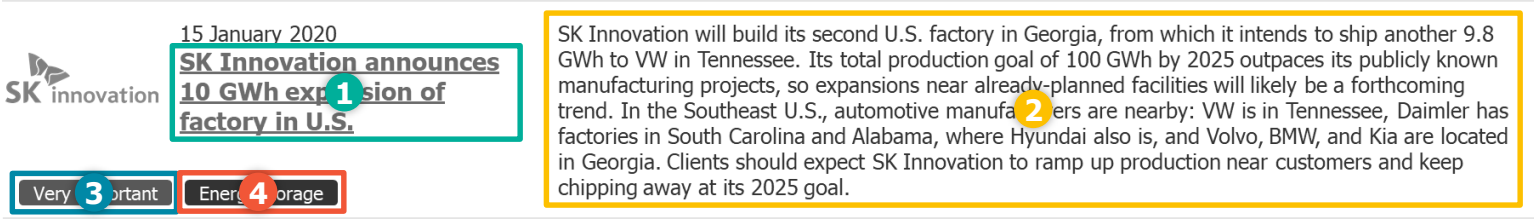
Singapore Battery Consortium

2021 Q3 Newsletter

SINGAPORE BATTERY CONSORTIUM

Understanding curation of recent industry developments and technology news

Recent industry developments and technology news are specifically curated based on the relevance to the progression of the industry. Each news event is categorized based on importance and area of focus (see below for description for both).



1. **Link**: Hyperlink to original news article. Note some news articles may be behind paywall.
2. **Analysis**: Writeup of the news event as it relates to industry development and recommendations for action.
3. **Importance**: Take on the potential importance of the event from "Truly Disruptive" to "Ignore"
4. **Area of Focus**: Category of the news event based on the to the topic.

Importance	Description
Truly Disruptive	A game-changing, landmark development
Very Important	Significant news that will have strong implications
Average Importance	Worth noting, but not likely to be too important or disruptive
Low Importance	An over-hyped development, which is not worth monitoring closely
Ignore	Misleading or irrelevant development, worth being cautious about

Area of Focus	Description
Built environment energy use	Hardware and software technologies for commercial and residential energy consumption
Business models and regulations	Novel business models for energy production, consumption, and distribution, as well as policies with transformational impact on new energy technology development
Energy for mobility	Energy sources for powering road, rail, aviation, and marine – includes movement of goods and people
Energy storage	Various forms electrochemical energy storage, such as Li-ion and solid-state batteries
Stationary storage	Utility-scale and long-duration energy storage for grid services, renewables integration and backup, and microgrid support

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

China's proposed ban on second-life Li-ion battery use a boon for battery recycling technology developers

30 June 2021

Tesla transitions to LFP in its Megapacks

Very Important | Stationary storage

Though Tesla has consistently used nickel-based cathodes in its products – NCA cathodes in its vehicles and NMC in its stationary storage products – the company announced it would begin using LFP-type cathodes in its stationary storage line of products. The move was probably motivated by several factors, but costs and supply chain concerns are likely at the top of the list. Prices for LFP-type cathodes dropped faster than those of Ni-based counterparts in recent years, with the chemistry now cheaper on a $/kWh basis, while concerns over the availability of Ni-based cathodes have pushed Tesla to use LFP in some of its vehicles.

9 July 2021

China proposes ban on second-life Li-ion battery use in large stationary storage projects

Very Important | Stationary storage

The new regulations aim to address safety concerns over retired batteries from BEVs. Although system size was not defined, the policy would impact a large portion of China's energy storage demand, making it a decisive loss for second-life applications. With increasing concern about material supply for Li-ion batteries and in the absence of second-life Li-ion energy storage, lower-cost alternatives like Na-ion and flow batteries could capitalize on this opportunity. The loss of second-life applications will also cement China's dominance in battery recycling.

19 July 2021

Neometals announces Li-ion battery recycling demo plant

Average Importance | Energy storage

Following the announcement of its spinoff for nickel sulfide operations in Australia, Neometals formed this JV with SMS Group to commission a Li-ion battery (LIB) recycling demonstration plant in Germany. Neometals already claimed to develop a sustainable process targeting end-of-life LIB and plans to recover materials like lithium cobalt oxide and nickel with this plant. The initial phase will involve shredding, though it plans to use hydrometallurgy at a later stage. With the disposal of spent batteries becoming a challenge, clients interested in this development should note that the JV is indicative of a slowly maturing recycling industry, but dreams of a circular economy won't be realized until hydrometallurgy successfully scales.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

Potential raw materials supply chain shortage remains a key concern for automaker electrification ambitions

23 July 2021

GM invests in U.S. lithium project to secure future material supply

Average Importance | Energy for mobility

GM will make a multimillion-dollar investment in Control Thermal Resources' geothermal brine lithium extraction project near the Salton Sea in California. Extracting lithium from geothermal brines has long been considered as a viable alternative to brine evaporation ponds or hard rock mining, but it contains more impurities than traditional sources. Neither cell manufacturers nor OEMs are well-positioned to directly enter the extraction industry, which requires specialized expertise; however, investment in existing or upcoming project is one of the best ways to secure future supply. Clients should view this move as one of the better ways to vertically integrate.

23 July 2021

Group14 and SK Materials announce JV to develop lithium-silicon anode materials

Very Important | Energy storage

The announcement comes following Group14's successful Series B round, which was led by SK Materials in December. With a further investment of $52 million by SK Materials, the company is looking to develop a manufacturing hub in South Korea. The JV follows Group14's April announcement of a commercial-scale manufacturing factory it had launched in the U.S. SK Materials is one of the leading producers of silane gas, an important factor Group14 can leverage, as Group14's process requires a gaseous silicon infiltration step.

23 July 2021

Form Energy emerges from stealth mode with iron-air long-duration chemistry and $200 million in funding

Very Important | Stationary storage

While Form Energy had been pursuing both iron-air and polysulfide-air batteries, it emerged from stealth mode touting its iron-air chemistry, with $200 million in funding led by ArcelorMittal, a strategic investor and major supplier of iron ore. While the claimed $6/kWh in materials and $20/kWh for complete systems will capture the most headlines, clients should recognize that the low efficiency and cycle life of metal-air batteries will limit the impact of this chemistry to applications like seasonal storage, where it will compete primarily with hydrogen. While a promising long-duration chemistry, its value will only be captured when grids exceed 80% penetration of renewables, which most large economies won't reach for a decade or more.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

Europe continues to make progress towards establishing the region as a major battery and EV manufacturing hub

5 August 2021

Nissan announces EV36Zero Electric vehicle hub in U.K.

Average Importance | Energy for mobility

The EV36Zero hub will be centered around the existing plant; by partnering with Envision AESC, the company is looking at creating a hub capable of manufacturing electric vehicles and batteries and also involves the battery recycling process. It may not come as a surprise as Envision AESC has been manufacturing EV battery cells, modules, and packs since 2012 in the U.K., and Nissan claims that the hub will help in ramping up the production rate. Although the center has yet to start functioning, clients interested in this development should note that Nissan can gain an advantage in the EV production chain across Europe through this manufacturing ecosystem.

9 August 2021

Heart Aerospace lands $35 million Series A round and announces potential orders for 200 aircraft

Average Importance | Energy for mobility

United Airlines directly invested in the round through its venture arm along with the smaller regional partner of United Mesa Airlines. While the $35 million Series A round is in line with similar funding rounds from other companies like ZeroAvia, the orders for 200 planes caught the most headlines. However, like many early-stage orders, these are not firm orders and are conditional upon the company meeting certification and performance milestones. Heart is differentiated from other electric aviation companies in that its main focus is not on maximizing range (it can only fly roughly 250 miles on a single charge) but instead on reducing costs to make it attractive for short flights.

12 August 2021

Tesla sells Maxwell Technologies but retains the dry battery electrode technology

Average Importance | Energy storage

After acquiring the company in 2019, Tesla sold Maxwell Technologies to ultracapacitor company UCAP Power but retained the dry battery electrode (DBE) technology. Tesla expects Maxwell Technologies' DBE to be a key to reducing cell manufacturing costs, and Lux had also predicted Tesla's core interest in DBE. The company never integrated the ultracapacitors into any of its products and has focused on 4680 cells, a new form factor announced during Battery Day. Although Tesla is keen to commercialize the DBE technology, it has so far not succeeded in achieving a commercial-ready product. For UCAP, a company consisting mostly of former Maxwell Technologies employees, the acquisition expands its technology portfolio.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

Electric vehicle charging remains critical and underdeveloped part of the value chain

13 August 2021

TotalEnergies acquires Blue Charge to operate Singapore's EV charging network

Average Importance | Energy for mobility

The deal will see TotalEnergies acquire more than 1,500 electric vehicle chargers from Bolloré Group, and the company will take over Blue Charge, which is currently the largest EV charging network in Singapore. As part of Singapore's Green Plan 2030, the company will manage the network along with the Land Transport Authority and other partners. This may not come as a surprise, as TotalEnergies has been actively involved in developing the public charging infrastructure in global cities and has been targeting operating about 150,000 charging points by 2025.

17 August 2021

SVOLT closes $1.6 billion Series B for nickel-manganese (NMX) cells

Very Important | Energy storage

Following a $538 million Series A in February 2021 and the launch of its NMX cells, SVOLT has raised an additional $1.6 billion that will enable R&D of novel cathodes and construction of new manufacturing facilities. SVOLT's cells reportedly achieve an energy density just 5% lower than incumbent NCM cells and have improved calendar life. Clients should note SVOLT's high momentum – besides the short interval between two major funding rounds, it claims to have secured 25 customers for its product and plans to scale its battery capacity from 12 GWh to 70 GWh next year.

19 August 2021

EV charging provider Allego to go public in Q4 2021 through SPAC deal

Average Importance | Energy for mobility

Dutch electric vehicle charging infrastructure provider Allego will go public through a merger with Spartan Acquisition Corp., a special-purpose acquisition company, in a deal that values the equity of the combined company at $3.13 billion. Allego already has strategic partnerships in place with more than 50 real estate owners and 15 OEMs and has deployed more than 26,000 charging ports across 12 countries. The funding received from the IPO is expected to help with the capex associated with further expansion. The deal, which includes private investments from automakers like Fisker, could incentivize ecosystems that increase consumer adoption of EVs; clients should monitor to see if Allego forms similar partnerships with other automakers.

Battery swapping gains traction as alternative to electric vehicle fast charging

25 August 2021

SK Innovation announces spinoffs for separate battery and exploration and production businesses

Average Importance | Energy storage

Following the split of SK Innovation's business, it will become a holding company for the activities of both new companies. In July 2021, SK Innovation held Story Day, where the company expressed a new focus on climate technology, pledging carbon neutrality for its green business by 2030 and for its fossil fuels business by 2050. Story Day additionally revealed that SK Innovation may use the opportunity to take the battery company public. A division of business activities is to be expected; battery manufacturing is a capital-intensive project, but the separation will attract eager clean tech investors to its battery business.

27 August 2021

French battery startup Verkor raises $118 million for battery manufacturing facility

Average Importance | Energy storage

EQT Ventures and Renault led the funding round along with investors like Arkema, Schneider Electric, Tokai Cobex, and EIT InnoEnergy. The funds will be used to construct Verkor's innovation center, which will focus on the construction of a pilot line facility for battery testing. It does not come as a surprise as Europe is quickly becoming a major battery development hub and the government is providing support to the local manufacturers and has announced stronger incentives for BEV adoption. Clients interested should recognize that Verkor will join the group of early-stage startups that will play a crucial role in battery manufacturing across Europe in the next five years.

27 August 2021

Ample raises $160 million to scale battery swapping network

Very Important | Energy for mobility

Ample emerged from stealth mode in March and has since made several high-profile announcements, including partnerships for testing with Uber in the U.S. and with Eneos in Japan. This latest announcement is an important next step, ensuring the company can continue to focus on developing its technology – which currently takes between 10 minutes and 15 minutes for a full swap – and more importantly scale its solution to more locations. Clients should continue to view Ample as the battery swapping leader outside of China, closely watch for further partnerships with automakers, and take note that large funding rounds have preceded SPAC mergers, which may be a target for Ample.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

Li-ion likely to remain dominant form of stationary storage for next decade, but activity continues for novel chemistries

27 August 2021

GAC demonstrates eight-minute charging with graphene-based batteries

Average Importance | Energy for mobility

Following the company's claims of 6C charging during its graphene battery launch this year, GAC's technology day showcased its use in a vehicle. The upcoming GAC Aion V will come in two versions, one with a slower 3C charge (16 minutes from 0% to 80%) and another with a faster 6C charge (eight minutes from 0% to 80%). Though this is an impressive technical feat, the required 500 kW of power is more than existing fast chargers can supply, and the company announced it would be building its own network with 100 stations this year. It also didn't provide useful details on cycle life, which is likely poor with frequent fast charging at this speed.

2 September 2021

Ambri raises $144 million for long-duration energy storage application

Average Importance | Stationary storage

Reliance New Energy Solar led the round, along with Paulson & Co., Bill Gates, and several other investors. The investment will support Ambri in commercializing its proprietary liquid-metal battery technology, with a goal to expand manufacturing capabilities across the globe. The company will develop calcium- and antimony-based electrodes. Although Ambri has continually missed its deadlines, it has managed to receive a significant amount of funding from the Indian company this round to support India's pursuit of nonlithium battery chemistries, as the country has no domestic lithium supply chain.

6 September 2021

United Energy to roll out "Australia's largest community battery"

Very Important | Stationary storage

The Electric Avenue program includes 40 30 kW batteries, which United Energy will mount on power poles along its distribution grid in Melbourne, Australia. The utility is implementing its own small-scale front-of-meter (FTM) distributed energy storage system, which can improve grid reliability and avoid costly investments to upgrade grid infrastructure in order to accommodate the growing number of residential rooftop solar installations. United Energy's Electric Avenue will allow taking care of utility needs first, unlike with behind-the-meter (BTM) systems, such as Sonnen's or Moixa's, that first intend to increase self-consumption of on-site generation and enable energy bill reductions.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

Major battery recycling startups continue to raise funding for commercial expansion

9 September 2021

Redwood Materials raises $700 million to finance its battery recycling expansion

Very Important | Energy storage

In 2019, Redwood Materials partnered with Panasonic to recycle nearly 3 GWh/year of battery scrap. In early 2021, Redwood announced its second customer, Envision AESC, to recycle manufacturing scrap and supply the recovered materials back to AESC. Redwood's recent funding will provide the necessary capital injection to expand its recycling capacity, hire personnel (it plans to grow from 150 to 600 employees), and scale its technology to reduce the overall cost of recycling. Clients interested in participating in the battery recycling value chain should look to companies like Redwood, Battery Resourcers, and Li-Cycle.

9 September 2021

South Korea to invest $41 billion to compete in the electric vehicle space

Average Importance | Energy for mobility

South Korea will invest $41 billion to boost the electric vehicle market by the end of the decade. The announcement follows after Korea's battery manufacturers reported positive performance in 2020. The trio of LG Energy Solution, SK Innovation, and Samsung SDI are planning to invest in research and development and have planned to develop a battery technology training institute by 2023. Moreover, the cell manufacturers aim to make Korea a major hub lest other groups encroach on their market share. Clients should expect competition to intensify as battery demand increases and the market continues to expand globally.

13 September 2021

Sicona raises $2.7 million to scale up its silicon-graphite anode production

Average Importance | Energy storage

Artesian and Riverstone Ventures led the round, along with Chaos Ventures, Bandera Capital, and SDGx Ventures, among others. The funding follows the company's successful $1 million seed round in July 2020 and a $704,000 grant by the Australian government in late 2020. Sicona is currently developing silicon-graphite composite anodes and is looking at deploying commercial-scale production plants in Europe and North America. In a crowded silicon-anode market segment, the company has managed to raise funds and test its anodes, with metrics comparable to startups like Volt14 Solutions. Clients should recognize that Sicona is an early-stage company and monitor its roadmap toward pilot manufacturing and commercial deployment.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

Traction for next-generation batteries in consumer electronics key step in wider adoption in electric vehicles

16 September 2021

LG Energy Solution fully acquires NEC Energy Solutions

Average Importance | Energy storage

The acquisition will provide a foothold for LG Energy Solution (LGES) in the U.S. energy storage market and will give the company further control over its ESS battery product. Recently, LGES batteries at the 300 MW Moss Landing project overheated, though no fire was reported. With the safety of Li-ion ESS becoming a larger concern as system sizes expand, battery analytics becomes a necessary safety mechanism. NEC has both the software and the experience to help LGES become a safer technology provider. Notably, LGES has historically only made nickel-based cell chemistries, while NEC primarily used LFP.

23 September 2021

StoreDot announces fast-charging silicon-dominant 4680 cylindrical cell prototype

Low Importance | Energy storage

StoreDot claims to have demonstrated a 4680 form factor prototype that can charge in 10 minutes. The prototype, which is currently undergoing a scale-up process at EVE Energy, has been a form factor favored by Tesla. StoreDot's XFC technology aims to reduce the charging time by replacing graphite with silicon, and it has filed for a patent on introducing the "Booster" function, which the company claims is key for its fast charging technology. However, we do not view this as a significant development, as the chemistry of the battery has not changed, and StoreDot has not disclosed any performance metrics related to the prototype.

23 September 2021

Sila Nanotechnologies to integrate its silicon anode materials in Whoop's fitness wearable

Very Important | Energy storage

WHOOP 4.0, a health and fitness wearable by Whoop, will use the silicon anode materials developed by Sila Nanotechnologies. Although Sila has secured partnerships with BMW, Daimler, and Amperex, its primary target has been consumer electronics applications. This can be viewed as a major development in the utilization of next-generation chemistry in commercial products, and Sila's roadmap toward commercialization is on track with the integration of anode materials. Although key issues like swelling still persist in silicon anodes, clients should regard this is as an important milestone and recognize that the timelines will be similar for the commercialization of silicon anodes for EVs.

SOLID-STATE BATTERIES

Improving energy density, safety, and lowering costs

Solid-state batteries have emerged as a promising candidate to replace conventional liquid electrolytes in today's Li-ion batteries, enabling the use of active materials can store more energy while also improving safety. Despite these advantages, solid-state batteries have yet to break into high-volume applications such as cell phones, tablets, or electric vehicles due to high costs, low power output, and poor room temperature performance.

However, rapid advancements in manufacturing processes and high-profile investments in the technology are improving performance and driving solid-state batteries nearer to commercial adoption. Of the various material chemistries, polymer electrolytes are the most mature technology, while ceramic and composite materials will need a longer time to commercialize. The first commercial of solid-state electrolytes in battery electric vehicles (BEVs) will unlikely occur earlier than 2030.

Source: QuantumScape

SOLID-STATE BATTERIES

Next-generation batteries replacing conventional liquid electrolytes with solid ion-conduction materials

WHY IT MATTERS

Today's incumbent lithium-ion batteries are hitting a performance plateau, and developers of electric vehicles and consumer electronics are looking to next-generation batteries like solid-state to improve specific energy, increase safety, and lower costs, with plans of commercialization by 2030.

HOW IT WORKS

Instead of a conventional liquid electrolyte, solid-state batteries use a solid material like a polymer or a ceramic to transfer ions from the anode to the cathode and vice versa; the solid electrolytes are nonflammable. These solid electrolytes replace the separators and liquid electrolytes.

KEY PLAYERS

Solid-state batteries attract a varied mix of stakeholders, ranging from automotive players like Toyota and VW to cell suppliers like Samsung SDI, CATL, and LG Energy Solution. There is an increasingly strong field of startups to watch as well, where much of the best work is being done.

CHALLENGES TO OVERCOME

While significant progress has been made in the increase of C-rates and cycle life, key technical hurdles remain – the manufacturing process has been a challenge and integrating solid electrolytes with lithium anodes without getting dendritic growth has been key to improving performance.

SOLID-STATE BATTERIES

The advantages and disadvantages of solid-state batteries

Solid-state batteries use a solid ion-conducting material which acts as both separator and electrolyte.

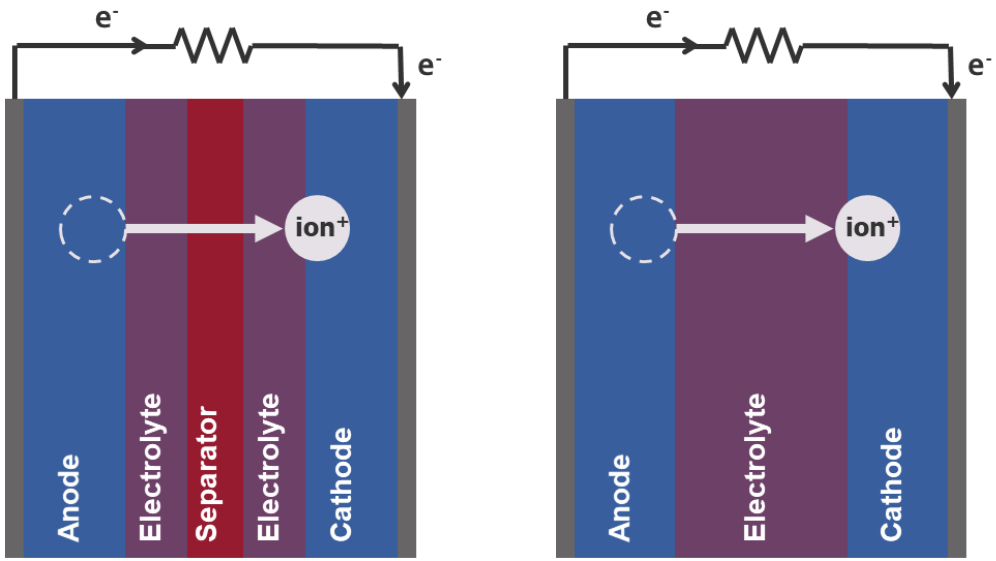
Advantages

- Solid electrolytes replace flammable liquid electrolytes and are more effective at preventing shorting, leading to improved safety.
- Metallic lithium anodes offer substantial improvements over graphite, but low cycle life and safety concerns have prevented the use of them. Solid electrolytes enable the use of lithium, resulting in higher energy densities of up to 350 Wh/kg and 900 Wh/L.

Disadvantages

- Most solid-state batteries have been unable to adopt conventional roll-to-roll manufacturing, leading to high costs at small production scales.
- Commercialization of solid-state batteries remains limited by a lack of mature supply chain for key materials and more importantly a lack of maturity – metrics like power output and electrolyte thickness limit the technology's appeal.

The first generation of solid-state batteries will likely adopt conventional Li-ion chemistries due to its well understood performance and mature supply chain. However, solid electrolytes can also enable a number of new chemistries as well.

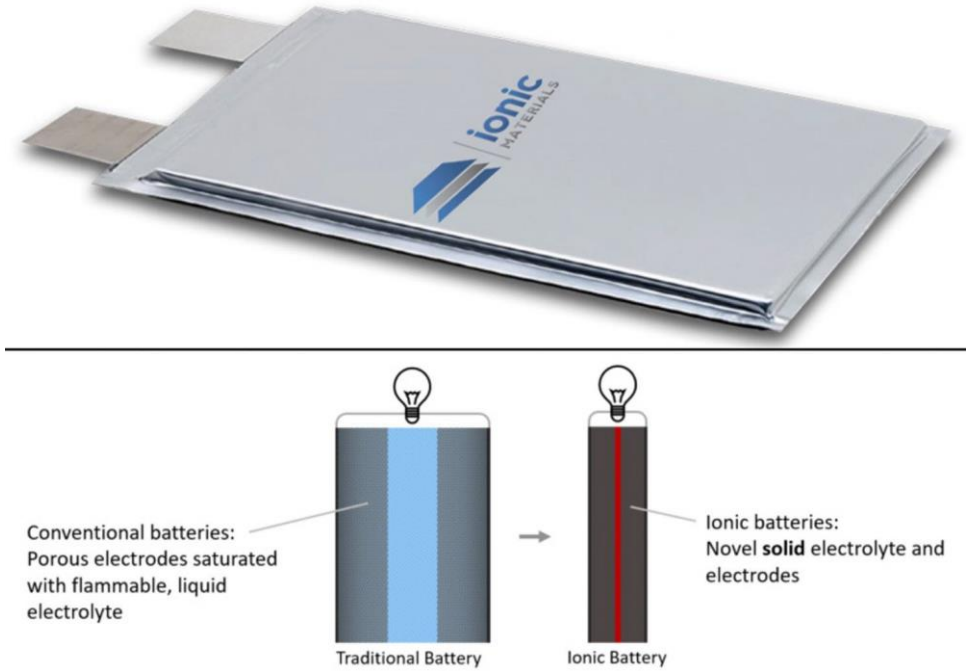


Schematic comparison of liquid electrolyte and solid-state electrolyte batteries

Solid electrolytes are not limited to lithium-based chemistries and are being pursued with other chemistries

Solid electrolytes are not limited in use to today's Li-ion chemistries, and they can enable more advanced chemistries using potentially lower cost materials. This is particularly important as cost reductions from economies of scale and improved production processes reach their limit; lower-cost active materials offer a promising path to future cost reductions. Other chemistries being investigated include:

- **Lithium-sulfur (Li-S):** Li-S batteries using conventional liquid electrolytes suffer from capacity loss from polysulfides shuttling from the cathode to anode that result in poor cycle life. Solid electrolytes, such as the Li_6PS_5Cl electrolyte in work at the University of Maryland, prevent polysulfide shuttling and could unlock the full potential of Li-S batteries.
- **Alkaline:** Ionic Materials is adapting its polymer electrolyte to enable rechargeable Zn / MnO_2 chemistries like those used in many primary batteries for consumer electronics, due to the low cost of input materials
- **Magnesium-ion (Mg-ion):** Multivalent batteries can potentially carry twice as much energy per ion – in Mg-ion's case two – and therefore offer a promising path to high energy density. Researchers in the U.S. Department of Energy discovered materials that can transport the larger Mg^{2+} ions, possibly enabling the solid-state Mg-ion battery.



Ionic Materials develops a solid polymer electrolyte for Li-ion batteries that achieves a high conductivity of up to 1.3 mS/cm at 20 °C by using the conduction of the lithium ions to move the charge. The company adjusts the polymer's particle size and mechanical properties to accommodate varying chemistries without affecting the ionic conductivity. (Image source: Ionic Materials)

SOLID-STATE BATTERIES

Key solid electrolyte materials under development

ORGANIC POLYMER

Polymers are the most mature solid electrolyte which have been adapted to large-format applications.

Examples

Polyethylene oxide (PEO) is the most common material which has seen commercial viability, and others being researched include polyacrylonitrile (PAN), polyvinylidene fluoride (PVDF), and polyphenylene sulfide (PPS).

Strengths

Most polymers can be adapted to conventional manufacturing techniques, and polymer extrusion is a well understood industrial process.

Weaknesses

PEO polymers have low room temperature ionic conductivity, which results in poor power output and slow charging. Low voltage stability also limits cathode choice and cutoff voltage.

INORGANIC SULFIDE-BASED

Sulfide-based inorganic electrolytes are the closest to commercialization in large-format cells of all inorganic electrolytes.

Examples

LGPS systems ($Li_{3.5}Ge_{0.25}P_{0.75}S_4$ or $Li_{10}GeP_2S_{12}$) and LPS systems ($Li_7P_3S_{11}$ and $Li_{3.25}P_{0.95}S_4$) are the most pursued materials.

Strengths

Sulfide-based materials exhibit mechanical properties which allow for roll-to-roll processing without unreasonably high pressures and are electrochemically stable at both high and low voltages.

Weaknesses

Exposed to air or water, sulfide materials generate toxic hydrogen sulfide gas. This is both a risk, potentially exposing customers to these gases, and an added cost, requiring additional dryroom requirements during manufacturing.

INORGANIC OXIDE-BASED

Oxide-based electrolytes attract less attention than organic polymers or sulfide-based inorganics but show promising performance.

Examples

Lithium lanthanum zirconium oxide (LLZO) is the most commonly investigated material, while many thin-film batteries have investigated lithium phosphorous oxynitride (LiPON) for thin-film batteries.

Strengths

Very high ionic conductivity and wide electrochemical stability offer promising performance, while LiPON can be deposited in thin layers for thin-film and flexible batteries.

Weaknesses

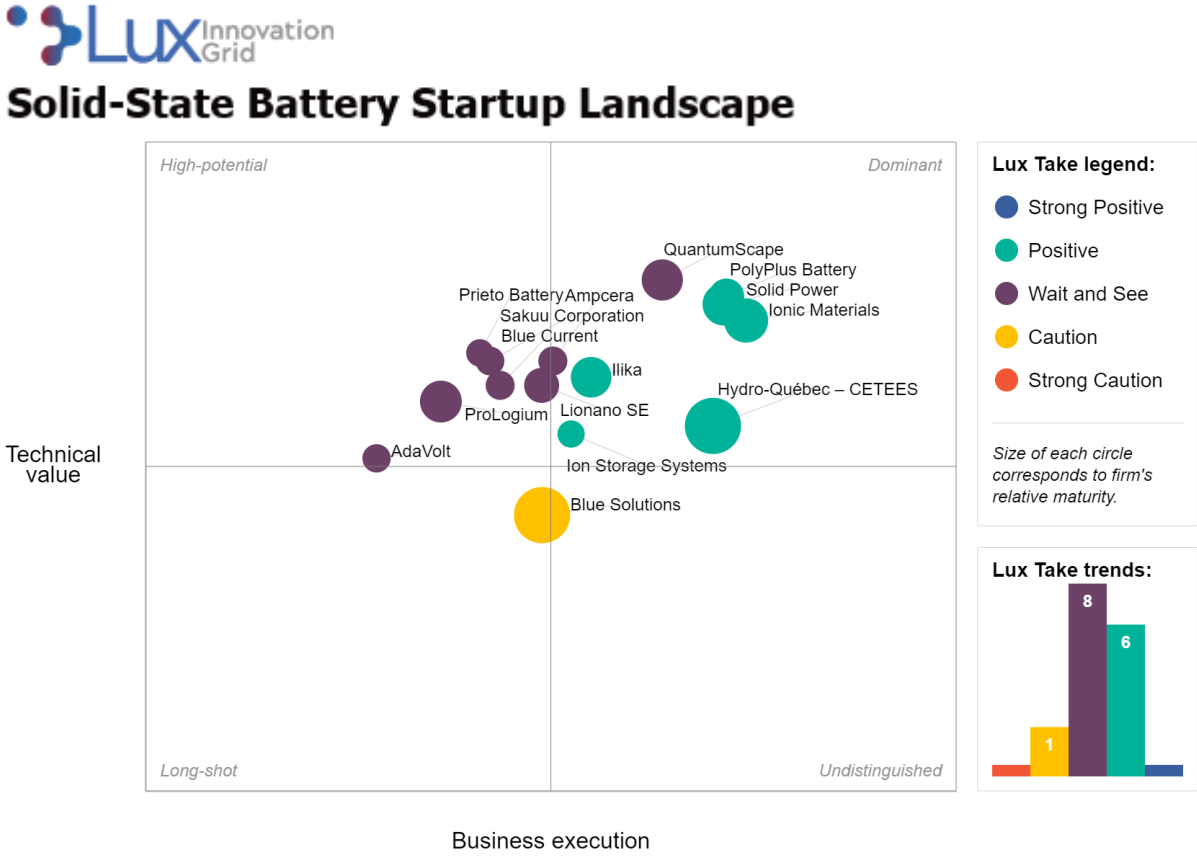
Materials are very brittle and cannot typically be adopted for use in conventional roll-to-roll manufacturing, requiring time and energy-intense deposition processes or tape-casting.

Vibrant startup ecosystem for solid-state batteries continue to push the advancement of next-generation batteries

Within the overall energy storage space, solid-state batteries enjoy a vibrant field of startups, much more so than competing chemistries like lithium-sulfur, lithium-air, and sodium-ion. Moreover, out of the more than a dozen companies Lux Research has evaluated in-depth, a good percentage of companies earn a Lux Take rating of Positive, indicating that there are some great investment, partnership, and acquisition opportunities in this space.

Startups' technology is valued, and technologies like APB's polymer-based solid-state batteries and Ionic Materials' polymer electrolytes are seen as promising. Solid-state batteries have also been a platform for innovation; for example, Sakuu Corporation is developing 3D-printed solid-state battery architectures.

However, companies should be wary that not all players can succeed; the early-stage companies that are developing novel electrolyte formulations are seen as promising, and this provides value to investors, as it can provide differentiation in the solid-state battery industry.



Note: The above is a representative list of solid-state battery startups evaluated on Lux Research's Lux Innovation Grid (LIG) and is not meant to be a comprehensive assessment of all developers in the market. Readers are recommended to focus on the startups with a Lux Take rating of Positive and view these startups as best-in-class in terms of both technology value and business execution.

SOLID-STATE BATTERIES

Key players emerging as leaders in the solid-state battery startup landscape

Solid Power develops and produces solid-state batteries using a sulfide-based electrolyte that is compatible with high nickel and conversion cathodes and either lithium metal or silicon composite anodes. Solid Power is considered a leader due to its advanced manufacturing capabilities and promising performance metrics.

PolyPlus Battery develops glass-protected lithium anodes for semi-solid Li-ion batteries. The anodes are made from sulfide glass, coating in a nanofilm to protect against hydrogen sulfide outgassing, and thin lithium metal. PolyPlus has an extensive IP portfolio and promising lithium anode technology.

Ionic Materials develops a solid polymer electrolyte for Li-ion batteries with a high ionic conductivity of up to 1.3 mS/cm at 20 °C by using the conduction of lithium ions to move charge. Ionic Materials is the clear global leader in solid polymer electrolyte with further opportunities in improving cycle life.

Ilika develops thin-film solid-state batteries using an LCO cathode and large-format solid-state pouch cells for electric vehicles using an NMC cathode. Ilika should be viewed favorably for its micro-batteries, but applications for electric vehicle battery development remains to be seen.

Ion Storage Systems develops an oxide-based solid electrolyte and multilayer ceramics manufacturing process for high-power, high-energy solid-state batteries using lithium metal anodes and a variety of cathodes. Ion Storage Systems specifically focuses on aerospace, defense, and mining where safety and stability are high priorities.

Patent activity witnesses accelerated growth in the past decade as technology moves out of academia

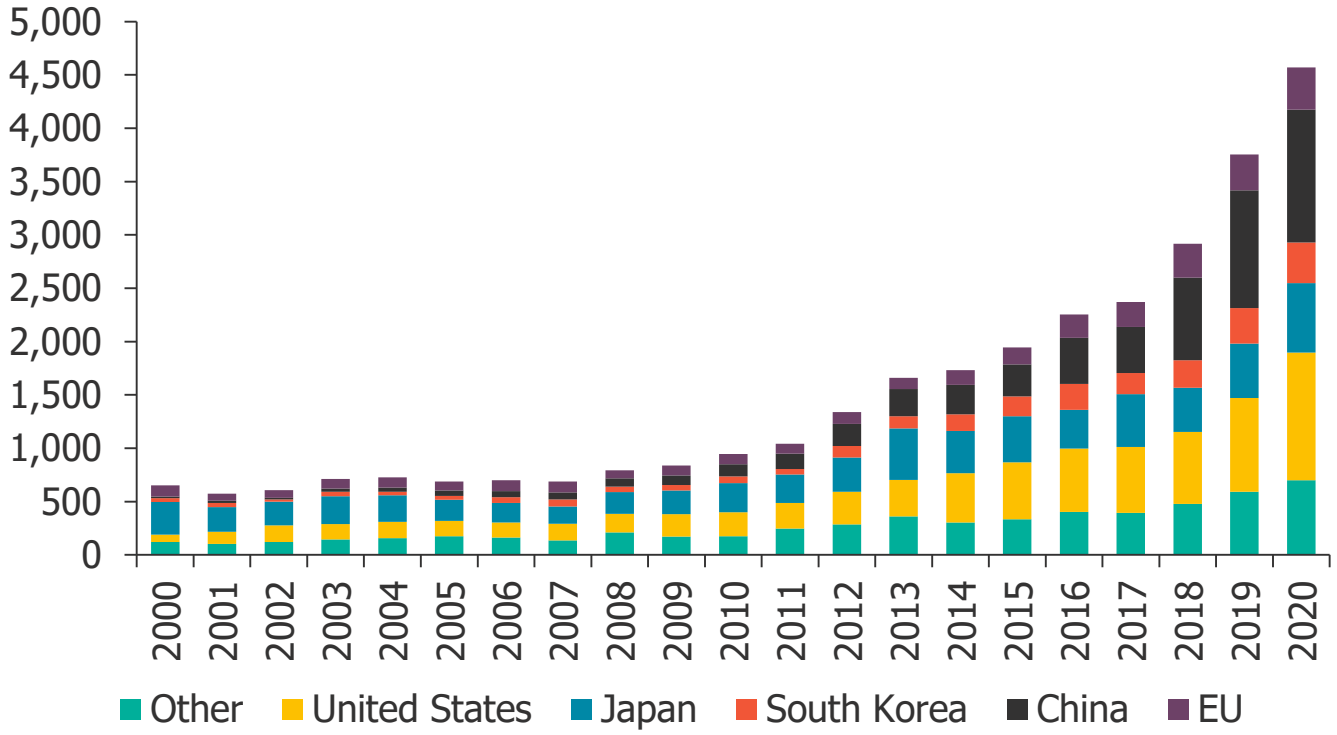
For most of the 1990s and 2000s, the solid-state battery IP space was relatively inactive, reflecting its niche and academic nature at the time. However, this picture has changed dramatically during the past decade as patent publications have been steadily rocketing up in solid-state batteries. While the U.S. and Japan have been long-time leaders in pushing innovation in this area, China has been a big story in the past few years.

Patent activity in solid-state batteries is led by China, which accounts for 27% of the patent publications in 2020. The United States is a close second, losing out its first-place position in 2018 to China. Similarly, Japan continues to be an active country for patent activity rounding out the top three. Up until 2015, it was second only to the United States, but has since been based by China.

Note that patent activity is based on the patent office in which the patent is applied for and granted and not based on the country of origin of the entity that is applying.

Global Solid-State Batteries Patent Activity

Total applications and grants by patent office



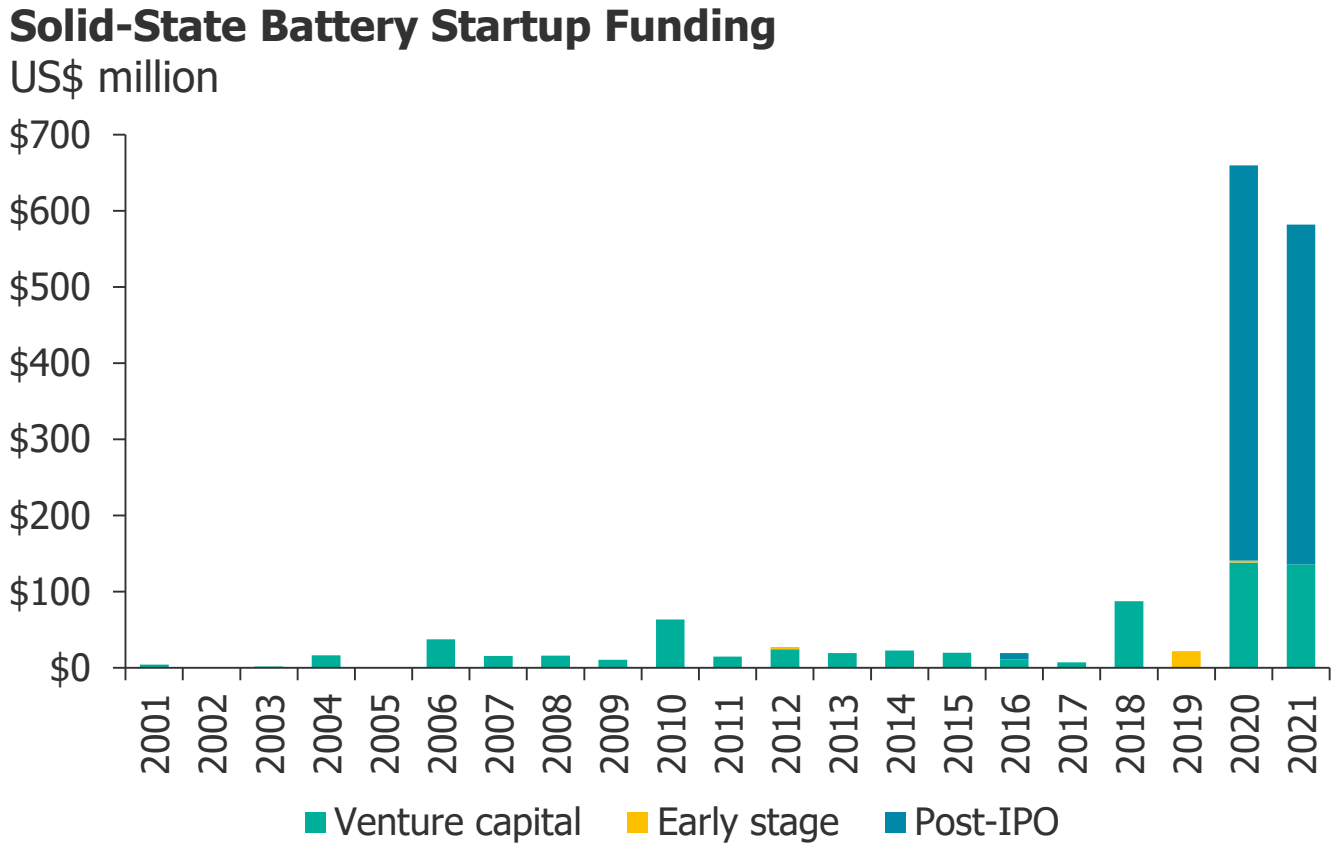
SOLID-STATE BATTERIES

VC and post-IPO funding has led to more than US$1.2 billion for solid-state battery startups the last two years

Solid-state battery investments were sluggish until 2018, when QuantumScape received $100 million in a corporate round with Volkswagen in an effort to commercialize its technology, and the company has cumulatively raised $1 billion in total. Since 2018, numerous strategic investments have boosted the field's investment activity to more than $200 million.

In the first half of 2021, Solid Power took a major step toward commercialization, and in addition to the Series A round for $20 million, Solid Power closed a Series B round for $130 million led by BMW Group, Ford Motor Company, and Volta Energy Technologies.

Automakers and energy companies are betting on solid-state technology to be the winning innovation in Li-ion batteries; however, startups will require far more support to successfully displace liquid electrolyte manufacturing. Automakers like Toyota have made large investments in solid-state batteries, including a JV with Panasonic, but have yet to commercialize the technology. The next decade will see a series of investments by large OEMs in their quest to commercialize solid-state batteries.



SOLID-STATE BATTERIES

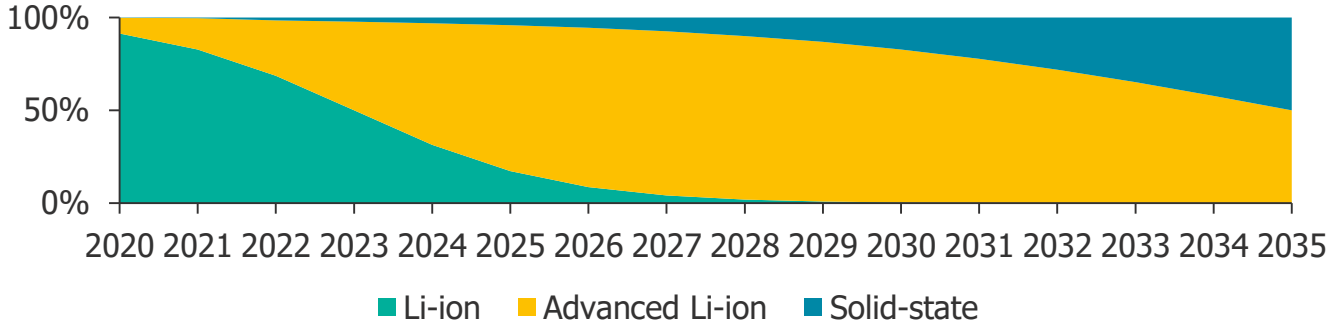
Despite growing momentum solid-state is unlikely to gain market traction until 2030

Consumer electronics, including wearables, cell phones, and tablets, will be first to a adopt solid-state batteries by 2025 as a safer, although more expensive, option in flagship phones and wearable devices. This is despite the fact that solid-state batteries are unlikely to be cost-competitive before 2030, highlighting its niche application in high-end consumer electronic products. Only once solid-state batteries can compete on cost will the consumer electronic market see a significant increase in market traction.

In terms of transportation, the existing supply chain will be the major barrier for commercial use in battery electric vehicles. Longer testing and qualification times, higher price sensitives, and large existing manufacturing capacity for conventional Li-ion batteries will stall meaningful adoption of solid-state batteries until the early 2030s. Initial adoption of solid-state batteries will come from higher-priced and low-production run electric vehicles that are willing to pay a premium for lighter and smaller batteries.

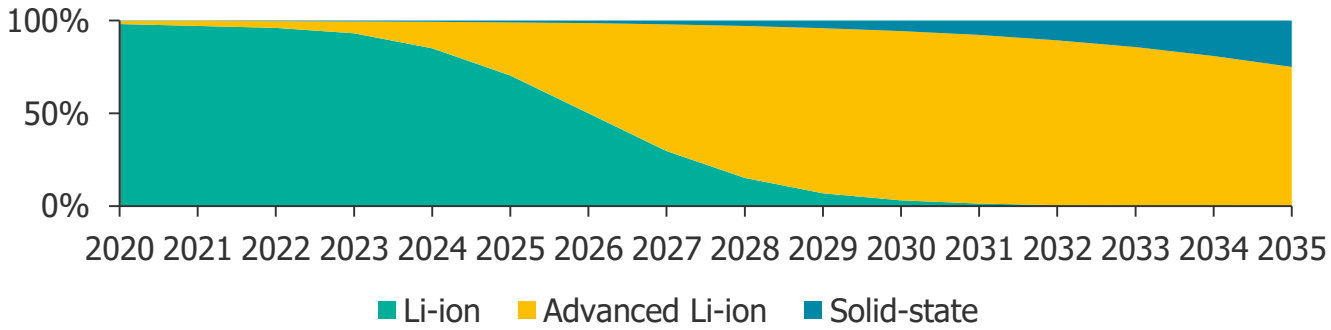
Solid-State Battery Adoption, Consumer Electronics

% market share by battery technology



Solid-State Battery Adoption, Transportation

% market share by battery technology



Solid-state batteries remain a complex problem that require novel innovations along the entire value chain

From 3-4 August 2021, researchers and industry leaders presented their work on solid-state batteries, offering technology progress reports and different perspectives on commercialization at the Solid-State Battery Summit hosted by Cambridge EnerTech. Most notably, the two leading solid-state battery startups, Solid Power and QuantumScape, delivered the two keynote presentations and each outlined its key technology achievements.

The event captured the potential and momentum of solid-state battery developments and its position as the next-generation battery to challenge incumbent Li-ion technology. The overarching takeaway from the summit and a summation of the developments of the solid-state industry thus far is that solid-state batteries are a complex problem that requires new material development, battery design engineering, and manufacturing processes. Without considerable consolidation of technology, each developer are bound to venture down a path and face its own unique problems that would need to be addressed individually.

The forwarding looking statements from developers, combined with the state of technology development lead to three major takeaways for the state of solid-state batteries.

KEYNOTE PRESENTATION

9:00 am **KEYNOTE PRESENTATION: Progress toward Automotive Qualification for All Solid-State Batteries in Passenger Electric Vehicles**

Josh Buettner-Garrett, CTO, Solid Power

As the company prepares a formal A Sample cell, which will be larger and higher capacity than the company's current 20Ah cell, Solid Power will discuss key cell improvements that have been realized through roll-to-roll process improvements and give an overview of the automotive qualification process as it relates to the company's all solid-state cell design.

9:00 am **KEYNOTE PRESENTATION: Lithium-metal Solid-State Battery Development at QuantumScape**

Tim Holme, PhD, Chief Technology Officer, QuantumScape Battery Corp

QuantumScape is developing a solid-state battery with a lithium-metal anode to enable long-range, faster charging, low-cost EVs. This talk will highlight recent developments in solid-state batteries as well as the challenges in commercializing a new battery technology. QuantumScape was founded in 2010 with a mission to revolutionize energy storage to enable a sustainable future.

No singular solid-state battery technology dominates, but the prospects of improved performance remains enticing

There is no silver bullet for solid-state batteries. Companies that are successfully pushing forward their technology are doing so with numerous challenges. Specifically, cell developers are responsible for all components of the cell, even if their differentiating technology is a material formulation for a solid electrolyte. Full cell design has an almost endless list of considerations, far beyond just edging the ionic conductivity of a solid electrolyte higher. The list includes solid electrolyte material formulation, interfacial compatibility with electrodes, silicon or metallic lithium metal anode integration, cell design, and manufacturability. The diverse array of solid electrolyte solutions consequently means that a solution for one technology may not work for others. When solid-state batteries reach commercialization, it will likely not be as easy for cell manufacturers to treat solid-state electrolytes as interchangeable battery components.

Solid-state commercialization timelines are ambitious. Despite the announcements made by almost every solid-state developer for late 2020s commercial production, the 2030s timeframe remains more realistic. Automakers with large appetites and even larger wallets are willing to bet on solid-state batteries right now, but fundamental flaws in chemistry or cell design will take time to fix. For established players, product development is an uphill battle where incremental improvements are hard-won. Less mature solid-state batteries developers have the flexibility to be more creative in their solutions, such as by using a layered electrolyte approach or exploring new cell designs. Either way, flaws in performance and manufacturing will hinder the aggressive goals set by solid-state batteries companies.

Yes, electrode wetting is cheating, but (almost) everyone is doing it. Interfacial resistance between the electrode and solid electrolyte haunts battery developers. The easiest workaround is using a small amount of liquid electrolyte between the cathode and electrolyte to improve performance. Depending on which company you talk to, the safety effects of that small amount of liquid electrolyte can be negligible, and some thermal modeling has shown the same. However, as energy density increases, that impact on heat release becomes greater. So yes, solid-state batteries using a little liquid electrolyte are much safer than fully liquid Li-ion battery electrolytes, but safety risks still exist. solid-state batteries developers must keep this in mind as they push for higher-performing batteries.

INNOVATE SMARTER & GROW FASTER

About Lux Research

Lux Research is a leading provider of tech-enabled research and advisory solutions, helping clients drive growth through technology innovation. A pioneer in the research industry, Lux uniquely combines technical expertise and business insights with a proprietary intelligence platform, using advanced analytics and data science to surface true leading indicators. With quality data derived from primary research, fact-based analysis, and opinions that challenge traditional thinking, Lux clients are empowered to make more informed decisions today to ensure future success.

TECHNICAL EXPERTISE | **PRIMARY RESEARCH** | **ADVANCED ANALYTICS**

BOSTON NEW YORK AMSTERDAM SINGAPORE TOKYO

Lux Research

www.luxresearchinc.com
www.luxresearchinc.com/blog
info@luxresearchinc.com
@LuxResearch
Lux Research, Inc.
Lux Research