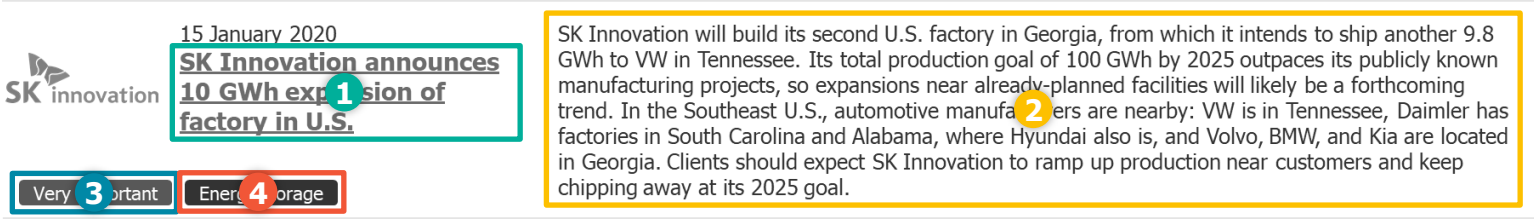
Singapore Battery Consortium

2021 Q1 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

Stationary storage startups continue to gain traction with funding and new projects

4 January 2021

Qatar Investment Authority invests $125 million in Fluence Energy

Average Importance | Stationary storage

Qatar Investment Authority (QIA) is committing to investing $125 million for a roughly 12% stake in Fluence Energy through a private placement transaction, making QIA another large partner in the AES-Siemens joint venture. Both AES and Siemens will remain majority shareholders, each with around a 44% stake. Fluence plans to mainly use the cash to accelerate development of digital products, which are key to optimizing energy storage business operations. Fluence will continue to bet on digital innovations developed both internally and externally; proof of this is its recent acquisition of Advanced Microgrid Solutions in October 2020.

12 January 2021

Connected Energy raises strategic investments from Engie New Ventures

Average Importance | Stationary storage

Connected Energy raised an undisclosed amount from investors including Engie New Ventures, Sumitomo, Macquarie, and Low Carbon Innovation Fund 2; in addition, the company received an R&D grant from Innovate UK. Connected Energy claims its battery analytics technology is able to extend battery lifetime by five to 10 years for short- or long-term stationary storage projects; afterward, batteries are ready for recycling. With its current automotive OEM partnerships, Connected Energy is well-positioned to leverage the large volumes of EV waste while the industry prepares to deal with battery recycling.

26 January 2021

Swell Energy awarded $25 million contract for large-scale VPP in Hawaii

Average Importance | Stationary storage

The contract between Swell Energy and Hawaiian Electric (HECO) is part of Hawaii's program to combine more than 25 MW of solar capacity and nearly 200 MW of energy storage to provide capacity and frequency response to the islands of Oahu, Maui, and Hawaii. Following in the footsteps of recent solar-plus-storage projects in Hawaii, this initiative aims to increase grid resiliency and support the state's ambition to reach 100% renewable electricity in 2045. For Swell Energy, this contract means an opportunity to deploy its largest VPP to date. The large penetration of distributed energy resources in island regions like Hawaii creates a potential market for VPPs; clients should monitor this project to verify Swell Energy's capabilities.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

Sila Nanotechnologies unlikely to be the last battery startup unicorn as capital continues to pour into the space

28 January 2021

E-Zinc raises $2.3 million from BDC Capital to support pilot projects

Low Importance | Stationary storage

The company received government funding last year to complete an installation in California by 2022. Zinc-air batteries have a low installed storage cost of approximately $100/kWh, due in part to the low bill of materials and long discharge durations of up to 72 hours. As renewables installations grow, multiday energy storage will become increasingly important, and zinc-air batteries offer one of the lower-cost options. While E-Zinc's technology appears promising, the impact of the company on the stationary storage landscape won't hold much weight until it can secure projects and prove its performance at large scales.

28 January 2021

Sila Nanotechnologies plans battery materials factory after $590 million investment

Very Important | Energy storage

The manufacturing plant will eventually produce enough silicon anode material for a 100 GWh capacity; it is slated to open in 2024 and ramp up production enough to supply materials for BEVs in 2025. Sila Nanotechnologies' silicon nanocomposite materials are designed to be a drop-in replacement for anodes in existing roll-to-roll manufacturing processes. It now has a valuation of $3.3 billion and has secured partnerships with BMW, Daimler, and Amperex Technology Limited. The company notably did not receive significant investment from battery makers or automotive companies, seeming to bet on widespread industry adoption to justify its high valuation.

1 February 2021

Azelio and Svea Solar sign MOU for multiple solar-plus-storage projects

Average Importance | Stationary storage

Both companies will develop at least three projects in 2021, five in 2022, and 10 in 2023, totaling 8 MW of power and 100 MWh of energy storage capacity. Azelio has mainly been targeting diesel genset replacements for solar installations and previously claimed that its system is cost-competitive when deployed at scale. However, its long-duration energy storage also competes with zinc-air and zinc-flow batteries, which can offer longer discharge durations at similarly attractive costs. The string of future projects is promising for Azelio, but the company will have to demonstrate that its technology can beat out other, simpler electrochemical energy storage systems while keeping costs low.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

Europe is emerging as the global center for battery recycling innovation and capacity

5 February 2021

Construction beings on Li-ion battery recycling facility in Norway

Very Important | Energy storage

Northvolt and Hydro announced JV Hydro Volt in 2020, which will open in 2021 and have a battery processing capacity of 8,000 tons per year. Hydro Volt will be responsible for crushing and sorting batteries. The aluminum will be sent to Hydro, while black mass will be sent to Northvolt. Commercial-scale hydrometallurgy is often the last and most difficult step in Li-ion battery recycling; however, Northvolt and Hydro's collaboration will benefit both companies by building out battery collection and shredding. Clients should expect more relationships like this to emerge as companies enter Li-ion battery recycling.

6 February 2021

BASF agrees to supply Aqua Metals electrolyte used for lead-acid battery recycling

Average Importance | Energy storage

Aqua Metals develops a water-based electrolytic process to retrieve lead from spent lead-acid batteries. BASF will become the exclusive supplier of Aqua Metals' electrolyte to licensees of the refining technology, and both companies will work together on improving the electrolyte formulation for enhanced performance. Aqua Metals claims its lead recycling technology can produce up to 32 kg of 99.996% purity lead per hour. The company's process serves as an alternative to pyrometallurgical battery recycling, but it has yet to gain significant market traction. Clients should note that BASF is pursuing multiple avenues of collaboration to insert itself in the battery recycling value chain.

9 February 2021

€2.9 billion IPCEI bolsters Europe's battery supply chain prospects

Very Important | Energy storage

The €2.9 billion project builds on a previous €3.2 billion project largely focused on the same goals: foster technical innovation in battery systems, keep the materials supply chain based in Europe, and consider battery end-of-life processing. Compared to the previous project, this includes more expected private funding (€9 billion compared to €5 billion) and a larger number of private companies. This project won't likely be the last, as the EU and European companies face an uphill battle in bringing and keeping the battery supply chain in Europe, and recognize that this could bolster opportunities for automakers to own cell manufacturing, similar to Volkswagen's joint venture with Northvolt following financial support from the EIB.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

Battery manufacturing capacity continues to expand, but questions remain on securing raw materials

11 February 2021

CATL to invest $1.86 billion for battery production in China

Very Important | Energy storage

The battery producer will build out three new facilities in Guangdong, China. The first phase will build a plant with an annual capacity of 25 GWh for an investment of $1.86 billion. By the end of 2030, CATL plans to install a capacity of up to 150 GWh. This is in addition to the announced 80 GWh of capacity by 2023. As large battery manufacturers continue to announce gargantuan investments in production facilities, clients should take note that it's just as important for these companies to secure a materials supply chain in the face of potential supply gaps.

15 February 2021

Volkswagen begins battery recycling pilot project, boasts 92% recovery of cathode active material

Average Importance | Energy storage

Volkswagen's pilot plant will have a capacity of up to 3,600 batteries/year. At an average of 400 kg/battery, it expects to recover about 1,500 tons of battery materials. This equates to roughly 92% recovery of cathode active materials like cobalt, nickel, manganese, lithium, and graphite from the shredded "black mass." It uses the patented LithoRec process, a combination of mechanical and hydrometallurgical processes, which it developed with the Technische Universität Braunschweig and 12 other companies. Once optimized, Volkswagen expects a commercial facility to be operational by the end of the decade.

22 February 2021

Highview Power raises $70 million with 4 GWh in project pipeline

Average Importance | Stationary storage

Concluding a year of fundraising, Highview Power adds additional investment after Sumitomo Heavy Industries' $46 million contribution in February 2020. The remaining sources of investment were private investors. The funds will be used to scale up the technology and support deployment of further projects. Highview Power claims it can achieve a levelized cost of storage (LCOS) of $100/MWh for a system with a 10-hour discharge and lifetime of 30 years, leading Lux to believe that the upfront investment costs are large compared to conventional electrochemical stationary storage systems. Highview Power will likely see a slow rollout of deployments in the coming years until electricity markets begin requiring longer-duration storage.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

Safety for existing and emerging battery chemistries remain a concern for the industry

22 February 2021

Zenlabs validates 1,000 cycles for 12 Ah cells with silicon anodes

Average Importance | Energy storage

Idaho National Laboratory recently validated Zenlab's 12 Ah pouch cells with 315 Wh/kg to have a cycle life of 1,000 cycles at a C/3 charge rate and 896 cycles at 4C. Zenlabs uses 50% to 80% silicon loading in its silicon-graphite composite anode, much higher than commercially available cells, which can use up to 5%. In comparison to Amprius' 350 Wh/kg for 12% silicon loading and LeydenJar's 420 Wh/kg pure silicon anodes, Zenlabs achieves a lower specific energy; however, it matches Amprius' cycle life of 1,000 cycles and outstrips LeydenJar's 200 cycles. Zenlabs offers only a slight improvement over graphite anodes at a likely much higher cost.

24 February 2021

Battery fires prompt expensive recall of 81,701 Hyundai electric vehicles

Very Important | Energy for mobility

The initial root cause of the failure is disputed, with Hyundai claiming a defect in the cathode tab and LG Energy Solutions claiming it was a battery management system design error. This is a particularly impactful failure, as more than 80,000 vehicles now need their batteries replaced, which at an assumed cost of $150/kWh and average pack size of 60 kWh would result in a $720 million battery price tag for the recall. Clients should continue to expect safety concerns to grow for automakers, as failures can not only be a large financial liability but also run afoul of regulators placing increasing scrutiny on battery fires.

3 March 2021

Svolt to begin manufacturing zero-cobalt NMX cells by mid-2021

Very Important | Energy storage

Svolt's multilayered, single-crystal cathode material utilizes a doping process to provide the stability that cobalt is traditionally used for. High-nickel cathodes will continue dominating the cathode materials space as a pathway to higher energy density batteries, but developers must engineer materials that can handle little to no cobalt while maintaining high safety. Clients should expect cell manufacturers to increasingly turn to these tweaks in cathode manufacturing, as high-nickel cathodes will require further engineering for utmost safety and a longer cycle life.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

New business models surrounding stationary storage are emerging in liberalized electricity markets

3 March 2021

Graphene battery to be mass-produced by GAC Group in September

Very Important | Energy storage

China's GAC Group is in the final vehicle testing phase for its graphene-based battery that can withstand up to 6C charge rates. Due to its high electron mobility and good rate performance, graphene has the potential to be a successful anode material. The cost to manufacture of graphene has been a barrier to mass production, and creating a 3D anode material has typically only been achieved at lab scale. While pure graphene batteries are unlikely to become the norm in Li-ion batteries, this announcement indicates that innovations in carbon nanotechnology will become increasingly important for competing with silicon-based anodes.

5 March 2021

Hitachi ABB Power Grids to supply battery storage to Singapore's first virtual power plant

Average Importance | Stationary storage

This project has been jointly developed by Singapore's Energy Market Authority, Sembcorp, and Nanyang Technological University since 2019. Details about the expected aggregated storage capacity remain unknown, as Hitachi ABB Power Grids only confirmed that it plans to deploy its e-mesh platform – a scalable microgrid and energy storage solution supported by digital control tools. This announcement is another sign of maturing energy prospects in Singapore, arising from the ongoing liberalization of the country's energy market. Markets undergoing liberalization are emerging hubs for innovation related to distributed energy resource management and business models.

11 March 2021

Be wary of hype around Blackstone "3D printed" battery technology

Average Importance | Energy storage

Blackstone's process appears to be more a matter of using screen printing to deposit electrode materials (and potentially other parts of the battery) than what most would usually regard as 3D printing. Thin-film battery developers like Imprint Energy have explored similar printing processes, though Blackstone's use of lithium iron phosphate (LFP) in such a process is unique, and it claims the thicker electrodes it can produce thanks to this process offset LFP's usual energy density disadvantage and allow it to reach 220 Wh/kg cell energy density. Monitor the company's progress, but be wary of its claims of achieving such a figure in volume production by early 2022.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

Startups continue to lean on SPACs to raise capital

12 March 2021

Battery Recycling startup Li-Cycle valued at $1.67 billion after IPO through SPAC

Very Important | Energy storage

Li-Cycle completed its IPO, raising $615 million through a SPAC led by Peridot and PIPE investors including Neuberger Berman Group, Franklin Templeton, and Li-Cycle's strategic partner Traxys. Li-Cycle now has a market valuation of $1.67 billion. It has patented both a mechanical and a hydrometallurgical method promising a 90% to 95% recycling rate. The company is now in its growth phase, where it builds four mechanical processing plants for every hydrometallurgical facility. This hub-and-spoke model is currently being showcased at its Rochester, New York, facility, which recycles 5,000 tons.

12 March 2021

VinFast and ProLogium announce JV to develop solid-state battery packs in Vietnam

Average Importance | Energy for mobility

VinFast has signed an MOU with Taiwanese battery manufacturer ProLogium (PLG) to accelerate the commercialization of solid-state batteries (SSBs) for electric vehicles (EVs). This JV will help VinFast, Vietnam's first national car brand, gain priority for using PLG's SSB technology to produce battery packs in Vietnam. PLG will provide support by producing SSB inlays for VinFast in its expected 1 GWh to 2 GWh Asia manufacturing center, with an ambitious plan of mass-producing EVs by 2024. Although PLG claims to have passed numerous safety tests in the EU and China, this partnership should not be viewed as evidence of SSB progress.

12 March 2021

Northvolt expands to U.S. though acquisition of Cuberg

Very Important | Energy storage

This marks the first major technology acquisition made by Northvolt, which historically manufactures conventional Li-ion batteries with graphite anodes. The company was founded to build up a battery supply chain in Europe, using undifferentiated battery technology to get there. Now that it has established that supply chain, Northvolt is moving into technology innovation with its acquisition of Cuberg. The company is already working with numerous automakers and aviation companies for higher-performing batteries. Northvolt's move to the U.S. will enable rapid entry into the innovation landscape and attract both the cleantech investors and technical talent needed to scale up Cuberg's battery technology.

Automakers and cell manufacturers are likely to increasingly secure access to IP from startups

16 March 2021

GM signs JDA with SolidEnergy, putting lithium metal anodes on its tech roadmap

Very Important | Energy storage

GM had previously invested in lithium metal anode developer SolidEnergy Systems (SES) through its venture capital arm, and this joint development agreement takes the partnership a step further. The two have already put cells through simulated drive cycles. In a vote of confidence, GM will now assist SES in building a "high-capacity, pre-production" manufacturing line due to be completed in 2023. Clients should note that these cells would likely be used to qualify cells for production, and assuming a two-year qualification period would mean the earliest GM would be using SES technology would be 2025.

18 March 2021

Neoen secures planning approval for AU$3 billion wind-solar storage project in South Australia

Average Importance | Stationary storage

This project is part of the so-called Goyder Renewable Zone – a production site that French renewable energy developer Neoen is developing in the South of Goyder. When completed, this project is expected to install up to 1,200 MW of wind power, 600 MW of solar PV power, and 900 MW of battery capacity. Neoen plans to begin construction of the next phase, which will have a total capacity of 400 MW, in early 2022. This project adds to Neoen's renewable energy (expected to reach 10 GW by 2025) and storage pipeline and goes in line with South Australia's ambition to decarbonize its energy system and reach 100% renewables by 2030.

19 March 2021

Georgia Tech reports using metal-infiltration technique for solid-state battery production

Average Importance | Energy storage

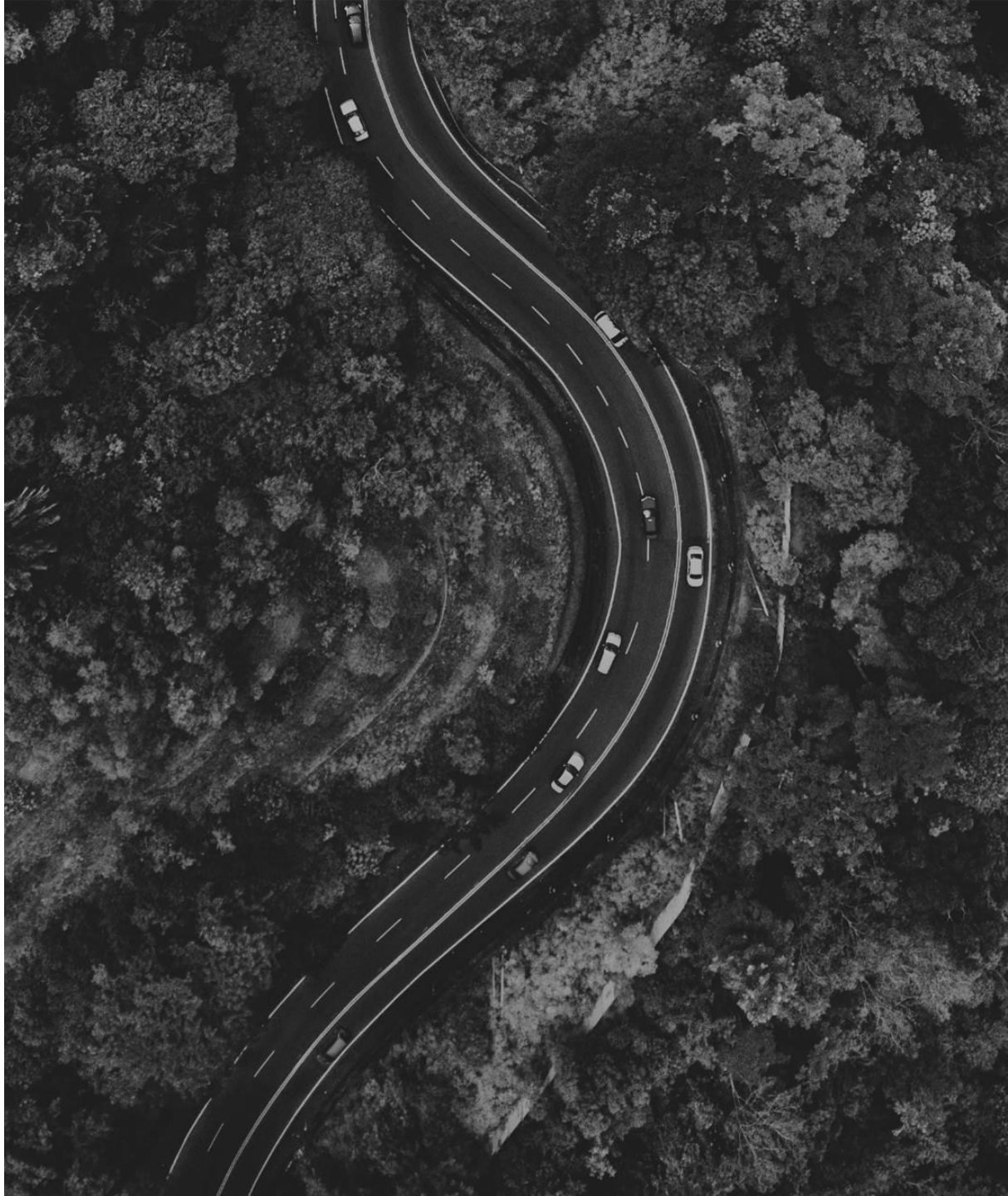
Researchers from the Georgia Institute of Technology have reported using the melt-infiltration fabrication technology for all-solid-state lithium-ion batteries (SSLBs) that can adopt the production of nonflammable ceramic electrolytes similar to batteries developed with conventional liquid electrolytes. The team has claimed that the technology uses solid-state electrolytes with low melting points that can infiltrate into dense, thermally stable electrodes at a temperature of 300 °C in a liquid state and then solidify during cooling. This patent-pending fabrication process is expected to improve scalability but yet to be commercialized. Clients interested in SSBs are encouraged to monitor this development due to its low-temperature approach.

NEXT-GENERATION LI-ION MATERIALS

Breaking down next-generation Li-ion batteries

Commercialization of innovative anode, electrolyte, and cathode materials will improve the specific capacity of Li-ion batteries, reduce pack costs, and increase the number of applications for electrification.

- **Silicon anodes:** Many automotive Li-ion batteries today incorporate low amounts of silicon into their anodes, with a resulting silicon loading of less than 5%.
- **Metallic lithium anodes:** Half of the value proposition for solid-state batteries is that they achieve double the energy density of incumbent Li-ion batteries by incorporating a metallic lithium andoe.
- **Solid-state electrolytes:** Unlike liquid electrolytes, solid electrolytes are nonflammable and more effective at preventing shorting, leading to improved safety – this is the other half of the solid-state battery value proposition.
- **High-nickel cathodes:** While NCA cathodes have always had a high ratio of nickel to cobalt, NMC are trending in the same direction to improve capacity.
- **Other next-generation cathodes:** Those include lithium/manganese NMC (LMR-NMC), lithium-sulfur (Li-S) batteries, and lithium-manganese-nickel-oxide (LMNO) cathodes, which provide specialized value over incumbents



SILICON ANODES

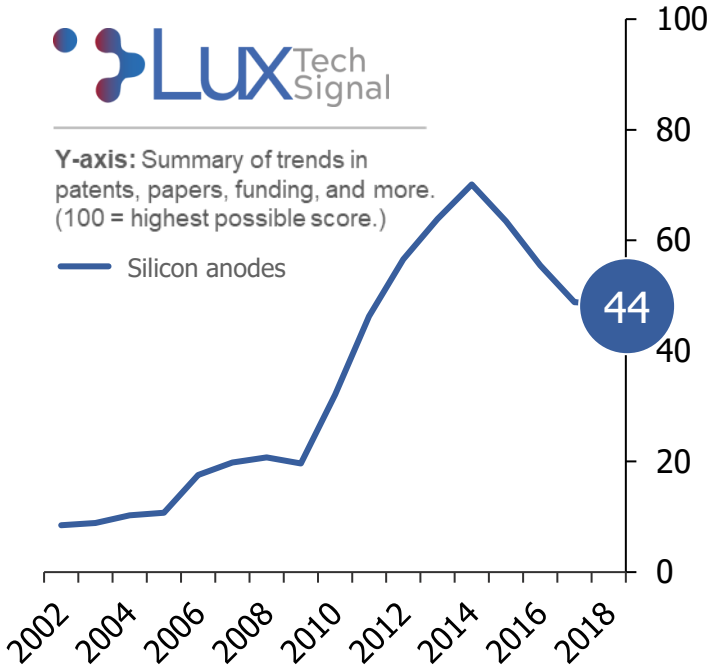
Silicon composite anodes today offer minor performance improvements over graphite anodes

HOW IT WORKS:

Silicon's superior capacity also causes one of its most challenging problems, as the material swells nearly 400% during charging. Mitigating this effect requires engineering costly nanostructures, mixing silicon with carbon to make a composite, or using electrolyte additives to stabilize solid electrolyte interphase (SEI) formation.

CHALLENGES TO OVERCOME:

Nanostructured silicon can achieve high energy densities, but manufacturing is prohibitively expensive; cheaper silicon-carbon composites, which today use less than 10% silicon, only offer minor performance improvements but are commercialized in high-volume applications.



TECH HIGHLIGHT

300-325 Wh/kg

Leading startups claim that cells with their silicon-carbon composite anodes achieve more than 300 Wh/kg and 1,000 cycles to 80% depth of discharge.

SILICON ANODES

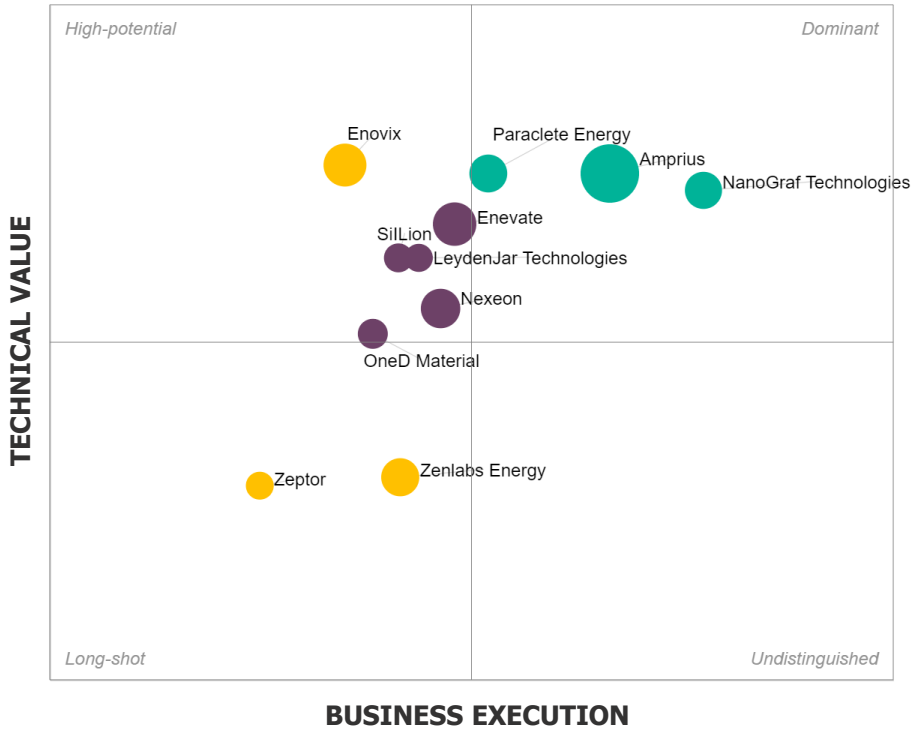
Silicon composite anodes today offer minor performance improvements over graphite anodes

KEY PLAYERS:

Panasonic became one of the first cell manufacturers to use silicon-carbon composite anodes in the 2015 Tesla Model S; today it leads all other companies in patent filings. Most other major cell manufacturers now offer a silicon-containing anode, albeit at lower volumes, and materials suppliers have also been able to innovate to retain their role in the supply chain.

LUX INNOVATION GRID:

The startup landscape for silicon anodes is somewhat crowded due to the material's promising theoretical performance and the availability of silicon and processing equipment. The clear early leader is Amprius, but few other startups are likely to succeed. These startups are mostly pursuing licensing strategies to avoid the high capital costs associated with manufacturing.



Lux Take Legend:

- Strong Positive
- Positive
- Wait and See
- Caution
- Strong Caution

Lux Take Trends:

Circle size corresponds to company's relative maturity.

METALLIC LITHIUM ANODES

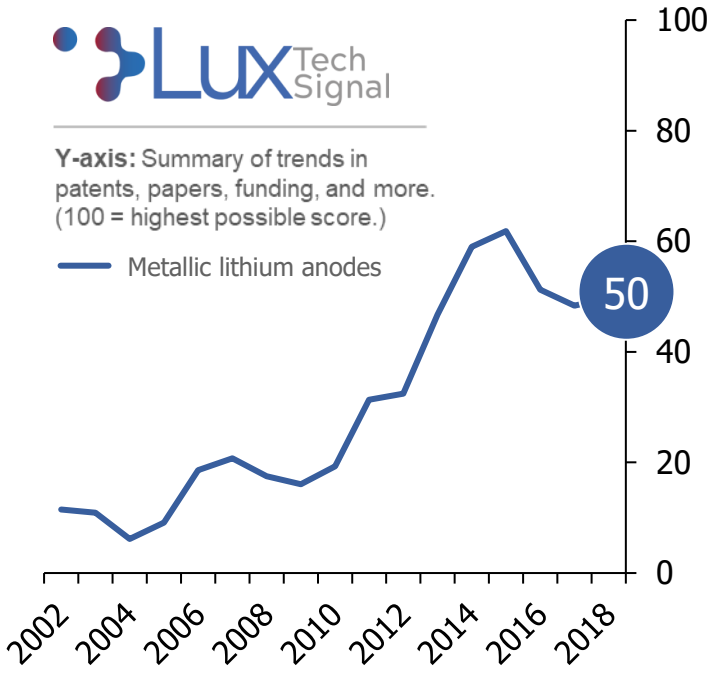
Lithium metal anodes offer 10 times greater theoretical specific capacity than graphite anodes

HOW IT WORKS:

In cells with metallic lithium anodes, lithium ions are stripped away from the anode during discharge and plated back onto the anode during charging. With its unbeatable theoretical capacity (3,860 mAh/g), lithium metal is the ideal material for Li-ion battery anodes. Yet the formation of uneven growths, called dendrites, on the anode surface remains a problem.

CHALLENGES TO OVERCOME:

Dendrite formation limits cycle life and can short-circuit the battery; developers seek to address both of these concerns by applying protective layers and pairing the anodes with solid-state electrolytes. Additionally, lithium metal is significantly more expensive than lithium chemicals, and a scalable supply chain does not yet exist.



TECH HIGHLIGHT

470-550 Wh/kg

Leading developer Sion Power claims its cells with conventional lithium foil anodes achieve 470 Wh/kg and its cells with its proprietary protected lithium anodes achieve 550 Wh/kg.

METALLIC LITHIUM ANODES

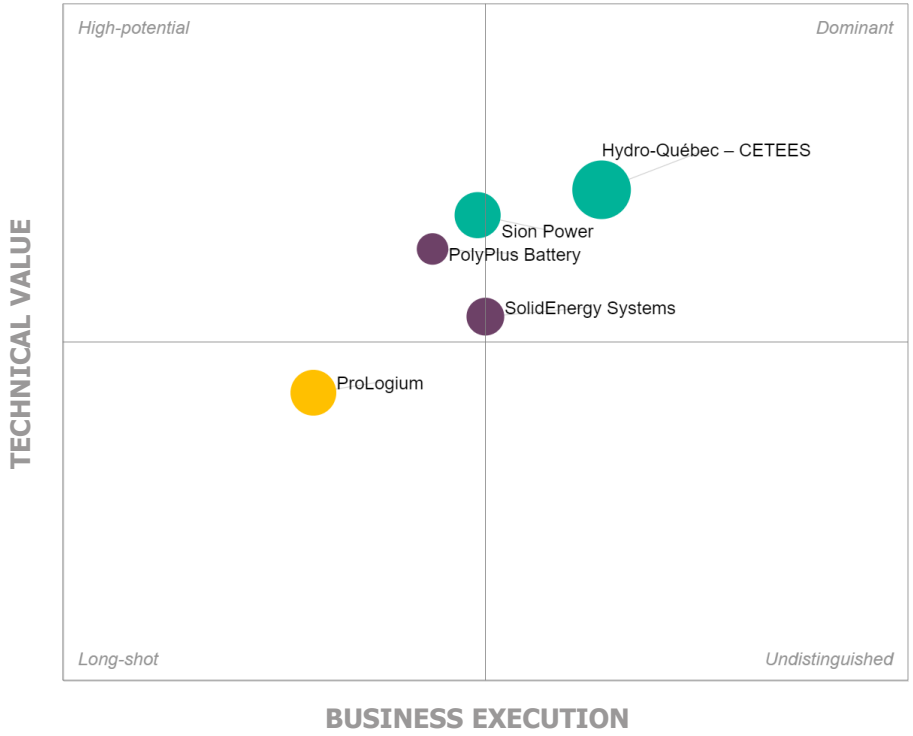
Lithium metal anodes offer 10 times greater theoretical specific capacity than graphite anodes

KEY PLAYERS:

Startups in this space currently source anode materials from laboratory chemical providers, as there is not yet a strong supply chain for lithium metal foils. There is a need for the lithium industry to build the capacity to address this need within the next 10 years before solid-state batteries reach commercialization, as these batteries only achieve higher capacities than incumbent Li-ion batteries if they use metallic lithium anodes.

LUX INNOVATION GRID:

There are a handful of startups developing methods to protect metallic lithium anodes from dendrite formation and manufacturing processes to make the anodes thinner and cheaper. The leading startups plan to license their technologies to incumbent cell manufacturers.



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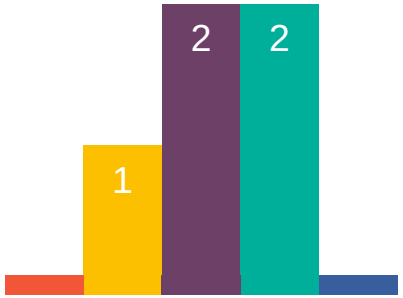


Circle size corresponds to company's relative maturity.

SOLID-STATE ELECTROLYTES

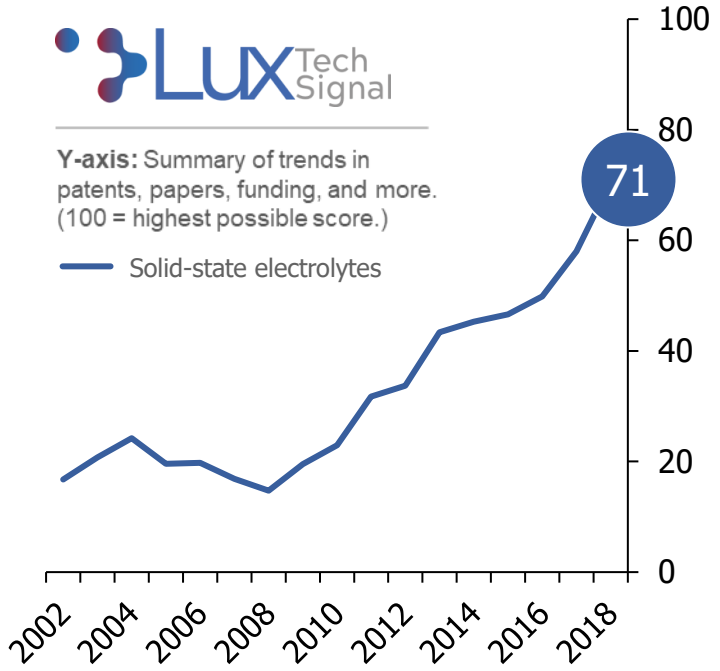
Solid ion-conducting materials offer improved safety and performance over liquid electrolytes

HOW IT WORKS:

Solid-state electrolytes are made of a solid ion-conducting polymer or ceramic material that acts as both separator and electrolyte. Unlike incumbent liquid electrolytes, solid electrolytes are nonflammable and more effective at preventing shorting, leading to improved safety. They also enable the use of metallic lithium anodes, resulting in high energy densities of up to 450 Wh/kg and 900 Wh/L.

CHALLENGES TO OVERCOME:

The difficulty of manufacturing at scale remains a key issue, as typically factories remain too small today and the processes they use too exotic. Moreover, power output remains a concern, and performance advantages require using the elusive metallic lithium anode.



TECH HIGHLIGHT

350-450 Wh/kg

Solid-state batteries incorporate solid electrolytes as well as metallic lithium anodes; thus, they offer both improved energy density and improved safety over incumbent Li-ion cells.

SOLID-STATE ELECTROLYTES

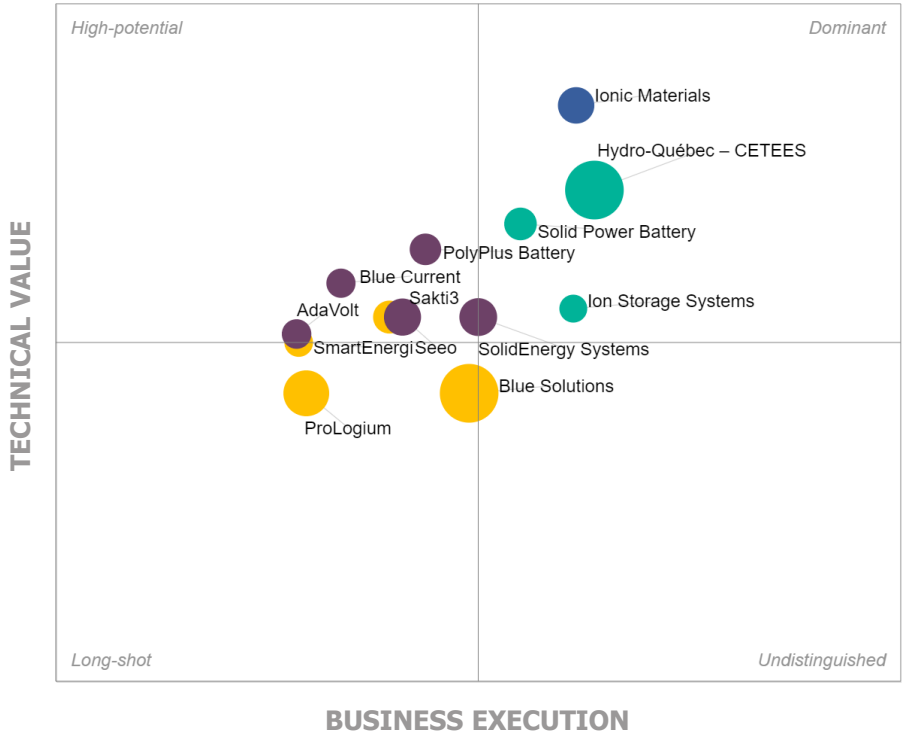
Solid ion-conducting materials offer improved safety and performance over liquid electrolytes

KEY PLAYERS:

The solid-state battery landscape is led by a mix of automotive players, materials developers, and battery makers: Toyota Motor has one of the world's foremost solid-state battery development efforts, while ceramics and materials developers are considering solid-state electrolytes as a way to grow in the future energy storage industry. Yet companies acquiring startups in this space have struggled to integrate them into their businesses.

LUX INNOVATION GRID:

Solid-state batteries enjoy a vibrant field of startups. Out of the more than a dozen companies we have evaluated in-depth, almost half earn Lux Takes of Positive or Strong Positive, indicating that there are some great investment, partnership, and acquisition opportunities in this space.



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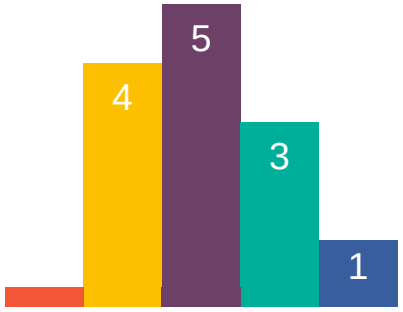


Circle size corresponds to company's relative maturity.

HIGH-NICKEL CATHODES

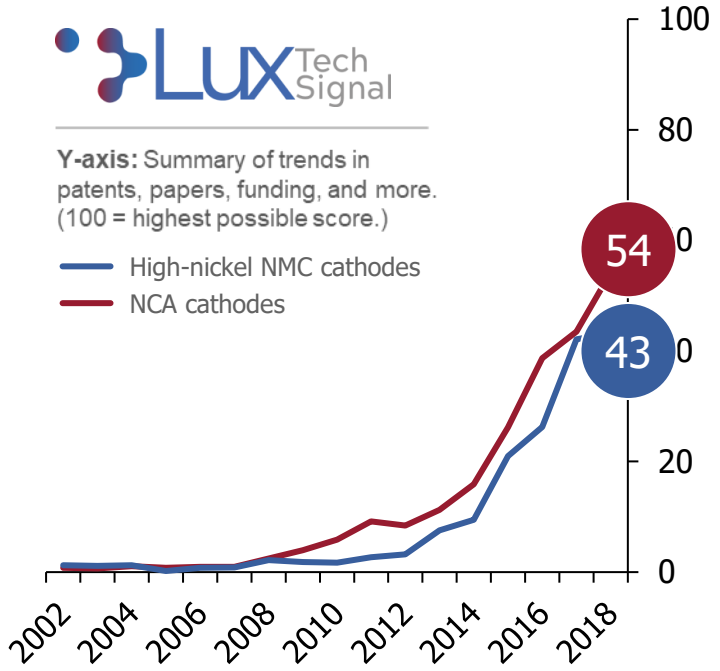
Cathodes with high nickel content offer improved specific capacity over those with low nickel content

HOW IT WORKS:

Increasing the nickel content of NMC and NCA cathodes increases the amount of nickel available for oxidation. By increasing the ratio of nickel to manganese to cobalt in NMC cathodes from 1:1:1 to 5:3:2 and up to 8:1:1, specific capacity increases while cell costs fall. NCA has a 6:1 ratio of nickel to cobalt and therefore also achieves a high specific capacity at lower cost.

CHALLENGES TO OVERCOME:

Structural instability and shorter cycle life are formidable challenges for high-nickel cathodes. Some also view NMC 622 as a more viable chemistry than NMC 811, as the lower-nickel variant can achieve similar performance by pushing voltage higher; it is also better-suited for fast charging.



TECH HIGHLIGHT

250-270 Wh/kg

NMC 811 enables a 30% increase in specific capacity over NMC 111 when paired with a graphite anode, but next-generation anodes are required to achieve more than 300 Wh/kg.

HIGH-NICKEL CATHODES

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Increasing the nickel content of NMC and NCA cathodes increases the amount of nickel available for oxidation. By increasing the ratio of nickel to manganese to cobalt in NMC cathodes from 1:1:1 to 5:3:2 and up to 8:1:1, specific capacity increases while cell costs fall. NCA has a 6:1 ratio of nickel to cobalt and therefore also achieves a high specific capacity at lower cost.

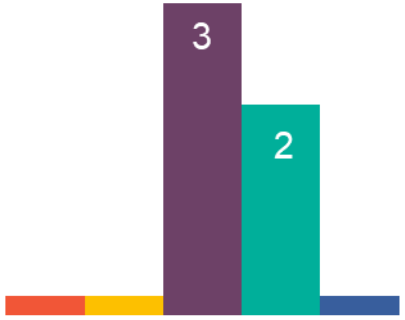
CHALLENGES TO OVERCOME:

Structural instability and shorter cycle life are formidable challenges for high-nickel cathodes. Some also view NMC 622 as a more viable chemistry than NMC 811, as the lower-nickel variant can achieve similar performance by pushing voltage higher; it is also better-suited for fast charging.

Lux Take Legend:

- Strong Positive
- Positive
- Wait and See
- Caution
- Strong Caution

Lux Take Trends:



Circle size corresponds to company's relative maturity.

OTHER NEXT-GENERATION CATHODES

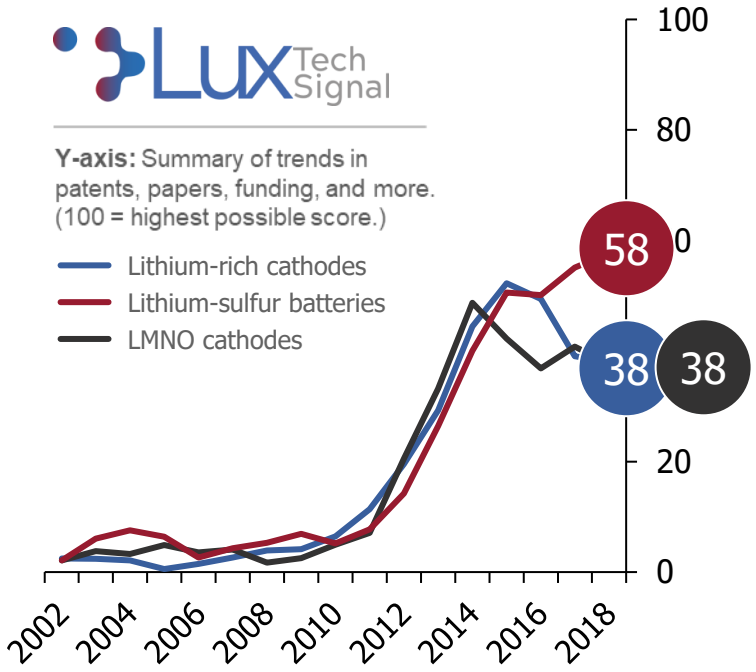
LMR-NMC cathodes, Li-S batteries, and LMNO cathodes offer specialized value over incumbents

HOW IT WORKS:

Next-generation cathodes rely on higher-voltage or higher-capacity materials to push energy density even higher. LMNO spinel is stable up to 5 V; sulfur conversion cathodes have almost 10 times the capacity of LCO, albeit at lower voltages. LMR-NMC combines both attributes by charging a layered NMC material to higher voltages, thereby accessing greater capacity.

CHALLENGES TO OVERCOME:

Despite their potential benefits, all of these alternative chemistries struggle with cycle life. Li-S batteries, the most mature chemistry of the three, still cannot achieve more than 200 cycles to 80% capacity while also improving capacity compared to incumbent Li-ion batteries. Developments in coatings, electrolytes, and chemistry will be necessary to enable these new cathodes.



TECH HIGHLIGHT

220-330 Wh/kg

Next-generation cathodes can offer increased energy densities; when paired with lithium metal anodes, they can reach 550 Wh/kg. However, cycle life remains an obstacle.

OTHER NEXT-GENERATION CATHODES

LMR-NMC cathodes, Li-S batteries, and LMNO cathodes offer specialized value over incumbents

KEY PLAYERS:

While most leading Li-ion battery developers are focusing their efforts on commercializing high-nickel cathodes, some are pursuing alternative cathode chemistries in parallel. Most notable is BASF, which is working to bring LMR-NMC cathode materials to market in the coming years.

LUX INNOVATION GRID:

Few startups are developing these alternative chemistries; those that are, such as Nano One Materials and Wildcat Discovery Technologies, typically do so on the side and focus on more conventional chemistries. The exception here is Oxis Energy, which is one of the only pure-play Li-S developers left since Sion Power pivoted to focus on metallic lithium anode development.

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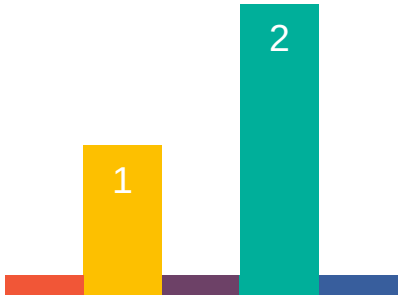

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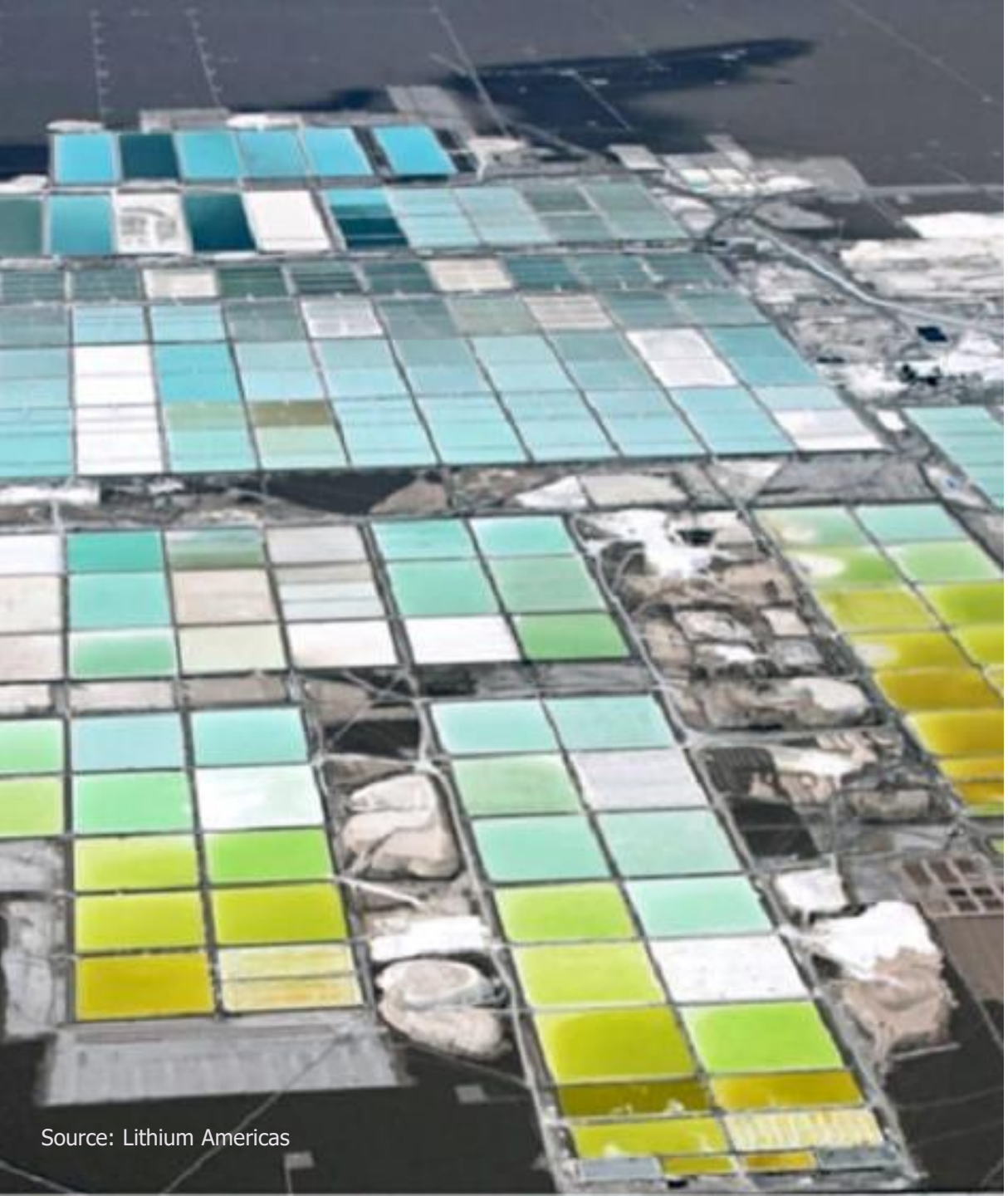


Source: Lithium Americas

NEXT-GENERATION LI-ION MATERIALS

Integrated supply chains for reducing costs

To meet long-term Li-ion battery demand, both lithium and nickel producers will need to adopt innovative technologies for extracting high-quality chemicals quickly from low-quality and unconventional resources, such as clay-based lithium reserves and recycled end-of-life batteries.

For advanced anodes, integrated supply chains will be central to reducing costs. Silicon particles for silicon/graphite anodes cost approximately $100/kg today and is likely to fall in line with high-purity silicon used in the solar industry, but the supply chain to provide those particles cheaply and at scale needs to be built up.

Similarly, the supply chain for thin, high-purity lithium foil is seen as necessary to evenly plate lithium during charging of solid-state batteries. This presents significant opportunities for Li-ion battery recycling companies to supply battery-grade precursor materials cheaply without necessarily innovating battery chemistry themselves, thereby also playing a crucial role as new nickel refineries are brought online.

NEXT-GENERATION LI-ION MATERIALS

Advanced electrodes adoption unlikely to be universal

Heavy-duty applications that require long-cycle-life will not rely on nick-rich cathodes and lithium metal anodes. Instead, they will opt for low-nickel NMC or LFP and graphite. The lowest-cost option for electric buses and heavy-duty trucks will prioritize higher-cycle-life chemistries, even as the expense of higher cell costs and lower energy density. This market can be substantial, with fully electrification translating to a demand of more than 1 TWh.

Stationary energy storage will likewise be a heavy-duty application and choose "low-tech" battery materials over advanced electrodes. Li-ion has quickly rose in market share in stationary energy storage, largely as LFP in residential behind-the-meter applications and NMC 333 in utility applications. However, as application stacking demands greater utilization from energy storage installations and the required discharge durations increase, other technologies like flow batteries may edge out Li-ion batteries.

Source: Bye Aerospace

NEXT-GENERATION LI-ION MATERIALS

New mobility platforms need different Li-ion batteries

New modes of mobility enabled by autonomous vehicles will not only drastically increase vehicle utilization, but also require powertrains suited to the task. These vehicles will likely have much different requirements, as they will be in near-constant use, making longer cycle life and faster charging more important metrics than today.

Electric aviation places an emphasis on energy density and that will make it a leading market for advanced Li-ion batteries. This market will be a key driver for the commercialization of next-generation cathodes and lithium metal anodes. While a 550 Wh/kg LMRNC – lithium metal battery might reduce cell prices incrementally in the passenger battery electric vehicle segment, it is transformative for electric aviation. It could increase electric aircraft range from 200 miles to 500 miles – long enough to tap some of the busiest airline routes in the world. Aviation will be a beachhead market for advanced, high-energy electrodes.

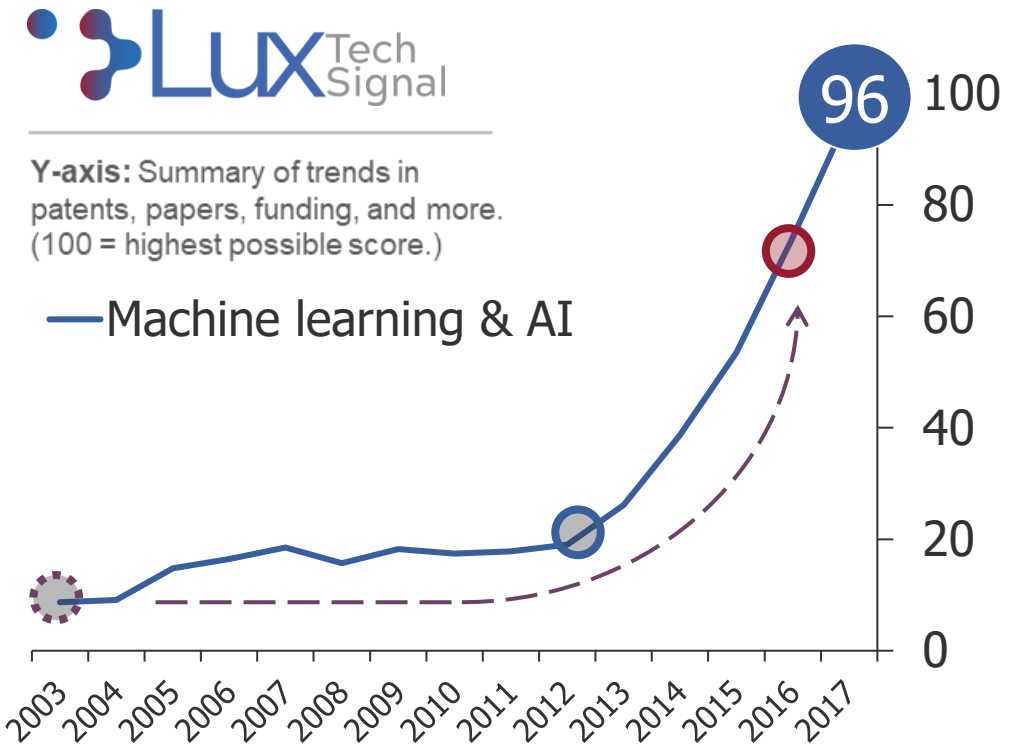
Lux Tech Signal

The Lux Tech Signal is based on our analysis of innovation data including:

- Patents
- Academic papers
- VC funding
- Government funding
- Lux proprietary data

The **Innovation Interest** score is calculated by analyzing multiple, diverse datasets weighted based on our evaluation of the role innovation sources play in each stage of commercial technology development; empirically tested and validated against real world historical data.

The maximum possible score is 100, indicating the highest observed rate of research, patenting, funding, etc.



Changes over time signal growing (or shrinking) innovation interest.

Inflection points may point to commercial opportunities or challenges ahead.

Current value indicates innovation maturity, distinguishing established technologies from those that are still emerging.

Lux Research

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.

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Lux Research

www.luxresearchinc.com
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info@luxresearchinc.com
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