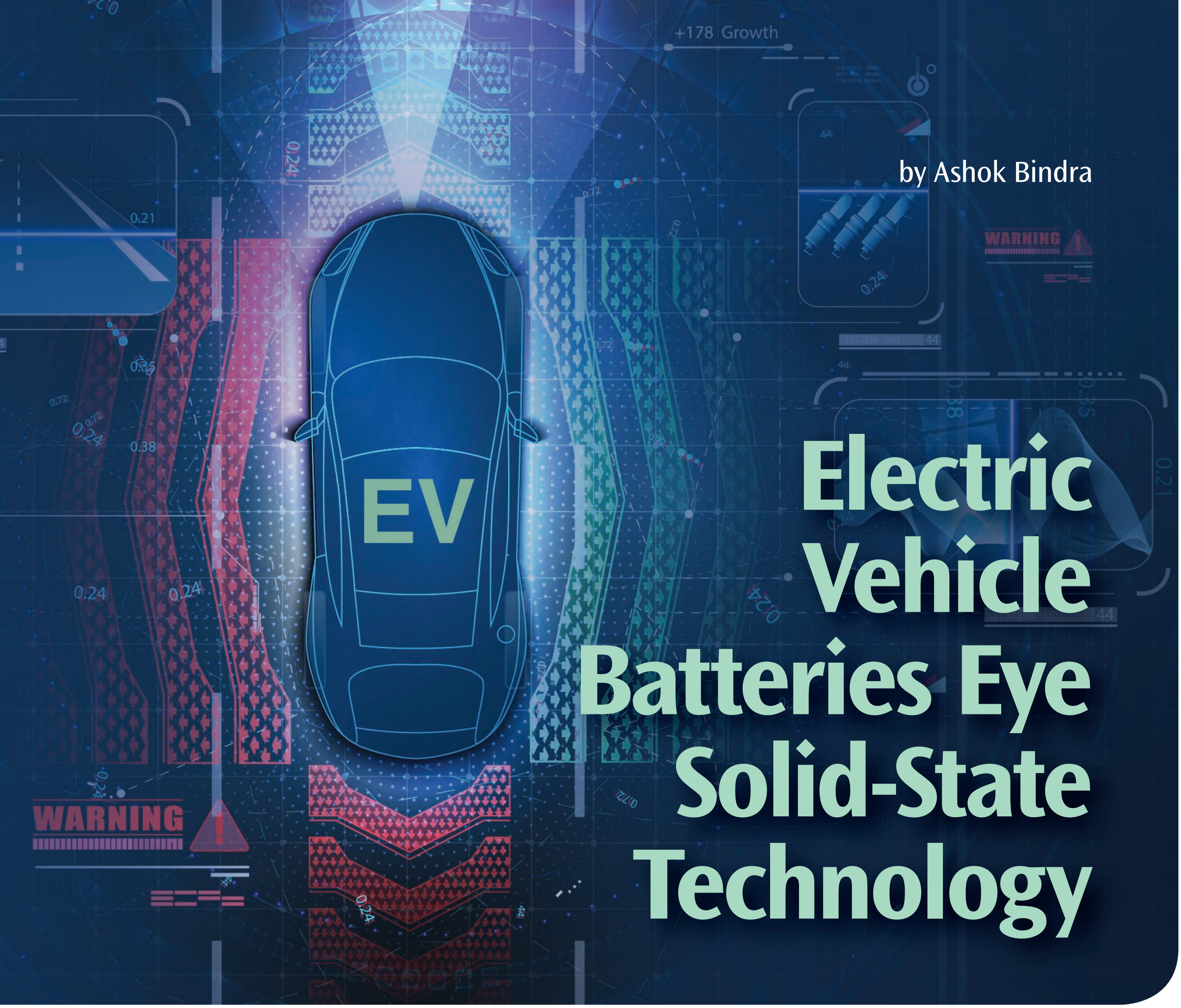

by Ashok Bindra

Electric Vehicle Batteries Eye Solid-State Technology

Prototypes promise lower cost, faster charging, and greater safety

The global pressure to cut carbon dioxide emissions from automobiles is driving more and more buyers toward electric vehicles (EVs) and hybrid EVs (HEVs). As the market for EVs and HEVs slowly grows with lithium-ion (Li-ion) as the battery technology of choice, for reasons well known, there is another technology emerging. Researchers are developing a solid-state (SS) version of Li-ion batteries for EVs that promises to charge and discharge rapidly, offer longer lifecycles, provide a much higher energy density, cost less, and provide greater safety. Besides the performance improvement, safety is a major factor driving automakers toward SS technology. In SS batteries (SSBs), the flammable liquid electrolyte, which passes the charge that carries Li ions during charge and discharge cycles, is replaced by a solid electrolyte. These ongoing improvements in battery technologies will pave the way for an installed EV base of 100 million vehicles by 2028, according to global technology market advisory firm ABI Research, Oyster Bay, New York. In fact, ABI's principal analyst James Hodgson says, "Lithium-silicon and SS are the future EV battery technologies that will improve performance, hold more energy, and last longer

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at a lower cost. The addition of silicon alone over the next seven years will grow the EV installed base from 8 million vehicles in 2019 to 40 million in 2025, as consumers' range anxiety slowly eases" [1].

During the past few years, several players announced prototype cells and expected commercialization dates, only to withdraw their claims or postpone the results. "Despite decades of development, many technological challenges remain unsolved," stated Dr. Milan Rosina, principal analyst for power electronics and batteries at market research firm Yole Développement (Yole), Lyon, France. Yole's latest SSB report indicates that mass production will begin by 2022 and account for less than 1% of the traditional Li-ion battery market by 2025. However, this scenario will change when large SSB manufacturers enter the arena. In fact, according to Rosina, "To commercialize SS batteries, four different technology players are joining forces to share knowledge and overcome challenges" (Figure 1). Those companies produce SS electrolyte technology, equipment, battery cells, and vehicles. However, with work still remaining, there is no commercially available bulk SSB today.

According to Yole, the key technology areas that need to develop include electrolyte-material screening, ionic-conductivity enhancement, electrolyte/electrode-interface stability, Li-metal anodes, cell- and pack-manufacturing methods, battery-management systems, and battery-pack designs. Yole's analysts have identified more than 100 companies and R&D groups that are involved in SSB development [2].

SSB Developers

Established automotive manufacturers, such as Toyota, Volkswagen, BMW, Daimler, and Hyundai, as well as newcomers Dyson and Fisker have joined SSB developers to commercialize EVs/HEVs with batteries that will be safer, lighter, and longer running than conventional Li-ion batteries. As a result, the number of companies and consortiums developing SSBs has risen. One example is Japan's Lithium Ion Battery Technology and Evaluation Center (LIBTEC), a consortium consisting of 30 companies, including heavyweights such as Toyota, Nissan, Honda, and Panasonic. "Sharing know-how from the four main technology areas is crucial for commercializing SSB," asserted Rosina.

With support from Japan's Ministry of Economy, Trade, and Industry and the New Energy and Industrial Technology Development Organization, LIBTEC hopes to develop an SSB that doubles the range of EVs from 400 km (249 mi) to 800 km (497 mi) by 2030. For the time being, it is targeting a more modest range of 550 km (342 mi) by 2025. The effort is led by Dr. Akira Yoshino, a winner of the 2019 Nobel Prize in Chemistry for the development of Li-ion batteries. Yoshino is an honorary fellow at the Asahi Kasei Corporation and a professor at Meijo University, Nagoya, Japan. He shared the Nobel Prize with John B. Goodenough, University of Texas at Austin, and M. Stanley Whittingham, State University of New York at Binghamton.

LIBTEC is the first organization to gather automotive, battery, and materials manufacturers in an effort to develop a standard SS Li-ion battery that has a capacity of 800 Wh/L. By setting standards for SSBs, Japanese companies hope to reclaim their global dominance. During the past several years, Japanese automotive-battery manufacturers have lost market share to manufacturers from China and South Korea.

More Investors

To speed up the development of SSBs, automotive OEMs, including battery manufacturers, have begun to invest in the technology. While the progress is encouraging, there are still many hurdles that must be overcome before SSBs can be adopted in automobiles. German automaker Volkswagen, for example, announced a US$100 million investment in QuantumScape, an SSB start-up that spun out of Stanford University, California. In a statement, QuantumScape Chief Executive Officer (CEO) Jagdeep Singh said, "We think the higher range, faster charging times, and inherent safety of SS technology will be a key enabler for the next generation of electrified powertrains."

Likewise, automaker Ford invested US$20 million in SSB developer Solid Power (Table 1). The partnership is expected to capitalize on Solid Power's fully automated, roll-to-roll production facility (Figure 2), which became operational last year. "From initial 2-Ah cells, Solid Power's automated pilot production facility will be capable of producing 20-Ah cells for larger battery packs by the end of the first quarter," said Solid Power's Dean Frankel, a strategic business development executive. He added that the company hopes to commercialize the technology in the next five to nine years with a target of 2027 for large batteries for automotive applications. In fact, according to Frankel, the company hopes to demonstrate the commercially ready EV SSBs by 2022. According to Solid Power, "By combining

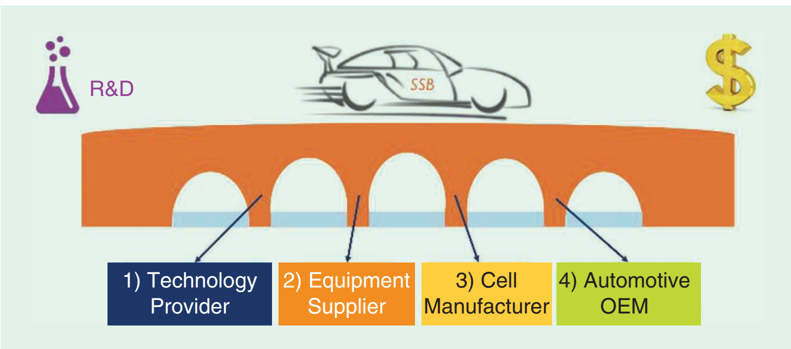

FIG 1 Companies in four different technology areas must share knowledge to overcome the challenges of SSB commercialization. OEM: original equipment manufacturer. (Source: [2]; used with permission.)

state-of-the-art cathodes with metallic-Li anodes, SSBs can achieve up to a 50% increase in cell-level energy versus current Li-ion cells. Even greater energy improvements are possible with more advanced cathodes, which is an additional area of development for Solid Power." The initial technology was licensed from the University of Colorado, Boulder. Like Ford, auto giants BMW and Hyundai are investors in Solid Power as is battery supplier A123 Systems.

Table 1. Notable investments and partnerships.

Company	Investor	Type	Battery Technology
Quantum Scape	Volkswagen	Investment	SS technology
Solid Power	BMW Group	Partnership	SS technology
	Hyundai	Investment	
	Ford		
	Samsung		
Northvolt	BMW Group	Partnership	Battery recycling
Umicore			
Enevate	Nissan Alliance	Investment	Lithium-silicon batteries
	Samsung		
	LG Chemistry		
Sila Nanotechnologies	Siemens	Investment	Lithium-silicon batteries
	Daimler		
	BMW Group	Partnership	

Source: ABI Research.

FIG 2 Solid Power's fully automated, roll-to-roll SSB production facility. (Source: Solid Power; used with permission.)

A123 Systems has also partnered with an advanced-materials company, Ionic Materials, to develop SSBs. By combining Ionic Materials' advanced, ionically conductive, polymer-based solid electrolyte with graphite anodes and metal–oxide cathodes, the partners plan to manufacture full-scale SSBs by using high-volume Li-ion manufacturing equipment, which would result in a cost-effective way to make EVs safer, lighter, and less complex (see "Fast-Charging Electric Vehicle Batteries"). "This unique approach is expected to enable the high-volume launch of SS technology into the market as soon as 2022," according to the partners. "By not using more exotic electrodes, such as Li-metal, an SSB with a solid polymer electrolyte can be introduced to the market much faster." In a press release, Mike Zimmerman, CEO of Ionic Materials said, "The synergy between our two companies produced a level of cooperation that is required to succeed in the ever-advancing battery space. We look forward to our continued success in commercializing this technology."

Earlier this year, Daimler led a US$170 million series E funding round for Sila Nanotechnologies, which developed a silicon-based anode (rather than graphite) to improve Li-ion battery efficiency. Toyota is developing an SSB for its own vehicle-electrification plan and recently partnered with Panasonic.

On the government front, the U.S. Department of Energy has awarded General Motors US$2 million for research and development of SSBs. This money will be precisely divided into two parts. While US$1 million will go for the fundamental understanding of interfacial phenomena in SSBs, the other US$1 million will go into research of hot pressing of reinforced all SSBs with sulfide glass electrolyte. In a 2014 study, it was shown that all bulk-type SSBs with sulfide glass electrolyte exhibited excellent cycle performance

Fast-Charging Electric Vehicle Batteries

Unlike the largest market for rechargeable batteries for consumer handsets, the ability to charge quickly (<15 min) is a key necessity for electric vehicles (EVs). Given the size of the battery and the need to create a battery that will last at least 10 years with a nonsignificant amount of degradation, the ability to create a battery with fast-charging capabilities is highly complex.

Consumers in the automotive market desire charge times that are similar to filling up a vehicle at a gas station. In a bid to meet consumer demand, automotive market incumbents and infrastructure providers are continually aiming to develop charging technology to achieve high-charging powers and establish fast charging times.

Not only do fast-charging stations have a huge impact on the grid, but they also introduce large stresses on the EV battery. Charging an EV battery requires intercalation of Lithium (Li) ion and electrons on the electrodes. The process of intercalation of lithium into free sites slows as more free sites become occupied with Li ions. Trying to push more Li ions quickly into less free space on the anode effectively creates an overload, whereby lithium starts to build up on the anode, unable to find a free site on the anode. This results in extra stresses, reducing capacity over time in the anode, and eventually leading to lithium plating, which could lead to short circuiting, if severe. The same conditions also occur when charging is carried out in cold temperatures, which significantly reduces the rate of intercalation.

—ABI Research

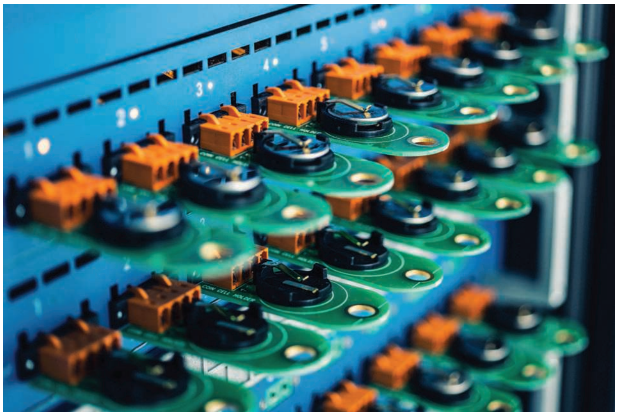

FIG 3 imec's pilot line for SS Li-metal battery cells. (Source: imec; used with permission.)

at room temperature. As a result, it could play a key role in bringing SSBs to market.

Europe and Asia

During the European Electric Vehicles Batteries Summit in June 2019, imec announced that it had doubled the energy density of its SS Li-metal battery cell and that it was scaling a pilot line in Genk, Belgium, to manufacture the product (Figure 3). To achieve an energy density of 400 Wh/L at a charging speed of 0.5 C (2 h), the researchers used a solid nanocomposite electrolyte combined with a standard Li-iron phosphate cathode and Li-metal anode. imec aims to reach densities of more than 1,000 Wh/L at a charging speed of 2–3 C (less than half an hour) by 2024. According to imec, the solid nanocomposite electrolyte has an exceptionally high conductivity of up to 10 mS/cm, with a potential for even higher levels. A distinguishing feature of the new material is that it is applied as a liquid via a wet chemical coating and converted into a solid when it is in place in the electrodes. As a result, says imec, the material is well suited to be cast into dense power electrodes where it fills all of the cavities and ensures maximum contact, much like a liquid electrolyte.

Per imec's description, the assembly of the cells could be done by slightly modifying existing manufacturing lines for Li-ion batteries. As a result, the technology does not require expensive investments to switch from wet to SS cells. The pilot line, which is located at the imec EnergyVille Campus in Genk, was established in coordination with the University of Hasselt, Belgium, enabling the manufacture of prototype pouch cells with up to 5 Ah of capacity. In a statement, imec's scientific director said, "The pilot line allows us to take the next step and upscale the battery breakthrough to industrially relevant processes and formats, using manufacturing processes similar to those for wet batteries."

imec said that bringing the emerging SSB battery technology to market will require the cooperation and commitment from the world's major materials suppliers and battery producers. Therefore, it performs its battery research and development as an open collaborative program and works with all interested parties. In China, a startup spun out of Tsinghua University called Qing Tao Energy Development Co. has deployed an SSB production line in Kunshan, East China. After achieving an energy density of over 400 Wh/kg, Chinese EV startup Enovate has inked a deal with battery cell maker ProLogium on commercializing SSBs. Under this agreement, Enovate will use ProLogium's SS lithium ceramic battery (LCB) technology in its newest EV model ME-S premium sports sedan. The SS-LCB is expected to offer an energy density of 750 Wh/L. According to ProLogium, unlike rechargeable Li-ion batteries, its SS-LCB technology does not need any protection circuit and is intrinsically safe with no leakage.

Meanwhile, in partnership with Panasonic, Toyota is also developing an SSB under its vehicle electrification plan. Toward that goal, according to the Japanese automaker, it will debut a prototype EV equipped with an SSB at the 2020 Tokyo Olympics. However, a production EV with SSB will not be available until the middle of this decade.

Unlike others, Tesla continues to advance the conventional wet Li-ion technology and is developing new chemistries in collaboration with Dalhousie University in Canada. As per Tesla's press release, the new technology offers the energy density of SSBs while maintaining the same format as today's lithium-ion cells.

About the Author

Ashok Bindra (bindra1@verizon.net) received his M.S. degree from the Department of Electrical and Computer Engineering, Clarkson College of Technology (now Clarkson University), Potsdam, New York, and his M.Sc. degree in physics from the University of Bombay, India. He is the editor-in-chief of *IEEE Power Electronics Magazine* and a Member of the IEEE. He is a veteran freelance writer and editor with more than 35 years of editorial experience covering power electronics, analog/radio-frequency technologies, and semiconductors. He has worked for leading electronics trade publications in the United States, including *Electronics*, *EE Times*, *Electronic Design*, *Power Electronics Technology*, and *RF Design*.

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