sales of internal-combustion-engine (ICE) vehicles²⁰. For example many cities such as Copenhagen, Milan and Paris have signed the Fossil-Fuel-Free Street Declaration that bans ICE vehicles from 2030 on. France and Italy have already committed to 100% zero-emission vehicle sales by 2040²¹. McKinsey estimates that by 2040, about 70 percent of all vehicles sold in the EU will be electric, with rapidly improving economics. Under Horizon 2020, €114 million of funding were available for R&D on next generation batteries, while €500 million were requested in sum by applying actors. For the special field of solid-state-batteries, €25 million of funding were foreseen, while €101.9 million were requested by project proposals²².

1.2 Objectives of this report

The objectives of the remainder of this report are to map out the value chain of solid-state-li-ion-batteries and the key actors, provide an analysis of the EU's competitive positioning therein, and indicate related challenges and opportunities. This report therewith aims with an analytical and empirical approach to provide relevant stakeholders a clear overview of the current and future landscape of this technology in the EU. Analyses were based on desk-research, patent analysis and expert interviews.

¹⁹ World Economic Forum, 2019

²⁰ McKinsey, 2019

²¹ McKinsey, 2019

²² European Commission, 2019a, European Commission, 2019b

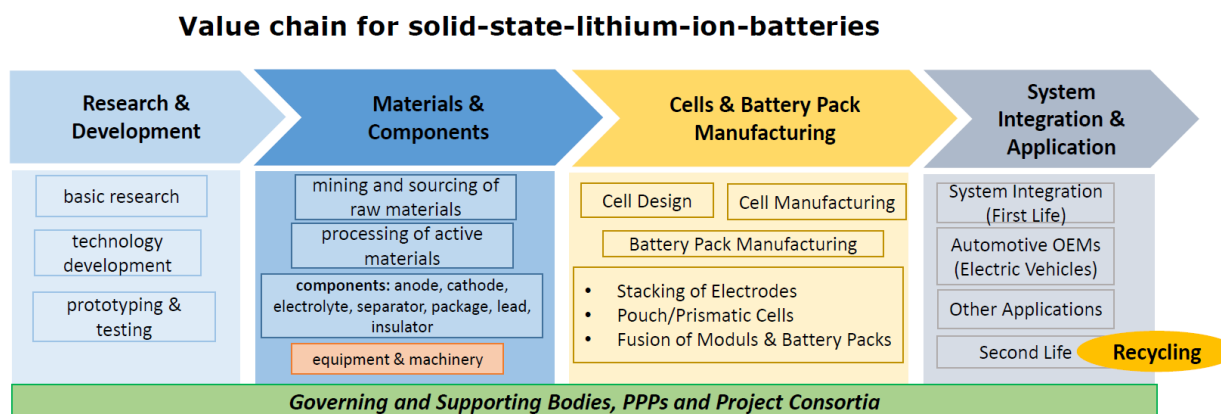
Section 2

2. Value chain analysis

2.1 Value chain structure

As mentioned above, the technology of solid-state-batteries is still under development and therefore no established value chain exists to date. However, the value chain of conventional li-ion-batteries (LIB) exists and can be taken as an orientation²³, also with the thought that relevant actors in LIBs are turning their focus on SSBs. The main assumption for the graphical representation of this emerging value chain is that R&D still plays a crucial role for the development of every step of the value chain, as well as funding bodies, public private partnerships (PPPs) and project consortia. Although R&D is important for all stages of this emerging value chain, it is indicated at the beginning as starting point for the development of the value chain for SSBs as shown in figure 3 below:

Figure 3: Structure and Characterisation of the Value Chain for SSBs



Source: Fraunhofer ISI, 2020

Equipment and machinery manufacturers are also relevant to the later steps of the value chain but are indicated in the group of material and component suppliers. As the exact manufacturing processes for SSBs are still not established, so is not the needed equipment and machinery yet.

With the development of SSBs, the processes and the process environment will change, but not the value chain of lithium-ion-batteries as such. Although several production steps on cell level might be transferable from LIB to SSB production, major changes will need to be introduced in electrode manufacturing, stacking and formation. Even if SSB-cells can be packed closer together, the casing will still be the same. Technologically there will not be a big difference, except the different materials. However, this would mean that production plants and machinery will have to change slightly, which causes reinvestment for firms.

Different possible cell chemistries for SSBs

SSB technologies include different groups. One of them already marketed since 2000 is the 100% solid li-metal polymer (LMP) technology²⁴. However, LMP is not considered sufficient from its performance so other groups are further developed. In the Call "*Strongly improved, highly performant and safe all solid-state batteries for electric vehicles*" (Research and Innovation Action under Horizon 2020)²⁵ three dominant categories of solid electrolyte materials are mentioned:

- 1) **inorganic** electrolyte materials (crystalline/amorphous): without organic components and based on Li-metal anode and solid ceramic electrolytes (e.g. oxide, sulphate, phosphate based),

²³ See also the presentation of the li-ion-battery value chain in the JRC-Report (European Commission, 2016)

²⁴ Hettesheimer, Thielmann, Neef, & Durand, 2019

²⁵ European Commission, 2018

shall bring high safety and high energy density batteries. Here often high temperature sintering steps are required.

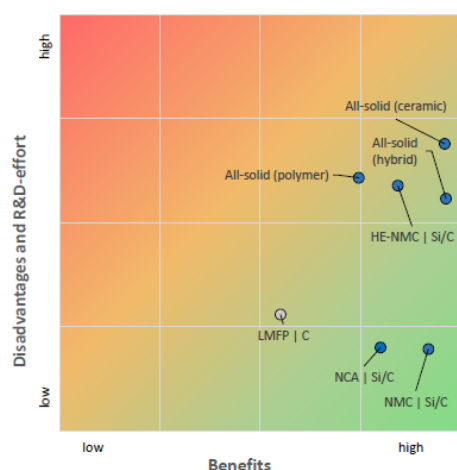
2) (**organic**) solid polymers/polymeric materials: based on Li-metal anodes and polymeric/salt (e.g. Polyethylene oxide) have a high potential to be used with existing production equipment (e.g. roll to roll). Problematic is the low ionic conductivity at room temperature, which implies that batteries require external heater. LMP-based batteries already exist on the market with Blue Solutions²⁶.

3) all solid-state **hybrid** systems: which would be based on Li-metal-anode and solid ceramic electrolyte embedded in a polymeric matrix, could bring higher safety, higher energy density for SSBs. They have the potential to be used with the existing production equipment.

As in conventional LIB, the cathode active materials in SSB are metal oxides. Here almost no materials have been developed specially for the SSB, the perfect material combination is still to be found. For the automotive market, it is estimated, that SSBs will only be successful when Li-Nickel Manganese cobalt Oxide (NMC) or Li-Nickel-Cobalt-Aluminium Oxide (NCA) will be used.

Lithium Anodes have the theoretical capacity to achieve highest energy densities, but they tend to form dendrites which must be prevented by the solid electrolyte. They must also be handled in inert atmosphere, as the lithium forms a passivating layer with the ambient oxygen.

Figure 4: Graph on comparison of high energy battery approaches



Source: Thielmann & Neef, 2019

Figure 4 shows the balance between benefits and the disadvantages and the R&D-efforts of different technologies and materials for li-ion-batteries. It is indicated that the deployment of SSBs is still associated to considerable R&D effort and expenses. The biggest challenges are seen in the development of suitable large-scale manufacturing techniques for electrodes and cells. Particularly the processing and compaction of ceramic layers in solid composite electrolytes (SCE) are seen as a major challenge. Ceramic solid electrolyte materials are still in development and processes for electrode production are not yet established²⁷.

In the following, the different steps of the value chain will be explained in more detail. Under each step of the value chain the most relevant active actors will be listed.

2.2 Key actors in the value chain

Focussing mainly on Europe, the main stakeholders relating to the various groups depicted in the SSB-value chain are mapped out below²⁸. As to distinguish between EU and non-EU companies, those with their headquarters located in the EU are indicated in blue. Actors were identified by desk-research,

²⁶ <https://www.pv-magazine.com/2019/06/03/blue-solutions-on-why-its-betting-on-solid-state-batteries/>

²⁷ Thielmann & Neef, 2019

²⁸ As the SSB activities of the actors are not in all cases well known or clearly visible, additional explanations of their research focus / activities on SBB are provided in the tables

patent analysis and analysis of relevant market studies. The definition of types of actors follows the depicted value chain structure.

2.2.1. Research & Development (R&D) Players

It has to be stressed, that R&D is still the most important and the only really established part of the value chain for SSBs. The perfect material combination for a high energy density and other targeted properties is still to be found. For the landscape of solid electrolytes for li-ion Solid-State Batteries around 5 800 patents grouped in 2 460 patent families can be found. Behind these patents are more than 1 140 patent applicants²⁹. This shows that there is still a high diversity of different approaches.

Research landscape and relevant players

The strongest R&D-Players in 2018 identified by Yole Development were in the US, Europe and Japan³⁰. As there are so many actors in the research on SSBs, here only the most relevant European Players in R&D are listed³¹.

Before, a short overview of R&D-Players outside the EU is given:

- **US:** Texas University Austin, University of Michigan, University of California, University of Houston, University of Colorado Boulder, Washington State University, Stanford University, Oak Ridge, Massachusetts Institute of Technology.
- **Japan:** Osaka prefecture university, Tokyo Institute of Technology, TOHOKU University, KEK, AIST.
- **UK:** of Oxford, Imperial College London, University of Bath, Lancaster University, University of Glasgow, UCL, Warwick University, University of Southampton, University of Cambridge.

Table 1: Relevant R&D players

Institution	Research Focus/Activities on SSB	Country	Website
CEA LETI	Coordination of the ASTRABAT-Project. CEA LETI Research Center for microelectronics has developed the world's first solid-electrolyte microbattery for specific healthcare applications (thin film batteries) ³² .	France	http://www.leti-cea.com
CNRS	Different patents and activities in the field of solid-state-battery technology.	France	http://www.cnrs.fr/
CIDETEC	Technology Center with strong Energy Storage department, developing gel electrolyte for hybrid solid-state-batteries.	Spain	https://www.cidetec.es
CIC energigUNE	Research center with strong focus on solid-state batteries, leading different projects such as SAFELIMOVE. CIC energigUNE drives a solid-state battery manufacturing facility called Basquevolt that will be launched in 2021 in cooperation with Innoenergy.	Spain	https://cicenergigune.com/en
Research center Jülich	Developed with MEET a high-energy solid-state-battery with	Germany	https://www.fz-juelich.de

²⁹ Research and Markets, 2019

³⁰ YOLE, 2018

³¹ based on YOLE (2018) and a patent analysis based on PATSTAT and WPI

³² http://www.cea-tech.fr/cea-tech/english/Pages/ec_2019/world-first-miniaturized-solid-electrolyte-microbatteries-energy-micro-sources.aspx

Institution	Research Focus/Activities on SSB	Country	Website
	pure lithium anode and a hybrid electrolyte ³³ .		
Fraunhofer Gesellschaft	The Fraunhofer Battery Alliance, consisting of 20 Fraunhofer institutes, researches in the field of electrochemical energy storage devices. The Institute CES, IKTS, ISC, IWM searching on solid-state-batteries. Fraunhofer ISC is developing ceramic electrolytes, recently the most active in SSBs-R&D ³⁴ .	Germany	https://www.fraunhofer.de/
University Of Gießen	Coordination of the FestBATT-Project, research on physical and chemical properties of solid-state-processes. ³⁵	Germany	https://www.uni-giessen.de
KIT Karlsruhe	Several research projects on solid-state batteries, especially FELIZIA and FestBATT.	Germany	https://www.kit.edu
MEET Münster	Working on innovative electrochemical energy storage devices with high energy density, longer durability and maximum safety. Partner in FESTBATT.	Germany	https://www.uni-muenster.de/MEET/
University of Delft	Research on solid electrolyte combinations, including highly conductive li-ion solid electrolytes, based on ceramic and glassy li-conducting sulphides and li-conducting polyelectrolytes based on alginates and SPEEK ³⁶ .	The Netherlands	https://www.tudelft.nl/en/
TNO/Holst Centre	TNO with support of the Dutch government, is investing in a pilot line for new 3D solid-state li-ion batteries ³⁷ . A Spin-Off will be launched in the next months.	The Netherlands	https://www.holstcentre.com/
IMEC	Developed solid-state-battery with energy density of 400 Wh/L, which can be recharged in 2 hours ³⁸ .	Belgium	https://www.imec-int.com/en
Université Catholique de Louvain	Has developed a new solid electrolyte with the university of Graz and Munich, patent for the discovery of LTPS ³⁹ .	Belgium	https://uclouvain.be/en

33 <https://www.fz-juelich.de/SharedDocs/Pressemitteilungen/UK/EN/2019/2019-02-26-high-energy-solid-state-battery.html>

34 https://www.batterien.fraunhofer.de/en/battery_network.html

35 <https://www.uni-giessen.de/fbz/fb08/Inst/physchem/janek>

36 <https://www.tudelft.nl/en/faculty-of-applied-sciences/about-faculty/departments/radiation-science-technology/research/research-groups/storage-of-electrochemical-energy/research/solid-state-batteries/>

37 <https://www.tno.nl/en/about-tno/news/2020/6/new-investment-in-holst-centre-s-new-generation-battery-technology/>

38 <https://www.electrive.net/2019/06/20/imec-verdoppelt-energiedichte-von-festkoerper-zellen/>

39 <https://uclouvain.be/en/discover/press/news/a-new-material-for-the-battery-of-the-future-made-in-uclouvain.html>

Institution	Research Focus/Activities on SSB	Country	Website
Research Projects on SSBs and their R&D-Partners			
ASTRA-BAT	The European funded project ASTRABAT aims to develop optimal materials for solid-state-batteries, optimal components and designs, that can be deployed in mass-production.		https://astrabat.eu/
	Politechnika Warszawska	Poland	https://www.pw.edu.pl/
	Université de Limoges	France	https://www.unilim.fr/
	Leitat Technological Center	Spain	https://www.leitat.org
FELIZIA	FELIZIA - solid state electrolytes for the next Generation of li-ion-cells. Other Partners involved: BMW, BASF, SCHOTT, Rockwood Lithium, Volkswagen.	Germany	https://batterie-2020.de/english/materials-for-secondary-high-energy-and-high-power-batterysystems/
ARTEMYS	Research institutes (Fraunhofer IKTS) and industrial partners (BMW, BASF, Thyssenkrupp, Rehmann Thermal Systems) working on the development of materials and production technologies for all solid-state-batteries, especially with all-ceramic electrolyte.	Germany	https://batterie-2020.de/projekte/forschungsfelder/hochenergie-und-hochleistungsbatteriesysteme/artemys-fertigung-von-assb/
FestBATT	Cluster of Competence for Solid-State-Batteries in Germany:	Germany	https://festbatt.net/cluster
	University of Marburg	Germany	https://www.uni-marburg.de
	University Duisburg-Essen	Germany	https://www.uni-due.de/
	TU Darmstadt	Germany	https://www.tu-darmstadt.de/
	TU Braunschweig	Germany	https://www.tu-braunschweig.de/
	Max-Planck-Institute Stuttgart	Germany	https://www.mpi-stuttgart.mpg.de/
	Helmholtz Institute Ulm	Germany	http://www.hiu-batteries.de/battery-research-center-in-germany/
	Helmholtz-Institute Münster	Germany	https://www.fz-juelich.de/iek
IE4B	Objective is to create the basis for the production of the next generation solid-state-batteries for electric cars:		
	Eidgenössische Materialprüfungs- und Forschungsanstalt (EMPA)	Switzerland	https://www.empa.ch
	Fraunhofer ISC	Germany	https://www.isc.fraunhofer.de/
SOLIDIFY	In the EU funded project, new materials and manufacturing processes are developed to find a new technology for the production of liquid-processed solid-state-bodies.	EU	https://solidify-h2020.eu/

Institution	Research Focus/Activities on SSB	Country	Website
SUBLIME	EU-funded project on the development of the next generation sulphide electrolyte for SSBs in EV applications-	EU	https://sublime-project.eu/
SAFELIMOVE	H2020 project that will develop new solid-state-based technology to produce a safe, reliable and high performing battery for electric vehicles.	EU	https://safelimove.eu/

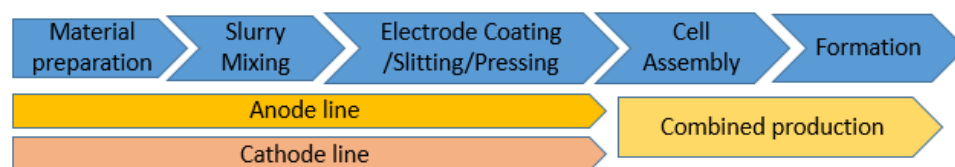
Source: Fraunhofer ISI, 2020

2.2.2. Materials & Components

Raw Materials. Depending on the type of used cell chemistry and electrolyte for the SSBs, different raw materials are needed. These raw materials, such as lithium, cobalt, nickel and manganese, have to be mined and sourced (often in countries with low environmental and social standards, which can create negative impacts at this stage of the value chain). Especially for the extraction of lithium negative impacts for local environment and populations has been reported, especially from Chile, Argentina and China⁴⁰. As the extraction of lithium is highly problematic due to difficult working and environmental conditions, research on alternative materials is going on⁴¹.

Processing of Active Materials. The raw materials are processed by the chemical industry to active materials. In some cases, it is the recycling industry that is re-processing 2nd life batteries to extract and recycle the needed materials. For the production process of the active materials of anode and cathode, the refined metals are dissolved to salt solutions. Then the salts solutions are mixed together and lithium is added. The solution is further mixed, dried and sintered to a fine powder of active material. When the preparation of the materials is completed, the active material is combined with additives and mixed to homogenous slurry.

Figure 5: Simplified production process of battery-cells



Source: Fraunhofer ISI, 2020

Production process. For the production of the battery cell out of the active materials, the different components of the cells (anode, cathode, electrolyte, separator) have to be produced. Also, other components such as the casing, package, the lead and the insulator are needed for the later integration of the cells into the battery packs. Besides that, specific equipment and machinery are needed for the manufacturing process of the cells and battery packs.

Difference to conventional LIBs. Cell components for solid-state-batteries might differ slightly with different current collectors at the anode, different binders, no liquid electrolytes and different kinds of protective layers at the electrodes. As the perfect material combination for electrodes and the solid electrolyte for SSBs still have to be found, there are only very few actors "specialising" in the production of materials or components especially for SSBs, as there is no market yet. However, research and pilots are done on small scales and OEMs are already working with their suppliers on solutions for SSBs. For a mass market application of SSBs in EVs, battery cells with hybrid or ceramic solid- electrolyte are estimated to be best suited and could be established from 2030 on⁴².

⁴⁰ An overview on consequences of the extraction of lithium and other raw materials can be found here: <https://ejatlas.org/>

⁴¹ European Commission, 2016

⁴² Fraunhofer ISI, 2017

Material costs make up for the largest share: from ~60% to >80% share of cell costs. The production of Li-metal anodes might, depending on their design, also add to the cost if larger amounts of expensive Lithium are needed. In the cathode active material, the tendency and objectives are to reduce cobalt content and nickel and in the long-term to deploy more manganese-based materials, in order to decrease costs.⁴³

Materials for the production of a polymer electrolyte are easily available, but they may not be suited for use in consumer EVs. Production of solid-polymer-electrolyte (SPE)-batteries could be established within the EU⁴⁴ for applications in the area of stationary storage and fleet vehicles such as city buses or last-mile delivery trucks.

Table 2: Companies active in materials & components

Company ⁴⁵	R&D/Activities on SSB	Country	Website
BASF Battery Materials	Joint laboratory with KIT: BELLA; research on innovative cathode materials for the next generation of li-ion-batteries ⁴⁶ ; planned battery material production in Finland with Norilsk Nickel.	Germany	https://catalysts.basf.com/
SCHOTT	FELIZIA project, develops glassy ceramic material for solid electrolyte. ⁴⁷	Germany	https://www.schott.com
Solvay	Is participating in the alliance with SAFT, Siemens and Manz to develop advanced high-density li-ion and solid-state technology. ⁴⁸	Belgium	https://www.solvay.com
UMICORE	Participates in the Battery-IPCEI consortium, in the part of "raw & advanced materials". Part of SOLIDIFY and ASTRABAT.	Belgium	https://www.umicore.de/
Northvolt	Northvolt anticipates the switch-over to solid-state batteries and will use supply from Europe's first lithium mine in Finland. ⁴⁹	Sweden	https://northvolt.com/
Ionic materials	Patented breakthrough polymer (solid electrolyte); partnering with the cell manufacturer A123 Systems; investment from Renault and Nissan. ⁵⁰	US	https://ionicmaterials.com/
NEI Corporation	Involved in producing different compositions of sulphide-based solid electrolyte materials.	US	https://www.neicorporation.com
Pathion	Develops a superionic solid electrolyte material.	US	https://www.pathion.com
Applied Materials	Developing electrolyte materials for SSB, Project IE4B with Fraunhofer ISC in Germany.	US	http://www.appliedmaterials.com/
Dana Incorporated	Supplier of cell components to Hydro-Québec, which is developing electric vehicles with solid-state technologies.	US	https://www.dana.com/
Wildcat Discovery Technologies	Received grant from US Department of Energy for discovery of materials for an all-solid-state battery.	US	http://www.wildcatdiscovery.com

⁴³ Fraunhofer ISI, 2018

⁴⁴ Hettesheimer, Thielmann, Neef, & Durand, 2019

⁴⁵ Main brands will not be listed, as in most of the cases companies have not yet commercialised a product. Instead, a short description of their main activities regarding solid-state- li-ion batteries is given.

⁴⁶ <https://www.basf.com/global/de/media/magazine/archive/issue-5/developing-the-batteries-that-will-drive-the-future.html>

⁴⁷ <https://www.schott.com/innovation/de/elektrisiertes-pulver/>

⁴⁸ <https://www.solvay.com/en/innovation/science-solutions/fast-charging-safe-batteries>

⁴⁹ <https://europe.autonews.com/automakers/france-germany-agree-first-battery-cell-consortium-report-says>

⁵⁰ <https://www.elektroniknet.de/elektronik-automotive/elektromobilitaet/hyundai-investiert-in-ionic-materials-155531.html>

Company ⁴⁵	R&D/Activities on SSB	Country	Website
MANZ	One of the leading providers of production equipment for li-ion battery cells, modules and packs as well as for capacitors.	US	https://www.manz.com
Hydro-Québec	Has been leading research on advanced battery materials and new battery technologies, including solid-state devices, now cooperating with Mercedes-Benz. ⁵¹	Canada	https://www.hydroquebec.com
Ganfeng Lithium	Announced to start operations at a 100 MWh capacity pilot production line for SSBs this year; cooperation with Volkswagen. ⁵²	China	http://www.ganfenglithium.com
GS Yuasa	Works on silicon metal electrode to be used in SSBs.	Japan	https://www.gs-yuasa.com
Toray	Establishes a new production facility for battery separator film in Hungary.	Japan	https://www.toray.com/
Kuraray	Supplying active materials and components for solid-state-batteries.	Japan	https://www.kuraray.eu/
Asahi KASEI	Develops advanced materials for battery manufacturing; research project together with MEET Münster in Germany.	Japan	https://www.asahi-kasei.eu/

Source: Fraunhofer ISI, 2020

2.2.3. Cells and Battery Pack Manufacturing

Under this section, actors who are active in cell design and manufacturing (prototyping) of SSB-battery cells are presented.

The manufacturing methods for SSB depend on the final choice of the electrolyte material. The production of SSBs can be divided into three overall steps: active material, electrode and electrolyte production, cell assembly and cell finishing. For SSBs a generally valid process does not yet exist. Instead, a large number of alternative process chains may be applied, which differ in part from the manufacturing process of a conventional li-ion-battery. There could be different processes possible, which differ primarily depending on the electrode and electrolyte production⁵³.

In contrast to bulk SSBs for applications in EVs as focused in this report, solid-state microbatteries are already produced in the EU, e.g. by the French company Iten, but they are aimed to be used in autonomous sensors, smart cards or bio-electronics⁵⁴.

Table 3: Companies active in cells and battery pack manufacturing

Company	R&D/Activities on SSB	Country	Website
Blue Solutions (Bolloré Group)	LMP-technology (all-solid-state-li-metal-polymer) on the market since 2011. Now selling its solid-state batteries to Daimler for the eCitaro-bus.	France	https://www.blue-solutions.com
Envites Energy	Patented in 2019 a new, efficient manufacturing technology for solid-state-batteries (prismatic and pouch cells).	Germany	https://www.envites.de/
SAFT (Total)	Alliance with Siemens, Solvay and Manz to develop a new generation of batteries based	France	https://www.saftbatteries.com/

⁵¹ <https://www.pv-magazine.com/2020/02/05/mercedes-benz-teams-up-with-hydro-quebec-for-solid-state-battery-development/>

⁵² <https://www.pv-magazine.com/2019/08/29/ganfeng-lithium-prepares-solid-state-battery-test-line/>

⁵³ PEM of RWTH Aachen and VDMA, 2018

⁵⁴ <https://www.eenewspower.com/news/iten-starts-production-solid-state-microbatteries>

Company	R&D/Activities on SSB	Country	Website
	on advanced high-density li-ion and solid-state technology.		
Ilika	Developed Micro SSB (Strearax for powering wireless sensors), participated in Goliath project and aims to produce solid-state-batteries in 2022/2023.	UK	https://www.ilika.com
A123 Systems	Cooperation with Ionic Materials, advanced conductive polymer with NMC/graphite li-ion chemistry. Envisioning market launch in 2022 ⁵⁵ .	US	http://www.a123systems.com/
Bright Volt	Patented polymer matrix electrolyte for solid state lithium polymer batteries.	US	https://www.brightvolt.com
Johnson Battery Tech	Produced thin-film batteries of various sizes, now focusing on solid-state batteries with ceramic electrolyte.	US	https://www.johnsonbatterytech.com
AdaVolt	New low cost, high rate vapor phase process that is ideal for depositing battery materials, developing solid-state Li-ion batteries.	US	http://www.adavolt.com
QuantumScape	In 2019, Volkswagen established a joint venture with QuantumScape Corporation for research and production of SSBs. ⁵⁶	US	https://www.quantumscape.com/
SolidEnergy	Semi-solid-li-Metal cell, which could be demonstrated in 2018, first application in drones, but aim is to get the battery into EVs by 2021. ⁵⁷	US	https://www.ses.ai/
Solid Power	Roll-to-roll pilot production facilities for SSBs. Cooperation with BMW and Ford to develop SSBs for the next-generation EVs. ⁵⁸	US	https://www.solidpower.com
ProLogium	R&D on ceramic solid electrolyte and production of battery packs. ⁵⁹	Taiwan	http://www.prologium.com/
CATL	Leading battery cell vendor in the world by gigawatt-hours per year delivered, working on SSBs manufacturing.	China	https://www.catlbattery.com

55 <https://www.globenewswire.com/news-release/2019/06/24/1873229/0/en/A123-Systems-and-Ionic-Materials-Advance-All-Solid-State-Battery-Development-Using-Solid-Polymer-Electrolyte-with-Conventional-Lithium-ion-Electrodes.html>

56 <https://www.volkswagenag.com/en/group/the-a-to-z-of-e-mobility/s-is-for-solid-state-battery.html>

57 <https://spectrum.ieee.org/energy/environment/first-semisolid-lithium-batteries-to-debut-this-year-in-drones>

58 <https://www.dailycamera.com/2019/08/12/solid-power-showcases-facility-solid-state-battery-work-to-local-state-officials/>

59 <https://www.electrive.net/2020/01/06/ces-prologium-zeigt-feststoff-batteriepakete/>

Company	R&D/Activities on SSB	Country	Website
LG Chem	Cooperates with Samsung SDI to develop solid-state-batteries for EVs until 2025, will found a company with General Motors. ⁶⁰	South Korea	https://www.lgchem.com
NGK Insulators LTD	Manufacturing of large-capacity batteries, using beta-alumina solid electrolyte.	Japan	https://www.ngk-insulators.com
Panasonic /Sanyo	Joint venture together with Toyota for the production of SSBs (Prime Planet Energy & Solutions). Patenting activity on solid electrolytes.	Japan	https://tech.panasonic.com
Prime Planet & Energy Solutions	Joint venture between Toyota and Panasonic, focus on the development and manufacture of prismatic li-ion batteries, as well as solid-state and "next-generation" batteries.	Japan	https://www.electrive.com/2020/02/03/toyota-panasonic-battery-joint-venture-to-launch-in-april/
NEDO (New Energy and Industrial Technology Development Organisation)	Japanese state agency is developing li-ion solid-state batteries for application in electric vehicles with the target for production in 2022 together with 23 automobile, battery, material manufacturers as well as 15 universities and public research institutes. Among others, these are the main battery manufacturers:	Japan	https://www.nedo.go.jp/english/
	Murata Manufacturing Co. Ltd.		https://www.murata.com/
	Panasonic Corporation		https://www.panasonic.com/
	Fujifilm Corporation		https://www.fujifilm.com/
	Idemitsu Kosan Co.		https://www.idemitsu.com/
	Toshiba		https://www.toshiba.de/

Source: Fraunhofer ISI, 2020

Companies which have patents, but seemingly no more recent or visible activity in solid-state-li-ion-batteries: BYD Company Limited (China) and Nanotek Instruments (US). Bosch GmbH acquired the battery technology start-up SEEO for developing solid-state-batteries, but sold it in 2018, because the company estimated that the economic risks would be too dangerous, as the operating costs for the commercialisation of solid-state-cells were still too high⁶¹.

2.2.4. System Integration and application of SSB: Automotive OEMs

Largest interest in SSBs has been displayed by automotive OEMs, especially those in Japan, Korea and Europe⁶². EV-makers, such as Toyota, VW, Dyson and BMW are driving SSB commercialisation. These automotive OEMs are the future system integrators of SSBs and therefore decide on mass

60 [https://m.futurecar.com/3647/General-Motors-&LG-Chem-Are-Investing-up-to-\\$2-3-Billion-in-New-EV-Battery-Joint-Venture](https://m.futurecar.com/3647/General-Motors-&LG-Chem-Are-Investing-up-to-$2-3-Billion-in-New-EV-Battery-Joint-Venture)

61 <https://insideevs.com/news/334935/bosch-disbands-internal-battery-cell-research-will-sell-solid-state-startup-seeo/>

62 YOLE, 2018

commercialisation. They have a decisive influence on the organisation of the supply chain, as they give the requirements. This is why the final market-uptake could strongly depend on strategic decisions of OEMs. OEMs could launch SSB as optional battery in form of a premium option, which would also allow for low manufacturing volumes in the beginning. Many automotive players are aiming to get into the market with SSB-powered EVs between 2022-25⁶³.

Table 4: Automotive OEMs

Company	R&D/Activities on SSB:	Country	Website
BMW	Investment in <i>Solid Power</i> for developing high-capacity li-metal anode in a solid-state cell with an energy capacity "2-3X higher" than conventional li-ion-batteries ⁶⁴ .	Germany	https://www.bmw.de
Mercedes-Benz AG (Daimler)	Cooperation with <i>Hydro-Quebec</i> for the development of solid-state-batteries. The new eCitaro is the first series production city bus equipped with solid-state batteries free of cobalt (2020). ⁶⁵ .	Germany	https://www.daimler.com/
PSA Group (Opel)	Participates in the ASTRABAT project on solid state batteries.	France	https://www.groupe-psa.com
Volkswagen	Investment in <i>QuantumScape</i> and aims to bring first EVs with solid-state battery on the market in 2025.	Germany	https://www.volkswagenag.com/
Ford	Ford invests in <i>Solid Power</i> to develop next generation solid-state-battery for EVs. ⁶⁶	US	https://www.ford.com/
General Motors	GM has won state grants to develop solid-state-li-ion-batteries ⁶⁷ .	US	https://www.gm.com/
Fisker	Currently developing the EMotion luxury electric car based on solid-state-batteries, which could reach up to 750km range.	US	https://www.fiskerinc.com/
Honda	Works with <i>Toyota</i> and <i>Nissan</i> on solid-state-battery technology ⁶⁸ .	Japan	https://global.honda/
Hyundai / KIA	Investment in <i>Ionic Materials</i> to develop solid-state-batteries for EVs ⁶⁹ .	South Korea	https://www.hyundaimotorgroup.com/
Nissan	The Renault-Nissan-Mitsubishi Alliance and Hyundai Motor Group are investing in <i>Ionic Materials</i> a U.S. battery technology start-up ⁷⁰ .	Japan	https://www.nissan-global.com/
Toyota	Toyota is developing solid-state-li-ion batteries in a joint venture with Panasonic (Prime Planet Energy), focusing on sulfur-based electrolytes and aiming to start series production in 2025.	Japan	https://global.toyota/en/

⁶³ Navigant Research, 2019

⁶⁴ <https://electrek.co/2017/12/18/bmw-solid-state-batteries-next-gen-electric-cars/>

⁶⁵ <https://media.daimler.com/marsMediaSite/en/instance/ko/Immediately-before-the-rollout-the-new-fully-electric-articulated-bus-the-Mercedes-Benz-eCitaro-G-with-innovative-solid-state-batteries.xhtml?oid=47447805>

⁶⁶ <https://www.cleantalking.de/solid-power-ford-investiert-festkoerperbatterien/>

⁶⁷ https://www.greencarreports.com/news/1124702_gm-wins-us-grant-to-develop-solid-state-batteries

⁶⁸ <https://www.cnet.com/roadshow/news/toyota-nissan-honda-libtec-solid-state-battery-development/>

⁶⁹ <https://www.automobil-produktion.de/zulieferer/hyundai-investiert-feststoff-batterie-spezialist-ionic-materials-130.html>

⁷⁰ <http://www.businesskorea.co.kr/news/articleView.html?idxno=42752>

Company	R&D/Activities on SSB:	Country	Website
China Dynamics	The Company's electric vehicles business leverages solid state polymer lithium batteries and also holds a mining business activity ⁷¹ .	China	http://www.chinadynamics.hk/

Source: Fraunhofer ISI, 2020

2.2.5. Governing and supporting bodies, consortia and PPs

Several industrial and public initiatives exist to build up significant production capacities for li-ion-batteries in general. The research and innovation alliances on EU (Batteries Europe) and national level (e.g. Battery 2020 in Germany) also support research on solid-state-batteries as emerging technologies.

The European Commission has declared research and innovation on batteries a European priority area and has approved an "Important Project of Common European Interest" (IPCEI), which was jointly notified by Belgium, Finland, France, Germany, Italy, Poland and Sweden. These Member States will provide up to €3.2 billion in the coming years, with expectations to unlock an additional €5 billion in private investments⁷². In the framework of this IPCEI, consortia of companies were formed with the objective of building battery manufacturing capacity. The Focus is on li-ion-batteries with both liquid and solid-electrolytes (the first consortia for the battery IPCEI include Opel, SAFT, BMW, VARTA and BASF⁷³, a decision on another, much larger, battery IPCEI is expected by the end of 2020).

EU legislation, such as the Batteries Directive, applies to all batteries no matter their chemical nature, size or design. The aim is to avoid batteries with hazardous substances, reach high recycling rates and set provisions on labelling for the removability of batteries. It does have a big influence on all steps of the value chain and especially for the distributors, end-users and operators.⁷⁴ The European Commission is due to adopt a proposal for a new legislative framework for all batteries before the end of 2020. The expected aim is to help make batteries placed on the EU internal market more sustainable, regardless of where they have been manufactured.

Table 5: Governing and supporting bodies, consortia and PPs

Initiatives	Goal	R&D/Activities
Batteries Europe⁷⁵	European technology and innovation platform - one line of funding is SSBs	<ul style="list-style-type: none"> new emerging battery technologies raw materials and recycling advanced materials cell design and manufacturing application and integration: mobile and stationary
European Battery Alliance⁷⁶	European Commission initiative bringing together main EU battery actors to develop a globally competitive and complete battery value chain in the EU	Actions to support all aspects of the value chain and address challenges. No particular focus on solid-state-batteries.
Battery 2030+⁷⁷	Action to facilitate the invention of the batteries of the future, without developing a specific battery chemistry	<ul style="list-style-type: none"> creating a generic toolbox for transforming the way we develop and design batteries

⁷¹ <https://www.bloomberg.com/profile/company/CUFA:GR>

⁷² European Commission, 2019

⁷³ https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6705

⁷⁴ European Commission, 2020

⁷⁵ <https://batterieseurope.eu/>

⁷⁶ <https://www.eba250.com/about-eba250/>

⁷⁷ <https://battery2030.eu/about-us/>

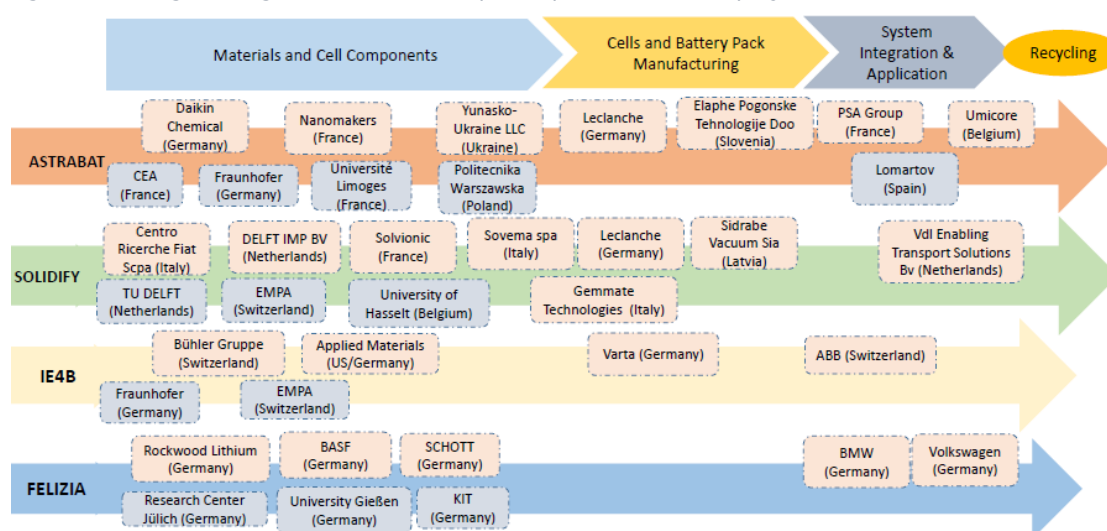
Initiatives	Goal	R&D/Activities
		<ul style="list-style-type: none"> roadmap with actions needed to invent sustainable, safe and high-performance batteries of the future
Batterie2020⁷⁸	Funding initiative from Germany's federal government	44 collaborative R&D projects (among them 3D-SSB, Artemys, Felizia, ProFeli, SOLID on the the development of solid-state-batteries)

Source: Fraunhofer ISI, 2020

2.3 Linkages along the value chain

The linkages in the emerging value chain of SSBs still have to be developed between the actors on the different parts of the value chain. There are already some linkages, first and foremost between research institutions and technology players, especially through public and private collaborative research projects (see figure 6).

Figure 6: Linkages along the value chain in public-private-research projects



Source: Fraunhofer ISI, 2020

The different research and innovation projects in the EU link researchers, technology developers, chemical industries and material providers with cell manufacturers, system integrators (especially automotive OEMs) and recycling industries to build the basis of an emerging value chain of SSBs all over the EU. Here, figure 6 shows that many EU-countries are involved in these projects and that it is not only big companies. Some actors such as Fraunhofer are very active in more than one project on SSBs.

Actors from the end of the value chain, the automotive OEMs, are investing in the first parts of the value chain, e.g. in technology providers or start-ups. On the central part of the value chain, there are still few specialised companies as R&D is still on-going and therefore no specific manufacturing process for the batteries has been established. Seemingly, the alliances and cooperation built around SSBs are not restrained to continental affiliations. It seems that cooperation is more important than competition between Europe, US and Asia. Some European automotive players are cooperating with Asian Battery Cell manufacturers (e.g. Volkswagen) and some with US-Battery Cell companies (e.g. BMW).

⁷⁸ <https://batterie-2020.de/english/>

Section 3

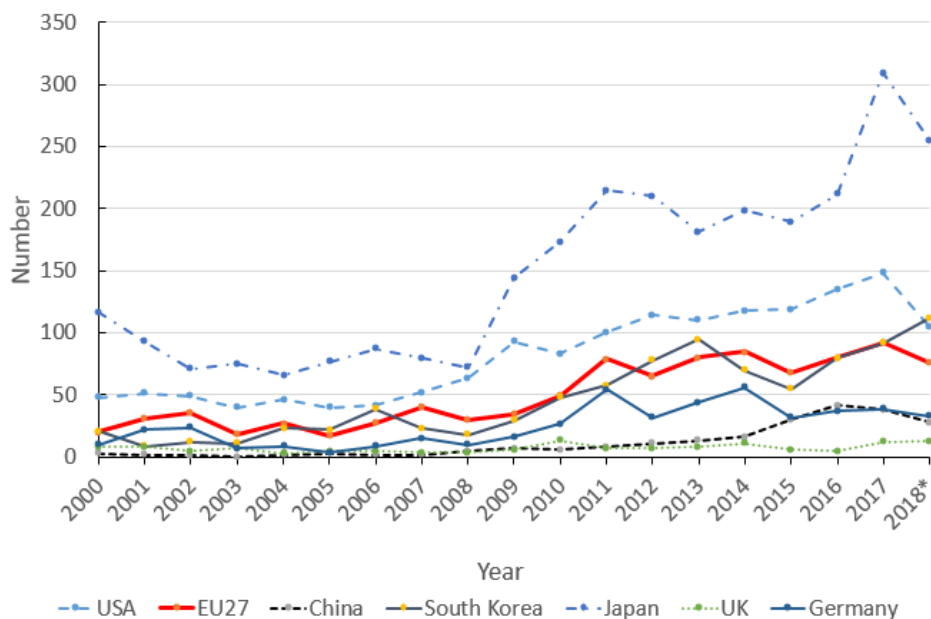
3. Analysis of EU competitive positioning

Today, the conventional EV-battery market is dominated by China, Japan and Korea. In 2018, less than 1% of the total global demand for EV-batteries was supplied by European companies. While European car manufacturers have struggled for sufficient battery supply, investments in battery manufacturing have been concentrated in Asia. 46 of the announced 70 Giga factories globally are based in China⁷⁹. Currently Asian companies (Japan, China, South Korea) are still dominating, but US-actors and as well Europeans are trying to play a bigger role regarding the development of the new SSB technology⁸⁰.

In the EU, Germany and France are the leading countries in lithium-ion-battery development. Leading countries in the EU on battery research, knowledge and skills are Germany, France, Italy, Austria, Finland and Denmark. The UK is also a leading actor in this World Region⁸¹. However, parts of the value chain for conventional LIB-batteries are still very weak in the EU, e.g. a competitive cell manufacturing is lacking and there are weaknesses in the provision of specific raw materials⁸².

Only for system integration, the last step in the value chain, Europe is better positioned, because OEMs and their suppliers are focusing on module/pack manufacturing and their integration into vehicles.

Figure 7: Patent registrations for solid-state-li-ion-batteries



Source: Fraunhofer ISI based of WPI & PATSTAT, 2020

The patent analysis (Figure 7) shows that Japan is leading in registering patents in the field on solid-state-li-ion batteries. The US follows and then EU27 and South Korea, with South Korea overtaking EU27 position since 2017. EU actors were active in registering patents too and China is on a similar level since 2015.

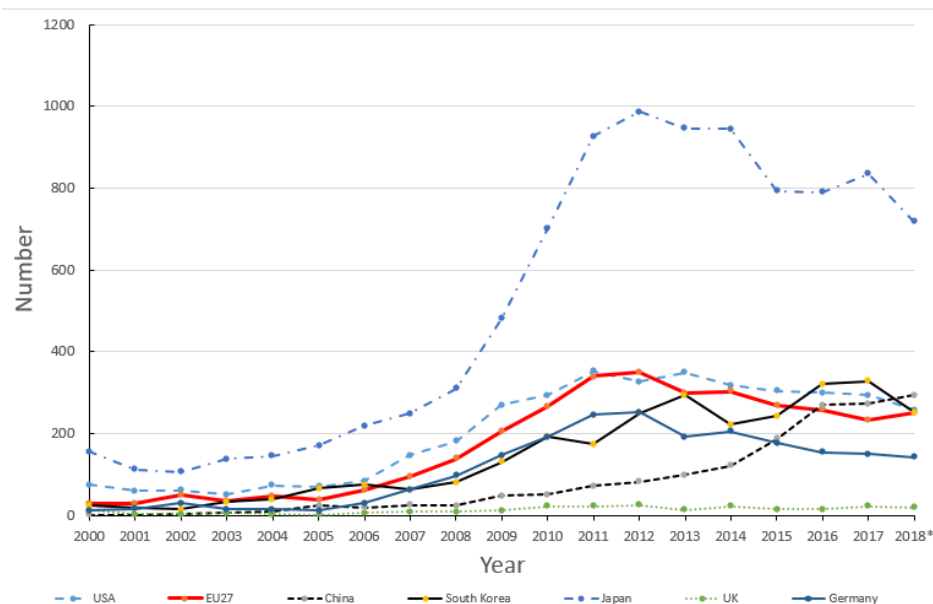
⁷⁹ McKinsey, 2019

⁸⁰ IDTechEx, 2019

⁸¹ Dufner, Krätzig, & Leker, 2020

⁸² Thielmann, Neef, Fenske, & Wietschel, 2018

Figure 8: Patent registrations for conventional li-ion-batteries



Source: Fraunhofer ISI based on WPI & PATSTAT, 2020

For the case of conventional li-ion-batteries with liquid electrolyte, the patent analysis (Figure 8) shows, that the numbers are up to three times higher than for the emerging solid-state-technology. Japan is leading the competition with a large head start. On similar levels, the US, South Korea, the EU27 and China follow. China has taken the lead in this group since 2018.

Recent investments in SSBs. Big players, mainly from the automotive industry, among them Ford, Hyundai, Nissan, BMW, Toyota and Volkswagen, have made investments in smaller companies and start-ups developing SSB technology⁸³. Japan has made large-scale investments in the development of the technology through the New Energy Industry Technology Development Organisation (NEDO) and Japanese car-maker Toyota has invested about €12 million⁸⁴. But also European actors are moving forward, with Volkswagen and BMW planning to launch EVs with SSBs in 2025 or 2026, forging a partnership with the American technology companies QuantumScape and Solid Power.

The other alliance is between Renault-Nissan, Mitsubishi and Hyundai Motor Group, which are investing more than €5 billion together into Ionic Materials, an US-based technology Start-Up.

In South Korea, LG Chem, Samsung SDI and SK Innovation are conducting research on the development of SSBs, with the goal of launching them around 2025.

⁸³ YOLE, 2018

⁸⁴ Business Korea, 2020

Figure 9: Strengths, opportunities, challenges and risks for the SSB-value chain



Source: Fraunhofer ISI, 2020

In the following section, the analysis of strengths, challenges, opportunities and risks is presented in more detailed arguments.

3.1 Strengths

Strong collaboration and research programmes in the EU. Alliances and collaboration around public and private R&D-projects on SSBs are forming. Especially concerning research on optimised electrolyte material design, there are many very relevant players in the EU. For the EU, the existing partnerships, initiatives and networks are an important strength to build on. SSBs are on the roadmaps of most major LIB-cell producers and automotive actors, which are participating in these collaborations. In the framework of the important project of common European interest (IPCEI), consortia on solid-electrolytes are forming. There are also public funds and programmes, e.g. national projects such as the initiatives for the building of cell manufacturing capacities in Germany.

Political push for green mobility in the EU, such as emission control regulation, is creating an interesting market with informed consumers. As more safety and greater charging cycles could be achieved through SSB-technology, this might reduce scepticism of consumers towards EVs. From political side, the pressure for more sustainability is increasing, with regulations such as the battery directive 2006/66/EC, targeting a more efficient design and use, as well as the recycling of batteries. Also, the European Commission plans to adopt a new battery legislative framework which will cover all batteries placed on the EU market and will include provisions to support sustainability as key requirement. It could be a strategic advantage for EU-SSBs to address sustainability issues in the value chain and to push forward eco-design and eco-labelling, second life and improved recycling for SSB.

Relevant knowledge-base and skills in the EU. There are relevant competencies and skills in chemistry & cell engineering in the EU to build on. There is a strong knowledge base in battery research, when seeing the numbers of publications and patents in the EU. While at present, the LIB production industry in Europe and the respective job market is rather small, it can be expected that relevant manpower and skills in other domains exist which could be transferred to SSB production.

Many actors for materials, equipment and advanced manufacturing processes. In the EU, many relevant actors, especially technology providers and companies working on specialised materials for SSBs, are building a base that enables the creation of the SSB-value chain. For the production of SSBs, higher requirements in precision and automatisisation have to be fulfilled and therefore, the EU could potentially use its strengths in advanced manufacturing techniques. Hence, Asian cell manufacturers have not yet developed specialised machinery and production technologies for SSBs. The competences of the EU-countries especially in industry 4.0, automatisisation of production and mechanical engineering could build the basis for the creation of a competitive production of solid-state-batteries.

3.2 Opportunities

Long-term strategic interests of OEMs in SSB-EVs. The market potential for SSBs is growing, because in order to enable greater ranges and energy density, SSBs might be needed in the long-term. Therefore, the interests of OEMs, especially in the car industry, are articulated by huge investments. Industrial players as well as R&D laboratories are motivated by the potentially accessible market of EV-

batteries, to develop SSBs. The EV-makers are attracted to SSBs by the need of product differentiation, higher energy density and better safety. The reciprocal interest from both technology and application sides drives the innovation in SSBs for automotive applications. The other applications (aerospace, satellites, consumer) will probably benefit from these efforts⁸⁵.

Establishing next generation battery value chain. It would be an extraordinary opportunity to build a European value chain for SSBs. As the head start of other world regions is very small, chances are still good to establish a competitive value chain, based on the existing networks and actors around materials, advanced manufacturing, battery engineering and the automotive sector.

Potential for improved recycling of materials when establishing a value chain in the EU. Depending on the chosen design for SSBs recycling could be improved. As often, the cost of recycling is higher than the value of its output, political incentives would be needed here, e.g. by supporting eco-design and pre-cycling principles. Nickel and cobalt could be sourced to 90% out of collected batteries, and for some material designs no cobalt is needed. Also lithium in old batteries could be recycled, which could help to reduce dependence on sourcing of expensive and critical raw materials. BASF is planning a battery material production in Finland with Norilsk Nickel which could also improve resource independency. The initiative of Northvolt, Umicore and BMW for the development of sustainable cell manufacturing and a circular economy will also contribute to that goal.

Creating of a competitive advantage for the EU. For SSB-production no competitor has much experience until now, so there is still a possibility for European actors to gain high competitiveness. The imbalance in number of staff trained in battery production between Asia, the US and Europe found today, might hence be more equal in the future, when specialised training programs for SSB development and manufacturing are created in the EU. The announced cell manufacturing capacity increases in the EU could first be used for conventional li-ion and then be readapted and used for SSBs.

3.3 Risks

Lagging behind other world regions, while competing with other emerging battery technologies. The risk here is twofold. On one side, the speed of upscaling SSB technology in the EU could be insufficient in comparison with other world regions. On the other side, other emerging battery technologies are competing with SSBs and could be developed faster. The US, Japan, South Korea and China are strong competitors and committing with strong investments in moving forward SSB. Associated is also the risk, of European research and innovation commercialised elsewhere, because the conditions for companies and start-ups in the EU are not sufficiently attractive. European automotive actors are making partnerships mostly with American technology companies and start-ups.

Moreover, when other next generation battery approaches are developed faster, arguments for the commercialisation of SSB might be weakened. Also, other technologies (like liquid electrolytes combined with protective coatings/membranes and lithium-metal anodes) might have a higher compatibility to state-of-the-art manufacturing techniques.⁸⁶

Risk of dependence from Asian battery manufacturers. The worldwide production of state-of-the-art lithium-ion battery cells is currently mainly controlled by Asian companies and European automotive OEMs producing EVs are heavily dependent from these supplies. Asian cell manufacturers are establishing manufacturing capacities in the EU (Germany, Poland, Hungary) and strengthen their supply relations to European OEMs. Cells could be marketed as "Made in the EU", but the basis are Asian technologies. For European OEMs such model is very attractive because of low prices and short supply chains. If the European automotive industry with its 3.4 million employees was to switch from internal combustion engines to electric drive systems, it would be dependent on traction batteries from Asian manufacturers - if it did not succeed in bringing this key technology to Europe.⁸⁷

Risks associated with the sourcing of materials. Although the worldwide resources of metals and minerals seem to be sufficient for the transition to EVs based on renewable energies, there can be always temporary shortages in supply and price increases for the raw materials (e.g. when new mines have to be built). Through technological developments, the percentage of the "conflict mineral" cobalt could be reduced significantly, whereas the percentage of lithium might be at the same level as today. As with conventional LIB, there are social and ecological implications especially in the sourcing of materials extraction of resources (human toxicity, acidification, water withdrawal, armed conflicts and

⁸⁵ YOLE, 2018

⁸⁶ Fraunhofer ISI, 2018

⁸⁷ <https://www.isc.fraunhofer.de/en/press-and-media/press-releases/solid-state-batteries-for-tomorrows-electric-cars.html>



danger to indigenous populations). Even if SSBs are estimated to have a more sustainable life cycle, the Greenhouse gas footprint of the battery production in general is still high. Depending on the materials and design it might be more difficult to recycle them. Often, they are hybrid, complex mixtures of different materials. There will be also a need for critical raw materials for some solid-state-electrolytes (e.g. Germanium).

3.4 Challenges

Lack of start-up-culture and sufficient technology transfer. In the future, there will be a high demand for specific skills in the battery industry and for now, there is a lack of skills in the field of production and cell manufacturing processes for SSB. Further, there are very few SSB-start-ups in the EU working on approaches with lower TRLs, that would be needed to further test and adapt prototypes and enable production of SSB in the EU. There is not enough support and early-stage financing for start-ups and so US-based start-ups are leading in the competition about the first commercialisation of SSB. Joined efforts for technology transfer, in order to bridge the "valley of death" between R&D, prototyping and up-scaling of manufacturing processes, would be needed.

No dominant design approach established for SSBs. The deployment of solid-state batteries is still associated to considerable R&D effort and expenses, with a low TRL in many different approaches of material combinations and cell architectures. Technology challenges remain, as for example, SSB have to work at ambient temperature and under harsh conditions (EVs) before they can be commercialised. Also the ionic conductivity of SSBs is often one or more orders of magnitude lower than that of liquid electrolytes. Further, the resistance at the interface of electrolyte and electrodes must be optimised, the material compatibility between the solid electrolyte and the lithium metal anode must be ensured and dendrite formation be prevented.

Barriers to mass-production and commercialisation. In 2018 there were already years of R&D and first cell prototypes realised, but the industry still struggles to bring this technology to mass production. The biggest challenges for SSBs is seen in the development of suitable large scale manufacturing techniques for electrodes and cells.⁸⁸ Supply chains and production processes have first to be organised and established. Even with further investment efforts and R&D, there may be considerable gaps in such a potential value chain in the EU, as is already the case for li-ion-batteries (cell manufacturing, sourcing and processing of materials). Additionally, as there are no specialised suppliers yet for a young technology that has to compete with conventional li-ion, actors have to develop and re-adapt their own materials and components, which creates a further barrier.

⁸⁸ Fraunhofer ISI, 2018

Section 4

4. Conclusion & Outlook

4.1 Conclusions

SSBs could allow more safety, energy density and greater ranges for electric vehicles, without a physically larger battery pack. The analysis of this emerging value chain has shown that there are **still important efforts to make for the uptake of this technology**. Until major technical challenges are solved, it is not sure whether SSBs can be produced on a larger scale with success. Also, there are other competing emerging battery technologies which could outperform SSBs.

But these uncertainties are impeded by the observation of **many relevant research and industry players**, their activities and investments in the generation of SSB-technology. Here a clear dominance of Asian and US actors can be observed. But also, European actors especially in R&D, as well as potential users (automotive OEMs) are also very active. And with the political push to electric mobility, the **EU has the best market conditions for SSB development**.

What is lacking in the EU are innovative start-ups and SMEs trying to test SSBs on larger scales and real-world conditions to finally enable the uptake of this technology. In contrast, the US offers better conditions and **a different kind of venture capital culture**, but also a mentality of risk, that has allowed the creation of the strongest start-ups for SSBs for now (e.g. QuantumScape, SolidPower, Ionic Materials). European OEMs such as VW or BMW are cooperating with these start-ups to develop SSBs for their electric vehicles.

In the view of the interviewed experts, the promises of some actors are very optimistic (e.g. Toyota promised to commercialise first SSB-EVs in 2025). However, it seems possible to see a **market introduction of competitive SSBs by 2030**, in case technical issues can be solved, sufficient investments made and industrialisation processes improved.

Companies such as Bosch, which had invested strongly in SSB already withdrew from it for reasons of economic risk. This is also due to the long-time horizon and payback period, as commercialised results are probably for 2030+. These financial risks and uncertainties of payback in the time horizon, create the need for public investment in this phase and a **roadmap of all relevant players for the commercialisation of SSBs**.

As Asian manufacturers are leading in the production of conventional lithium-ion-batteries, it might be possible that they will take the lead on SSBs as well in the long-term. The development of Asian cell manufacturers constructing production facilities in Eastern Europe, could be seen highly problematic for the EU. Cells could be marketed as "Made in Europe" and for European OEMs this will be very attractive, but European companies in general will hardly benefit from it. In solid-state-battery development, the head **start of other world regions is though very small compared to the EU**, which would offer the competencies for high precision, intensified automatisisation of the production process and specialised machinery. Gigafactories for conventional li-ion-batteries could be refocused on SSB, plants and production process will have to be readopted, but competences and equipment will be similar. Also, the **EU could take the lead on a more sustainable and socially responsible sourcing of the materials and production then other actors**.

To sum up, the EU would still have a chance to build on its strengths in R&D and manufacturing technologies for the development of an SSB-value-chain. However, first of all it seems important to **upscale manufacturing capacities for batteries in general**, which is already targeted by initiatives such as the European Battery Alliance and its Business Investment Platform⁸⁹. This industrial development programme brings together more than 400 industrial and innovation actors with the objective of building a competitive European battery industry. The Priority Actions identified by the European Battery Alliance, e.g. *"Develop and strengthen skilled workforces in all parts of the value chain and make Europe attractive for world-class experts"* are also valid with regards to relevant actions for the uptake of SSBs.

⁸⁹ <https://www.eba250.com/>



Besides, it would be important to **bundle existing projects and competencies at EU and national level**. This wouldn't mean to ignore other approaches to next generation batteries, but to bring knowledge on SSBs together and increasing the search for an optimised design and material mix. As well, special programs for the support of start-ups would stimulate the testing and upscaling to real world conditions of SSBs. For this, **strategies and programmes between Member States and European level should be coordinated to find a way to the commercialisation of SSBs**.

4.2 Outlook

In the long term, there is a high chance that SSB will experience commercial breakthrough, as they might be needed to enable pure lithium-anodes, which will guarantee higher energy densities. Electrolytes will most probably be produced based on a hybrid material design approach, as conductivity of solid materials such as polymer has to be enhanced with other material combinations.

These SSBs with **hybrid** solid-state electrolytes seem to have the highest potential for future applications in electric vehicles and could reach market maturity by 2030⁹⁰. It should be stressed, that in the view of experts, there are still significant technological challenges to solve and that first, there will be probably **applications of SSBs in niche markets** in order to demonstrate their advantages. For smaller applications in wearables, drones or scooters it might be possible to see first commercialisations in 3 to 5 years. For production, there will not be a "one-size fits all" approach, as for every application there will be different SSB-designs, produced by different companies in a diverse value chain.

Depending which exact material concept pushes through, **recycling loops and second use could be established** and with it the establishment of a full value chain with circular elements. This would mean, that until the first life cycles are ending, the materials would have to be sourced (from recycling) or mine capacities should be built up.

In the view of the experts, this would also be attractive in order to be less dependent from Asian battery manufacturers and to have **better control over the sourcing and recycling of the used materials**.

The CO₂ regulations for cars will influence considerably the development of this value chain, as electric cars will be more and more produced and demanded. From 2021, phased in from 2020, the EU fleet-wide average emission target for new cars will be 95 g CO₂/km. Also, the Commission has set out rules for monitoring the CO₂ emissions of new cars, which means that **automotive OEMs have clear incentives to invest in clean technologies such as SSBs**⁹¹.

In principle, the EU has the **potential to become a hub for SSBs in EVs**, with some of the main players of the value chain, especially in the area of R&D and system integration (European automotive OEMs). For cell manufactures all over the world, this localisation is very interesting due to the geographical proximity of users in the car industry, emissions control and a market with more and more environmentally conscious consumers.

A competitive advantage for the EU could arise through effort concentration on SSBs, if European players achieve improvements not only in energy density, but also in rapid charging, low costs, systemic safety of the product and the guarantee of a sustainable production. Cooperation between these actors is key to establish the emerging value chain of SSBs and bridge the gaps.

4.3 COVID-19 and impact on solid-state-batteries

The ongoing corona virus disease (COVID-19)-crisis will affect the development of SSBs on different levels.

First, many working places, especially laboratories and cleanrooms are restricted and cannot work normally. Also, there were significant delays in material supply due the crisis in many laboratories. This will lead to a **slowdown of research and prototyping in the EU**. Experts working in the field reported, that younger researchers and technicians still work in the facilities and laboratories if possible, but that senior researchers work most of the time in home office.

While there are some slow-down effects on testing and experimenting, positive effects on knowledge exchange can be observed by some of the experts. With the digitalisation of conferences and workshops, these have become more open especially to newcomers and young researchers in the fields. EU-wide or international online-webinars and conferences are offered to a wider range of participants and often

⁹⁰ Fraunhofer ISI, 2017

⁹¹ European Commission, 2020



without any fee, which facilitates **knowledge exchange and interaction** in the community of solid-state-battery research. In the meantime, travelling and therefore the **carbon footprint** of the actors has decreased dramatically

However, the COVID-19-pandemic and lock-down is related closely to the risk of an economic crisis. The research and technology centres, where most of R&D on solid-state-batteries is done are dependent on public and private funding. Companies with losses due to the crisis, that do or fund research on this technology might retreat from it and **cut R&D-spending**. Often discussions on this next generation battery technology are postponed and so might be the investments. In the same way it is possible, that public funds could be distributed differently. This could **postpone development of cutting-edge technologies**. While some experts are doubting, that there will be as much support and funding for such cross-cutting technologies as before the COVID-19 crisis, others are **more optimistic**. At least in Germany it can be observed that there is rising support, especially for "green" emerging technologies. Key areas such as batteries and hydrogen, needed for the transition to a more sustainable energy and mobility systems, will become more and more important in the long term - with or without the pandemic. The economic recovery programs will probably also focus on this transformational pathway and in some countries such as Germany, governments aim to implement targeted support strategies for forward-looking technologies.

Section 5

5. Annexes

5.1. List of interviewees

Interviewee	Company	Country
Mareike Wolter	Fraunhofer-Institut für Keramische Technologien und Systeme IKTS	Germany
Martin Finsterbusch	Forschungszentrum Jülich	Germany
Andriy Kvasha	CIDETEC, Materials for Energy Unit	Spain
Sandeep Unnikrishnan	TNO/Holst Centre	Netherlands

5.2 Bibliography

- Business Korea. (2020, March). *Battery Companies and Automakers Racing to Develop All-solid-state Batteries*. Retrieved April 29, 2020, from <http://www.businesskorea.co.kr/news/articleView.html?idxno=42752>
- Business Wire. (2020). Retrieved March 20, 2020, from [www.businesswire.com: https://www.businesswire.com/news/home/20200117005298/en/Solid-State-Batteries-2020-2026-Advantages-Power-Density](https://www.businesswire.com/news/home/20200117005298/en/Solid-State-Batteries-2020-2026-Advantages-Power-Density)
- Dufner, F., Krätzig, O., & Leker, J. (2020). Battery plant location considering the balance between knowledge. *Journal of Cleaner Production*.
- European Commission. (2016). *Lithium ion battery value chain and related opportunities for Europe. JRC Science for Policy Report*.
- European Commission. (2018). *Strongly improved, highly performant and safe all solid state batteries for electric vehicles*. Retrieved April 6, 2020, from <https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/lc-bat-1-2019>
- European Commission. (2019, December). *State aid: Commission approves €3.2 billion public support by seven Member States for a pan-European research and innovation project in all segments of the battery value chain*. Retrieved April 28, 2020, from https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6705
- European Commission. (2019a, January). *Innovation and Networks Executive Agency. €114 million available under Horizon 2020 for next-generation batteries projects*. Retrieved April 6, 2020, from <https://ec.europa.eu/inea/en/news-events/newsroom/%E2%82%AC114-million-available-under-horizon-2020-next-generation-batteries-projects>
- European Commission. (2019b, April). *Horizon 2020: Nearly €500 million requested for next-generation batteries*. Retrieved April 6, 2020, from <https://ec.europa.eu/inea/en/news-events/newsroom/horizon-2020-nearly-500-million-requested-next-generation-batteries>
- European Commission. (2020, January). *A European Strategy for low-emissions mobility*. Retrieved April 6, 2020, from https://ec.europa.eu/clima/policies/transport_en
- European Commission. (2020). *Batteries and Accumulators*. Retrieved May 14, 2020, from <https://ec.europa.eu/environment/waste/batteries/>
- European Commission. (2020). *Reducing CO2 emissions from passenger cars - before 2020*. Retrieved May 14, 2020, from https://ec.europa.eu/clima/policies/transport/vehicles/cars_en

- Fraunhofer ISI. (2017). *Energiespeicher Roadmap (Update 2017): Hochenergiebatterien +2030 und Perspektiven zukünftiger Batterietechnologien*. Karlsruhe.
- Fraunhofer ISI. (2018). *High Energy Batteries Roadmap 2030+: New technologies for automotive and other applications*.
- Hettesheimer, T., Thielmann, A., Neef, C., & Durand, A. (2019). *Preparatory study on Ecodesign and Energy Labelling of Batteries under FWC ENER/C3/2015-619-Lot 1*. European Commission.
- IDTechEx. (2019). *Solid-State and Polymer Batteries 2019-2029: Technology, Patents, Forecasts*. Retrieved April 20, 2020, from <https://www.idtechex.com/de/research-report/solid-state-and-polymer-batteries-2019-2029-technology-patents-forecasts/641>
- McKinsey. (2019). *Recharging economies: The EV-battery manufacturing market outlook for Europe*. Retrieved April 21, 2020, from <https://www.mckinsey.com/industries/oil-and-gas/our-insights/recharging-economies-the-ev-battery-manufacturing-outlook-for-europe>
- McKinsey. (2019). *Recharging economies: The EV-battery manufacturing outlook for Europe*. Retrieved 10 11, 2020, from <https://www.mckinsey.com/~media/McKinsey/Industries/Oil%20and%20Gas/Our%20Insights/Recharging%20economies%20The%20EV%20battery%20manufacturing%20outlook%20for%20Europe/Recharging-economies-The-EV-battery-manufacturing-outlook-for-Europe-vF.pdf>
- Navigant Research. (2019). *Is 2020 the Year of Solid-State Batteries for EVs?* Retrieved April 9, 2020, from <https://www.navigantresearch.com/news-and-views/is-2020-the-year-of-solid-state-batteries-for-evs>
- Neef, C., & Thielmann, A. (2019). *Preparatory Study on Ecodesign and Energy Labelling of Batteries under FWC ENER/C3/2015-619-Lot 1*. European Commission.
- New Mobility. (2019, August). *Technology University in Graz develops new electrolyte for solid-state-batteries*. Retrieved April 28, 2020, from <https://www.newmobility.global/e-mobility/technology-university-graz-develops-new-electrolyte-solid-state-batteries/>
- PEM of RWTH Aachen and VDMA. (2018). *Production of All-solid-state-battery cells*. RWTH Aachen, VDMA. Retrieved May 08, 2020, from https://www.pem.rwth-aachen.de/global/show_document.asp?id=aaaaaaaaabdbuc
- Qing Zhang, D. C. (2019). Sulfide-Based Solid-State Electrolytes: Synthesis, Stability, and Potential for All-Solid-State Batteries. *Advanced Materials, Vol.31, Issue 44,*.
- Research and Markets. (2019, October). *Solid Electrolytes for Li-ion Solid-State Batteries Patent Landscape*. Retrieved April 28, 2020, from https://www.researchandmarkets.com/reports/4849337/solid-electrolytes-for-li-ion-solid-state?utm_source=CI&utm_medium=PressRelease&utm_code=gpmxxh&utm_campaign=1311451+-+Solid+Electrolytes+for+Li-ion+Solid-State+Batteries+Patent+Landscape+2019%3a+Car+and+
- Samsung. (2020). *Samsung Presents Groundbraking All-Solid-State Battery Technology to 'Nature Energy'*. Retrieved March 21, 2020, from Samsung Newsroom: <https://news.samsung.com/global/samsung-presents-groundbreaking-all-solid-state-battery-technology-to-nature-energy>
- Thielmann, A., & Neef, C. (2019). *High Energy Batteries Roadmap 2030+: New Technologies for automotive and other applications*. Karlsruhe: Fraunhofer Institute for Systems and Innovation Research ISI.
- Thielmann, A., Neef, C., Fenske, C., & Wietschel, M. (2018). *Energiespeicher-Monitoring 2018: Leitmarkt- und Leitanbieterstudie: LITHIUM-IONEN Batterien für die Elektromobilität*. Karlsruhe: Fraunhofer ISI.
- Thielmann, A., Wietschel, M., Funke, S., Grimm, A., Hettesheimer, T., Langkau, S., . . . Edler, J. (2020). *Batterien für Elektroautos: Faktencheck und Handlungsbedarf. Sind Batterien für Elektroautos der Schlüssel für eine nachhaltige Mobilität der Zukunft?* Karlsruhe: Fraunhofer ISI. Retrieved April 25, 2020, from <https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2020/Faktencheck-Batterien-fuer-E-Autos.pdf>



World Economic Forum. (2019). *A Vision for a Sustainable Battery Value Chain in 2030: Unlocking the Full Potential to Power Sustainable Development and Climate Change Mitigation*. Geneva.

YOLE. (2018). *Solid-State-Battery. From Technologies to Markets*. YOLE Développement.



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