The Race to Fuel the Automotive and Aviation Future is on!

A look at three California companies vying with the world to power our cars and planes

On April 19, 2023, China's Contemporary Amperex Technology Co. Limited, (CATL) sent ripples through the automotive and aviation sectors by announcing that its new condensed battery has up to twice the energy output of equivalent sized lithium-ion cells.[(1)] CATL, the largest lithium-ion battery manufacturer in the world, offered few technical details on the product, except that it relies on condensed electrolytes which improve performance, when coupled with ultra-high energy density cathode materials, innovative anode materials and separators. CATL stated that the new cells would go into production this year and were suitable for both automotive and aviation applications. Bottom line – a Tesla Model S using these batteries could go up to 1,000 miles on a single charge, and the battery has the energy density Elon Musk believes is necessary to power an aircraft.[(2)]

So, is this the battery breakthrough we have been waiting for? The United States and multiple governments worldwide are betting it's not! In this article, we look at three California companies getting ready to take on the China's lithium-ion heavy- weight champ.

Before we dive in, let's do a quick "Battery 101." A battery is a device that converts chemical energy to electricity when attached to a circuit. It puts energy into the circuit when its positive (cathode) and negative (anode) poles are attached to it. The anode and cathode are contained in a solution called an "electrolyte" which can be solid or liquid, provided it only allows positive ions to pass through it once the circuit is completed. The battery also contains a porous separator that allows the flow of ions from the cathode to the anode but does not allow them to touch. When a circuit is completed, a chemical reaction begins where electrons flow from the anode to the cathode via the external circuit, while positively charged ions flow internally from the anode to the cathode through the electrolyte. This flow creates the voltage that the battery puts out when discharging. This cycle is reversed when a battery is being charged.

In high-performance lithium-ion batteries, the cathode is usually made up of one of the following three batteries: nickel manganese cobalt; nickel cobalt aluminum; or lithium cobalt oxide. However, Tesla does use lithium iron phosphate batteries in its current Chinese car models and plans to expand the use of that chemistry to its US vehicles.[(3)] The battery's electrolyte is usually composed of a liquid lithium salt and hydrocarbon solution, and the anode is usually made of graphite. The reason for this pseudo-chemistry lesson will become clear as you read on.

Cars, drones and planes need batteries that are: 1) cheap, 2) light weight, 3) fast charging, 4)

energy dense, and 5) long lasting. Back in 2010, when the electric vehicle (EV) revival began, lithium-ion batteries were the product best matching that description. In the words of the US Department of Energy, lithium-Ion batteries have "a high power-to-weight ratio, high energy efficiency, good high-temperature performance, and low self-discharge."[(4)] Also, the cost curves for this technology looked good. Commercialized in the 1990's, by 2010 lithium-ion was king of the consumer electronics space and, based on economies of scale, its costs were predicted to fall rapidly. Between 2013 and 2022, the price of the batteries fell from over $700 per kilowatt hour (kWh) to $151 kWh according to BloombergNEF (BNEF).[(5)] And, while costs have risen more recently due to supply chain issues, BNEF predicts price hikes will ease by 2024, leading to batteries costing $100 per kWh by 2026. This price point - $100 per kWh - is important, as it where an EV should retail at the same cost as an internal combustion car.[(6)]

This sounds good, but there are several issues associated with the manufacture of these batteries. Many batteries rely on cobalt in combination with other metals for their cathodes. The largest producer of the mineral is the Democratic Republic of Congo, which has long been criticized for the slave-like conditions under which it is mined.[(7)] There are also environmental issues with the toxicity of cobalt for the miners - frequently women and children – as well as soil, air and water- contamination issues.[(8)] There are similar concerns about the long- term impacts of mining lithium in South America[(9)] and the mining of nickel, another common cathode material sourced in Indonesia[(10)] and Canada.

The carbon footprint of battery production for EV's is also a big issue. In 2022, Tesla reported the carbon dioxide (CO_2) emissions from its upstream supply chain for the first time – a whopping 37 million metric tons![(11)] Some of this comes from mining which, in the case of lithium can emit as much as 15 metric tons of CO_2 for every ton of lithium produced.[(12)] More significantly, the Massachusetts Institute of Technology estimates that the manufacture of an 80 kWh lithium-ion Tesla battery in China may emit as much as an additional 16,000 kg (16 metric tons) of CO_2.[(13)] Tesla estimates that producing one of its vehicle emits, approximately 14 tons of CO_2.[(11)] All of this means that an EV may be paying off the "carbon debt" for its manufacture for many years prior to achieving any CO_2 emission-reduction benefits.[(14)]

The US government believes that American companies can slash these emissions and move away from cobalt and other precious metals in battery production. This belief is backed by a $3.1 billion investment into "Battery Materials Processing and Manufacturing" and "Electric Drive Vehicle Battery Recycling and Second Life Applications."[(15)] The idea is to give US products a competitive advantage in a marketplace ravenous to cut greenhouse gas (GHG) emissions and to shore up supply-chain security. That intention was clearly laid out by President Biden in a February 2022 speech in Sacramento: "We can't build a future that's made in America if we ourselves are dependent on China for the materials that power the products of today and tomorrow."[(16)] And - the US is not alone - similar investments are also being made by the European Union ($3.2 Billion) and Japan ($2.55 billion).[(17)]

In California, US government investment is already beginning to bear fruit. As reported on *60 Minutes*,[(18)] tax breaks and grants[(19)] to mining companies at the Salton Sea, a landlocked body

of water in southern California, have spurred a race to develop a domestic supply of lithium. That supply could eventually put batteries in half of the new EV cars sold in the country annually. The miners are targeting naturally occurring underground pools of superheated salty water – brine – that are rich in lithium. Using the heat from the brine, they can power their operations sustainably and cut mining GHG emissions. However, there are concerns regarding by-products, such as arsenic and other toxic metals, contained in the brine; and whether these mining companies can operate at scale.[20] California's tough environmental regulations should calm these fears and, with lithium currently trading at $70,000 a ton, there will be plenty of investment to help smooth any "teething" problems with the mining technology.

All of this is encouraging, but it is only the tip of the iceberg. Three California companies are making changes to lithium battery chemistry that promise revolutionary results for the automotive and aviation sectors:

Changing the Cathode: Lyten Inc., (Lyten) located in San Jose, California, is working on technology that eliminates the need for the use of cobalt and nickel cathodes in lithium batteries. Lyten's Lytcell EV battery uses a sulfur cathode and lithium anode that make it lighter and more energy dense than current lithium cells. However, sulfur in a lithium battery creates issues: it is an insulator and does not transmit electrons; and it reacts with lithium ions undergoing two phase changes: from solid to liquid, and then back to solid as more ions are added to it.

Lyten's chemistry uses 3D graphine as a stabilizing structure for the sulfur cathode. This solves both problems by preventing sulfur from migrating away from the cathode during the reaction, and by allowing the transfer of electrons to the lithium anode.

Celina Mikolajczak, Lyten's Chief Battery Technology Officer, recently revealed that the company believes this chemistry could deliver energy densities of 600 Watt hours per kilogram (Wh/kg) by the end of the decade, and that this would allow for the electrification of all transportation including aircraft.[21] Dispensing with the need for nickel and cobalt solves a number of the environmental concerns discussed previously, and sulfur is cheap, abundant and available domestically, easing supply- chain security concerns. Lyten also believes that the production of its batteries uses 65% less GHG than conventional lithium batteries.

In 2022 , Lyten received funding from the U.S. Department of Defense's National Security Innovation Capital (NSIC) program to help it expand its production capabilities.[22] This and other investment has allowed the company's production facility in San Jose to grow from an initial 55,000 square feet to 145,000. On May 25, 2023, Lyten announced further investment from Dutch firm Stellantis Ventures[23] and that it is working on applying its 3D graphine to "sectors beyond transportation, with more announcements planned for later this year."

Changing the Anode: Amprius Technologies (Amprius), located in Fremont, California, has launched a silicone anode battery with an energy density of 500 Wh/kg which can directly challenge CATL's battery in aerospace applications. Using silicone in a battery also has several

issues: when charging, silicon can expand up to 400%; this expansion cracks the silicon and delaminates it from charge carrying components of a battery over time; and the expansion can cause the battery to absorb more lithium over time, reducing the number of times the battery can be charged (cycle life).

Amprius uses silicone nanowires that allow for expansion during battery charging and their chemistry gives their anode mechanical properties which resist both delamination and prolong battery-cycle life. Using silicone means: lighter batteries, ones that can charge faster – up to 80% capacity in six minutes - and ones which can operate in a wide range of temperatures.[24]

In a press release on March 23, 2023, Jon Bornstein, President of Amprius, stated that "These cells provide a run time of 200% compared to state-of-the-art graphite cells, while being lighter and smaller than other batteries with the same energy content."[25] However, these cells are not cheap, and require a custom chemical vapor deposition process to create the anodes. Amprius has not talked publicly about the costs of its batteries but has acknowledged that a US government backed production-facility, scheduled for construction in Colorado,[26] is likely necessary to provide the economies of scale to make their batteries affordable for flying taxis.[27] Also, cathode construction in these cells remains the same as conventional lithium-ion batteries and thus requires the precious metals (and their associated baggage) we discussed earlier. But silicone's great advantage is in its abundance, making up 27% of the earth's crust. This, coupled with lower emissions from the US energy grid and the need for less silicone to do the same job as graphite, should give these batteries the advantage in terms of GHG and pollution emitted during their manufacture.

Amprius is not alone in the silicone anode space either. Several US companies, including Sila Nanotechnologies in Alameda, California and Group 14 Technologies in Woodinville, Washington, are also pursuing differing versions of this technology. The latter are also working on new production facilities utilizing US government grants in Moses Lake, Washington.[28] So the race to perfect this technology, even between US companies, is well and truly on!

Changing the Electrolyte: QuantumScape, located in San Jose, California, has removed liquid electrolytes and traditional graphite anodes from their batteries in favor of a combination of a solid ceramic separator and an in-situ formed lithium metal anode.[29] The company's ceramic separator appears to solve the problems that have plagued solid-state batteries in the past, and the issues which have prevented use of lithium metal as an anode. Lithium metal tends to: dissolve in liquid electrolytes; react with solid state separators; and form branch-like structures called dendrites that grow, causing batteries to short out. Solid state electrolytes have also had problems being as conductive as their liquid counterparts.

QuantumScape Founder and CEO, Jagdeep Singh claims that his company's product is cathode agnostic and can work with non-precious metals such as iron to deliver batteries that are safer, more energy dense and faster charging. He also claims that because the components of the ceramic separator are already in use by many other industries, supply chain issues are not a factor for his company's technology.[30]

The use of domestic supply chains, cleaner electricity for battery manufacturing and the use of non-precious metals should mean significant GHG and pollution reductions for QuantumScape's products versus conventional lithium-ion batteries. QuantumScape has backed their claims with data, publicly disclosing third- party test results for the performance of its battery,[31] and hosting an expert panel to discuss those results and their implications in 2021.[32]

The company also has several high-profile investors including Bill Gate's Breakthrough Energy Ventures and Kleiner Perkins.[33] Most notably, it received a $100 million investment from Volkswagen.[34] The auto giant is seeking to deploy QuantumScape batteries in its cars as soon as 2024. And this investment appears to be working, with the company delivering its prototype 24-layer solid state battery to its automotive customers for testing in 2022.[35]

Again, QuantumScape is not alone in this space. Colorado-based Solid Power recently received backing from the US government to expand production of its solid-state battery.[36] This is on top of previous investments in the company by both Ford and BMW.[37] So, there appear to be multiple approaches to commercializing this technology, all of which are moving forward domestically.

Conclusion

While the number of discoveries and technology announcements in the battery space is dizzying, there are numerous US companies that are on the cusp of delivering revolutionary commercial products. There is no doubt that China will not cede these markets willingly, but the competition with US manufacturers should make products better, cheaper, and more environmentally friendly. This is the type of technology race in which we all stand to benefit, and one which I believe California companies have a real shot at winning!

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