Q3 2019 | Pulse
Battery Energy Storage

FutureBridge

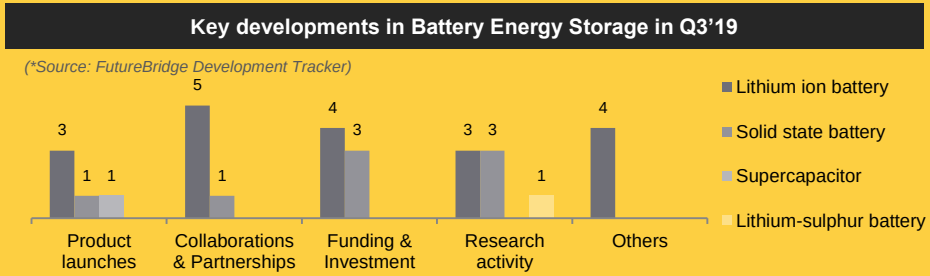
WHAT'S INSIDE!

Q3'19 saw OEMs and Suppliers exploring the repurposing of the batteries to delay recycling and get maximum output from used batteries.

Solid State battery development for commercialization is accelerating at a fast rate in Q3'19. Startups and Research institutes are working at a higher-than-ever pace as the deployment timelines set by OEMs are approaching quickly.

With this version of the Pulse we introduce a new segment, our "Electro-mobility Carmaker Leaderboard" which presents our forward-looking assessment of their rankings with respect to electrification technology innovation, strategy and market leadership.

MOBILITY INDUSTRY INSIDER



FutureBridge

01 Emerging trends

Delaying recycling through repurposing – Second life for batteries

CONTEXT

Recycling lithium ion batteries entails costs and potential waste making their repurposing for a second and even third life even more important in order to maximize their economic and environmental value before recycling.

Because second-life batteries will retain significant capacity, they may be well-suited for various customer and grid applications, particularly if aggregated for bulk energy storage. Residential and commercial customers may also use them in combination with on-site solar power for backup supply. These batteries could help integrate variable renewable energy.

To start, to handle the growing number of EV models and batteries, automakers can design their EVs with second-life applications in mind. For example, Nissan formalized a partnership with Sumitomo Corporation to reuse battery packs from the Nissan Leaf for stationary distributed and utility-scale storage systems.

Developments

- Daimler's subsidiary **Mercedes-Benz Energy GmbH** and **Beijing Electric Vehicle Co., Ltd. (BJEV)** have entered into a development partnership, intending to establish 2nd-life energy storage systems in China in the future. The partnership will see a consolidation of expertise and resources regarding the value-chain of automotive battery systems, while laying the groundwork for a sustainable renewable energy development.
- **UL** announced that 4R Energy Corporation, a joint venture of Nissan Motors and Sumitomo Corporation focusing on the effective reuse of EV batteries for energy storage systems, is the first organization worldwide to be certified to UL 1974, the Standard for Evaluation for Repurposing Batteries. Through this process, performance-validated "second-life" batteries can be utilized for energy storage systems to provide a safe, reliable, clean energy source.
- **Cummins** announced a multiyear partnership with the **University of California (UC) San Diego** and its battery validation lab to analyze viable business applications and technical approaches to reusing and repurposing electric vehicle (EV) batteries. The partnership will focus solely on lithium-ion batteries and is one of the first projects to exclusively study second-life battery capabilities that were designed for commercial applications.
- Researchers at **WMG, University of Warwick** have announced that they have found a way to repurpose old **Jaguar** I-PACE batteries as potential off-grid small energy storage systems. The repurposed units will contain about 2 kWh of energy capacity, and will likely be enough to power a small shop, a farm holding, or a residential unit.

DEVELOPMENTS Emerging trend

NREL's investigation found that regional repurposing facilities dedicated to a single model of PEV is likely to minimize repurposing costs while avoiding the increased transportation costs of nationwide battery collection and the complexities of repurposing heterogeneous batteries.

Potential supply of second-use batteries can overwhelm the depth of many markets for second-use batteries. The most promising application identified for second use batteries is to replace grid-connected combustion turbine peaker plants and provide peak-shaving services.

FutureBridge Insight & What should you investigate ?

FutureBridge on second life of batteries

- Second use of EV batteries is often seen as an opportunity to delay disposal and recycling, which currently present burdens for OEMs, as well as an opportunity to squeeze value out of existing resources. OEMs will have what it takes to seize a big part of the expanding energy storage market. They have the knowledge of their batteries and the best chance of maintaining or re-establishing control of the LIBs in their EVs.
- Recycling industries also see new opportunities, in making themselves natural intermediaries between the vehicle end-user or OEM and a second life for the battery. A number of third-party entrepreneurs are currently attempting to establish second-life battery businesses, with repurposing at the heart of their business models. For example, Powervault partnered up with Renault to turn old Renault Zoe battery packs into home storage systems helping households cut electricity bills by more than a third.
- Despite the potential for second life to be a good fit for several applications that are less demanding than an EV, there is currently no market for second life. There is also no standardization around EV battery recycling. It is very much due to uncertainty about the future: which LIB chemistries will be used, what will new batteries cost, and how will second-life batteries perform in different applications?.

What should you investigate ?

Would it be better to recycle used EV batteries directly, instead of giving them a second life?

What are the consequences of second life, with regard to ecological and social sustainability?

Electric-vehicle (EV) battery life cycle, illustrative

Source: Researchgate

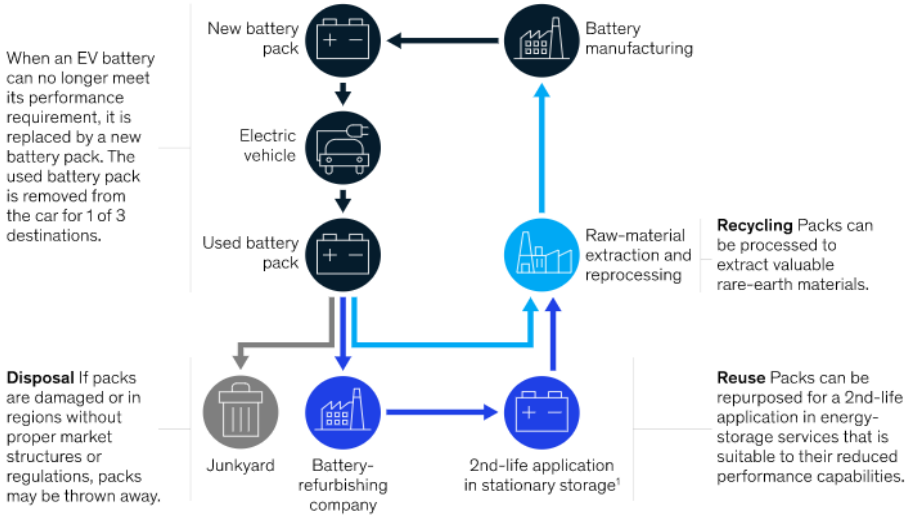


Table 2. Possible applications for second-life batteries.

Application	Actors	Comments
Storage of solar or wind power	Households, property owners	Small or large scale, off-grid or grid-connected
Peak shaving	Industries	Reducing power demand
EV charging	Property owners, grid owners	Reducing power demand at time of charging
Increased grid capability and stability	Grid owners	Instead of installing larger cables, or to avoid fluctuation
Backup	Industries, property owners	In case of electricity loss
Electricity trading	Electricity companies	Having a battery farm for electricity trading
Vehicle propulsion	Vehicle manufacturers	E.g., ferries, forklifts

Solid-state batteries inch their way towards EV commercialization in Q3'19

CONTEXT

Q2'19 saw different players (OEMs, Suppliers, Startups) focusing on the development of solid state batteries, as well as partnerships and funding to accelerate deployment.

In Q3'19, we observed continued drive towards solid state batteries which points to the direction of imminent commercialization of this technology. Some of the players launching EV powered by Solid state batteries are given below:

OEM	Solid state battery vehicle launch	Source
Volkswagen	2025	Link
Toyota	2020	Link
Enovate	2021	Link
Fisker	2020	Link

Launches

- US government awarded **GM** a total of $9.1 million, of which $2 million is explicitly related to research and development for solid-state batteries. Specifically, $1 million of the funding will go toward the "fundamental understanding of interfacial phenomena in solid-state batteries" while the remaining million dollars will help with the "hot pressing of reinforced all-solid-state batteries with sulfide glass electrolyte."
- **US Department of Energy** (DOE) has selected **Wildcat Discovery Technologies** for a grant of $1.2M to develop improved materials for solid-state batteries. The Wildcat project team will focus its efforts on two promising concepts: the development of a composite solid ion conductor and stabilization of a lithium metal anode. The project is scheduled to begin in October 2019 and is expected to conclude two years later in late 2021.
- Chinese EV startup **NIO** and solid-state battery cell maker **Prologium Corporation** (PLG) agreed a strategic cooperation on production and application of solid-state batteries. NIO teamed with ProLogium due to its high degree of commercialization and the innovative battery pack construction technology developed with regard to the advantage of solid-state battery.
- **Blackstone Resources** has partnered with several strategic partners from Germany, Belgium, Poland and Austria, the United Kingdom and Switzerland. It has started to build and will finance its own research team with these partners. They will develop new production technologies for Blackstone's planned battery production facilities. This will include developing and testing new solid-state battery technologies.

Blackstone Resources

DEVELOPMENTS Emerging trend

- Startups like Solid Power and ZapGO are working actively to develop solid state batteries and are being funded by OEMs for the same. Solid Power received funding from Ford and is now opening new solid-state battery production line.
- Research institutes like Graz University of Technology, CSIRO are continuously working to improve the properties of solid state batteries like conductivity, power density to make them more beneficial for automotive applications.

FutureBridge Insight & What should you investigate ?

Battery Energy Storage | Q3 2019 Pulse

FutureBridge Insight on Solid-State battery development

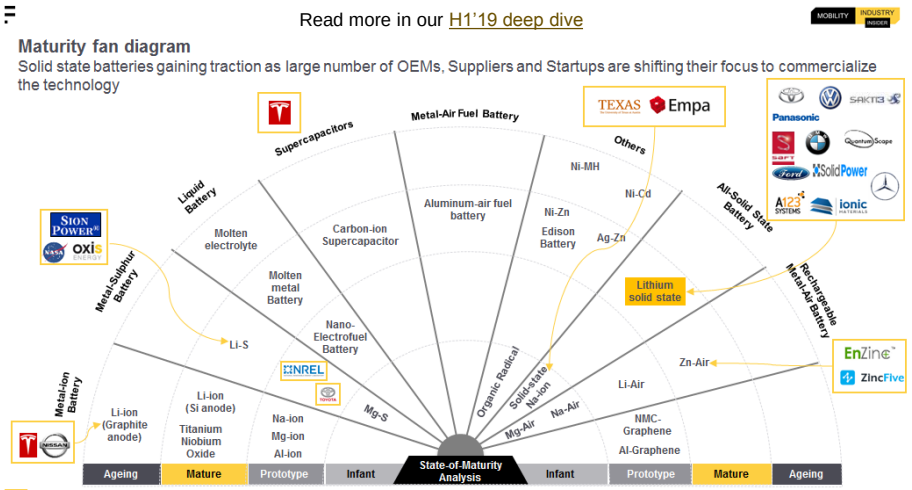
- Just a few years ago, the auto industry considered solid-state EV battery development a distant goal. Now commercial application is rapidly approaching. Read more in our Q2 Pulse 2019
- Solid-electrolyte technology not only offers safety but business opportunities as well. For solid-electrolyte batteries to be cost-effective, they require a dramatically different manufacturing system and supply chain, opening up opportunities for companies that couldn't otherwise compete with Asian plants that produce most of the world's lithium-ion batteries.
- Solid state batteries will extend the range of electric vehicles while eliminating the flammability issues that are inherent in lithium-ion batteries. Researchers conclude that a solid-state battery pack could give electric vehicles 500 to 1,000 miles of range on a single charge.
- Solid state batteries will be coming in 2020s as has been announced by various OEMs(Like Toyota) and there contribution in terms of market penetration will not be much in early stage. This is due to the fact that Lithium-ion battery has made strong roots in the industry. But if we look at the near term future, Solid state batteries are next in line to succeed Li-Ion batteries because they have superior properties (Like charge density, safety etc.). Also the developmental activity for Solid state batteries in **Q2'19** and **Q3'19** has been very immense with players investing more and more for early launch of ASSB powered vehicles like in case of **Toyota** which accelerated its plans to launch ASSB powered EV in 2020 from proposed timeline of 2025.

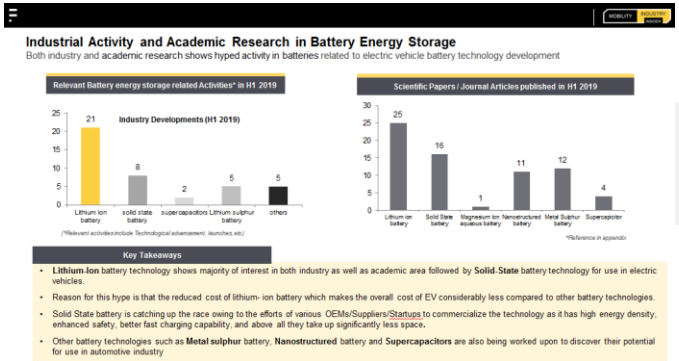
What should you investigate ?

What are the challenges slowing down the commercialization of solid state batteries?

What is the scope of solid state batteries in commercial vehicle segment? Are they going to be better than Li-Ion?

Read more in our H1'19 deep dive





Solid state battery showed increased activity and academic interest in H1'19

Major developments during Q3'19 – High research activity in lithium ion battery was observed with main area of focus being cathodes and electrolytes.

Investments/Funding

CATL ramps up investment in German gigafactory to €1.8 billion >>

LG Chem plans to invest $424.03m to build a battery factory in South Korea >>

US government awards General Motors $2M for solid-state battery research >>

Faraday Institution to award up to £55M to five consortia for energy storage research >>

Collaborations/Partnerships

DAIMLER — Electric vehicle batteries >> — FARASIS

Li-ion battery production >> — northvolt

LG Chem — Supply agreement for battery-grade lithium hydroxide >> — TIANQI LITHIUM

ProLogium — Developing solid-state-battery-powered prototype >> — NIO

Second life for batteries >> — BAIC

BMZ THE INNOVATION GROUP — Lithium-ion batteries for heavy-duty applications >> — KION GROUP

Research activities

UC San Diego / SOUTH 8 TECHNOLOGIES — Improved liquefied-gas electrolytes for Li-metal batteries >>

New cathode material for Li-S batteries: sulfur-anchored azulene developed >>

MIT — Method to make smaller, safer, and faster lithium-rich ceramic electrolyte >>

TU Graz — New solid electrolyte for improved conductivity of solid-state batteries >>

WARWICK — Recycle used batteries as Energy Storage Systems >>

Green Science Alliance — New type of Metal Organic Framework (MOF) based electrode for lithium ion battery >>

Launches

BMW 330e hybrid powered by lithium-ion battery >>

Volvo XC60 Polestar powered by lithium-ion battery >>

Plug-in hybrid X5 xDrive45e powered by lithium-ion battery >>

Hybrid Sián powered by supercapacitor >>

02 Quarterly review of early-stage research

Fast charging of an electric vehicle lithium-ion battery at the limit of the lithium deposition process

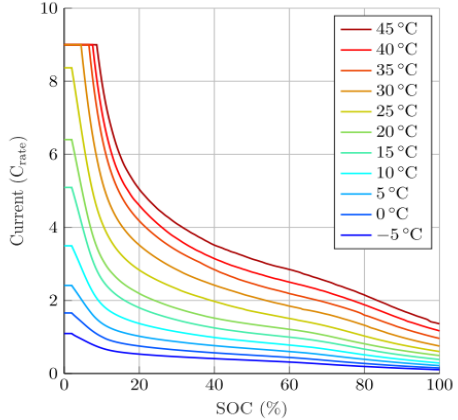
(July 2019,**JohannesSieg, Jochen Bandlow, Daniel Dragicevic, Torben Materna, Bernd Spier,** Daimler AG, Research & Development**, Tim Mitsch,** Institute of Applied Materials, Helmholtz-Zentrum**, Heiko Witzenhausen, Madeleine Ecker,** Daimler AG, Research & Development, RWTH Aachen University, Juelich Aachen Research Alliance, JARA-Energy **and Dirk Uwe Sauer,** RWTH Aachen University, Juelich Aachen Research Alliance)

Background

- To meet the range and cost requirements, battery cells with a high energy density are used for the traction battery. This contradicts the requirement for a high charging power. Therefore, to achieve short charging times, the charging process has to be well analyzed and optimized for the specific battery cell in use.
- In this paper, the charging process of a commercial high energy lithium-ion pouch cell is investigated.

Key insights

- Three-electrode test cells are assembled using electrode materials from the high energy lithium-ion pouch cell together with lithium metal as reference electrode to acquire the potential at the negative electrode-electrolyte interface.
- During charging, the cells' current is controlled in a way that the negative electrode potential is maintained constantly slightly above 0 V vs. Li/Li+.
- The resulting current map depending on temperature and state of charge is used to control the charging process of the pouch cell.
- New charging procedure enables a state of charge of **80%**, reached in **15 min** at 25°C ambient temperature.



Resulting charging currents versus SOC from -5°C to 45°C using three electrode test cells.

T_A	Time to 80% SOC	Time to 100% SOC
45°C	12.8 min ± 1.5%	19.6 min ± 1.1%
40°C	14.4 min ± 1.6%	22.2 min ± 1.6%
35°C	16.2 min ± 1.6%	25.4 min ± 2.6%
30°C	19.3 min ± 0.9%	30.8 min ± 2.4%
25°C	23.9 min ± 1.6%	38.2 min ± 3.1%
20°C	30.3 min ± 2.2%	48.5 min ± 2.9%
15°C	36.8 min ± 2.2%	59.6 min ± 2.7%
10°C	48.2 min ± 1.3%	78.8 min ± 1.9%
5°C	63.2 min ± 1.4%	104.0 min ± 1.6%
0°C	87.1 min ± 1.3%	145.7 min ± 1.4%
-5°C	123.6 min ± 0.6%	207.0 min ± 0.9%

Overview of charging times at three-electrode test cell level showing the mean value and standard deviation at ambient temperature T_A

Driver for research

- Fast charging can negatively affect the durability when the charging rates are chosen inappropriately. The underlying accelerated **aging process**, when charging a graphite-based lithium-ion cell with improperly chosen charging rates, is the deposition of metallic lithium on the surface of the graphite particles, known as **lithium plating**.
- The metallic lithium immediately reacts with the electrolyte and forms a passivation layer. The result is an irreversible **loss of capacity**.

Conclusion

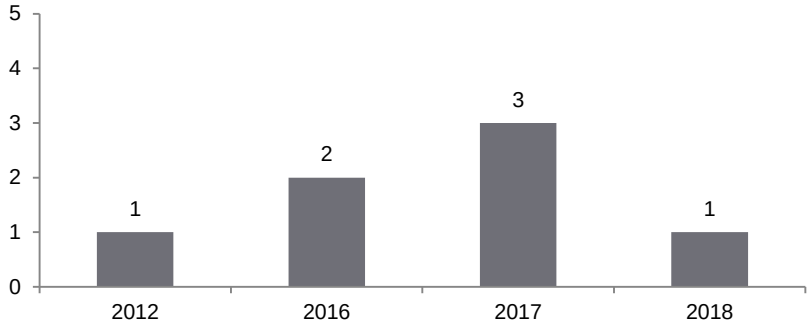
- Cycle life tests showed that the inhomogeneous current density in a large-format pouch cell has to be considered. For that, the charging current was reduced by 10% and, as a result, local lithium plating was prevented at the edge area of the cells.
- Cycle life tests revealed that the charging current has to be reduced over lifetime. An approach reducing the charging current in dependency of the cells' resistance increase over lifetime yielded to an extended cycle life.

03 Startups Tracker highlights in Q3’19

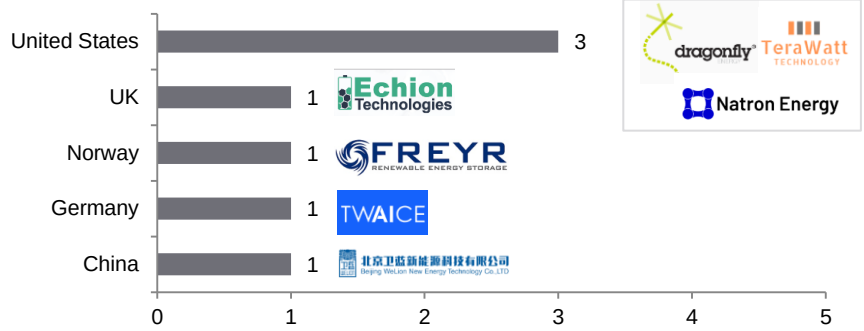
Startup Tracker summary

Segmentation of 7 new startups covered during Q3 2019 with major focus on Solid-State battery

Startups by founding year



Startups by geography for the 7 new startups we've included in Q3'19



Startups by technology

TWAICE

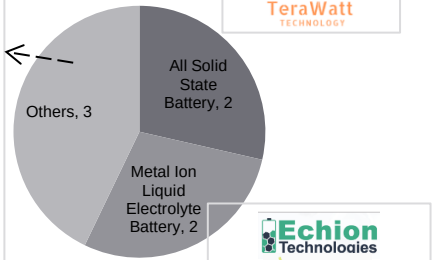
Battery management systems

FREYR RENEWABLE ENERGY STORAGE

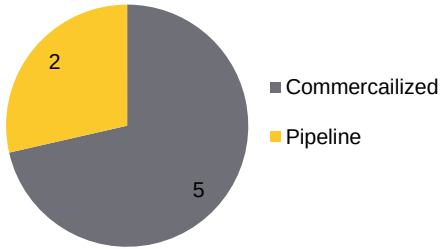
To provide cost competitive battery cell supply

Natron Energy

Developing a new high power, long cycle life, low-cost battery technology

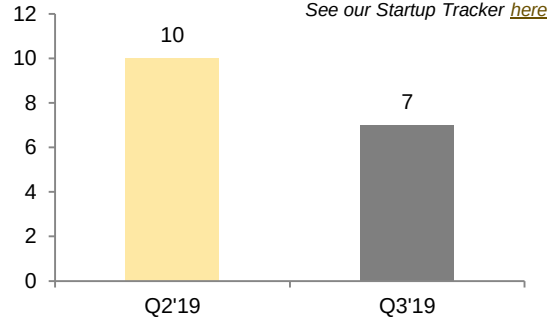


Startups with Commercialized and Pipeline products/solutions/technology



New startups added to our Tracker

See our Startup Tracker here



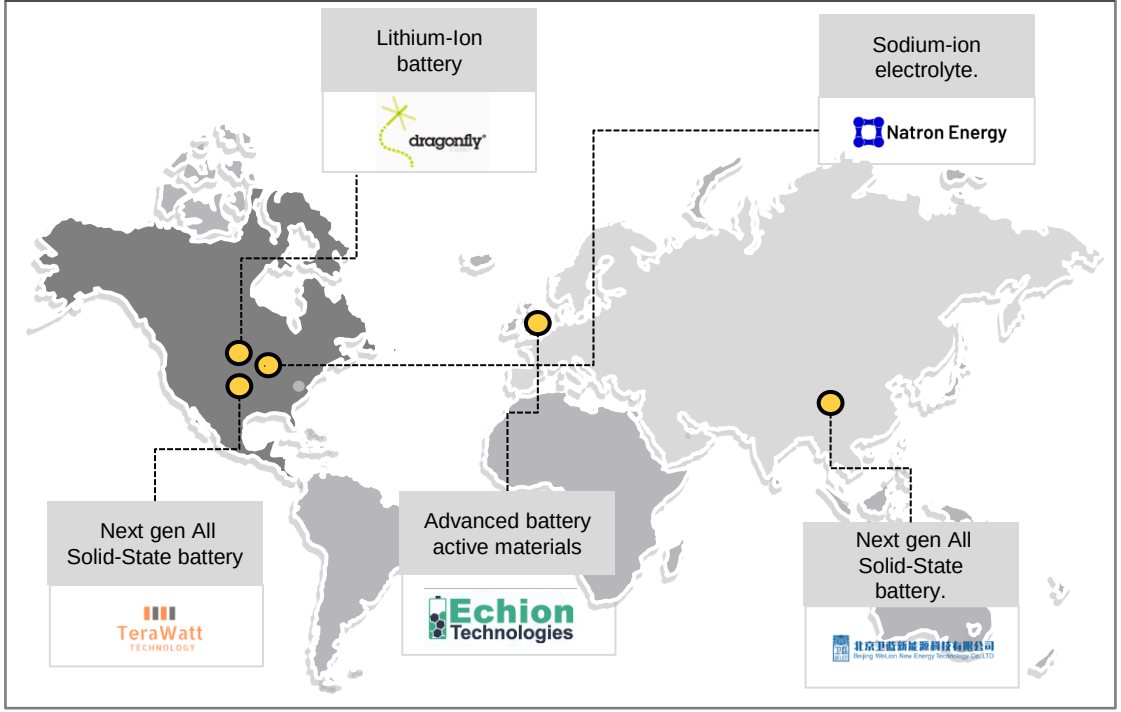
FutureBridge

What are the hubs of startup innovation for Battery Energy Storage

Solid-State battery is the major area were startups are working as the automotive industry is moving towards commercialization of solid-state technology

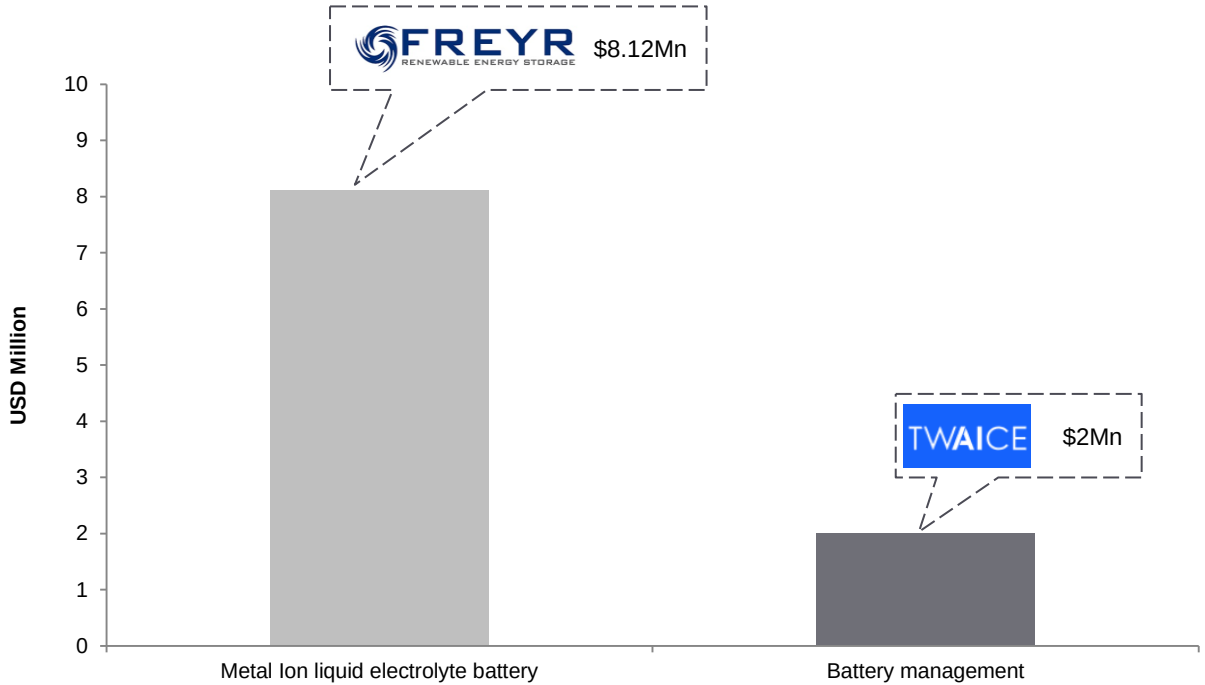
- Out of the **7** new startups we have included in our Tracker in **Q3 2019**, 43% focus on Other battery technologies and components mainly cathodes, electrolytes and even software's for battery management).
- Almost 29% are working on **Solid-State** battery technology owing to the growing interest of OEMs to commercialize the technology.
- The majority of Startups covered in Q3'19 are emerging from **USA** and others are equally shared between UK, Norway, Germany and China.
- Almost all startups have commercialized product/solution/technology portfolio.
- TeraWatt Technology announced that its 4.5Ah prototype solid-state battery design achieved a record-breaking energy density of 432Wh/kg (1122Wh/L).

Key startups from major hubs in automotive Battery Energy Storage



Funding distribution & activities

Startups continue to receive funding in Q3'19 with maximum amount flowing towards production of Lithium-ion batteries.



- 3 out of the 7 new startups we have included in our Tracker in **Q3 2019** received funding.(For one startup funding amount was not announced).
- FREYR AS will use the funding amount to build a **32 GWh** giga-factory that will produce Lithium-Ion Battery (LIB) cells based on proven in-licensed technology.
- Startups like Natron Energy are also receiving funding for development of charging infrastructure for EVs.

Startup highlight – Solid Power's focus on commercialization of solid state battery

Official website: https://solidpowerbattery.com/

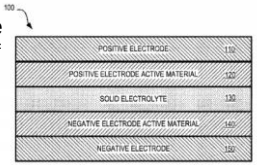
Link to the Mobility Insider platform for Solid Power's profile:
https://industryinsider.futurebridge.com/company/details/5b8a462aea6a14a54fd9a0cc

PATENTS

WO2018183365A1

Solid electrolyte material and solid-state battery made therewith

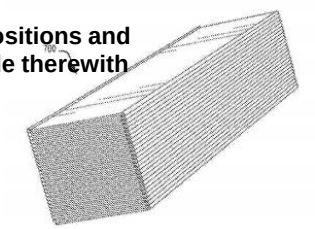
Patent relates to a solid electrolyte material comprising of Li, T, X and A were T is at least one of P, As, Si, Ge, Al, and B; X is one or more halogens or N; A is one or more of S and Se. The solid electrolyte material has peaks at 17.8° ± 0.75° and 19.2° ± 0.75° in X-ray diffraction measurement with Cu-Kα(l,2) = 1.5418Å and may include glass ceramic and/or mixed crystalline phases.



CN107534135A

Binder and slurry compositions and solid state batteries made therewith

Patent discloses various embodiments of binder and slurry compositions and methods of making a solid-state battery.



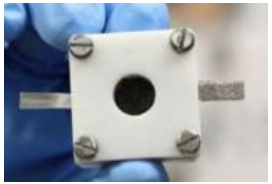
TECHNOLOGY

- **All Solid-State battery:**

➢ Solid Power's solid-state batteries (ASSB) replace the liquid electrolyte in a conventional lithium-ion battery with a highly stable solid ion-conducting material. As a result, ASSBs are inherently more stable across a broad temperature range while also enabling more efficient cell and pack designs as containment of a liquid is no longer required.

➢ The company has developed inorganic solid electrolyte materials that are uniquely suited to their intended use.

➢ High cell-level energy is enabled through the use of metallic lithium as an anode, a material with a capacity 10 times greater than the graphite anodes used in current lithium-ion batteries



➢ **Advantages:**

➢ Deliver greater than 50% more energy density compared to the best available rechargeable batteries.

➢ Safer battery with a simplified cell architecture.

ACTIVITIES

Investment/Acquisition/Funding

- Funding
  - Apr , 2019| Series B | Ford Motor
  - Sep , 2018| $20M / Series A | Hyundai CRADLE, Samsung Venture Investment Corp., Sanoh Industrial Co., Solvay Ventures, and A123 Systems.

Collaboration/Partnership

- Ford partnering with Solid Power to develop solid-state batteries for next-gen EVs.
- BMW teams with Solid Power on battery technology

Competitors

ENERDEL seeo oxis ENERGY

News

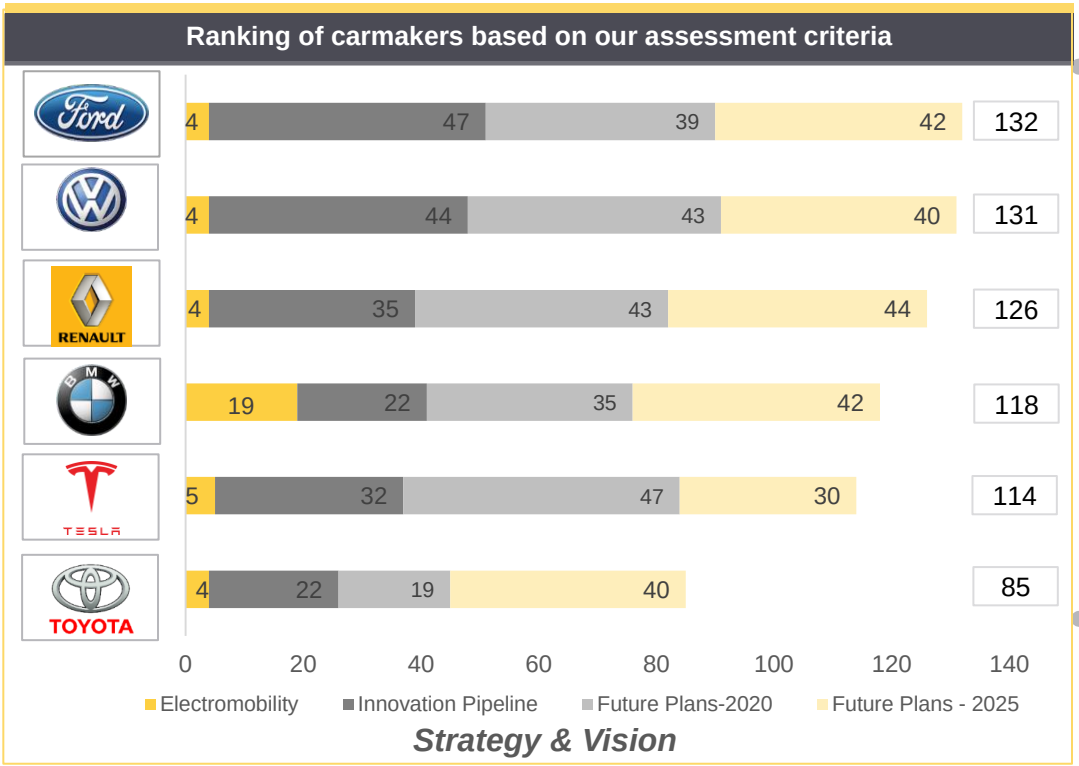
- Sep , 2019| Solid Power pilot production line operational, producing solid-state batteries

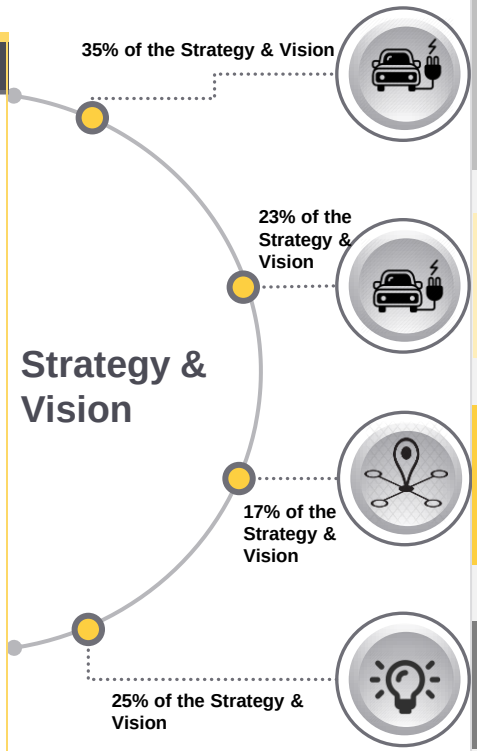
04 Snapshot from our Electro-mobility carmaker Leaderboard

FutureBridge's Electro-mobility Carmaker Leaderboard -2019

Forward-looking ranking of major OEMs based on 3 factors:

1. **Strategy & Vision**: Learn how they rank across the different parameters
2. **Innovation & Technology:** See our H1'19 Deep Dive
3. **Market Leadership**: in our upcoming deliverables





Parameters

Vehicle Pipeline & Future Plans – 2020

- No of new Electric models by 2020
- No of new Hybrid models by 2020
- Electric Brand Development
- No of electric concepts & prototypes
- 2020 EV/Total portfolio ratio

Vehicle Pipeline & Future Plans – 2025

- No of new Electric models by 2025
- No of new Hybrid models by 2025
- 2025 EV/Total portfolio ratio

Electromoblity

- Streaming operations, Mobility / Multi-modal Systems
- If offering electromobility service
- Investment done by OEM in electromobility

Innovation Pipeline

- Electrification-related publications
- Patents
- Consortia, collaborations, innovation partnerships

Source: FutureBridge forecasting

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