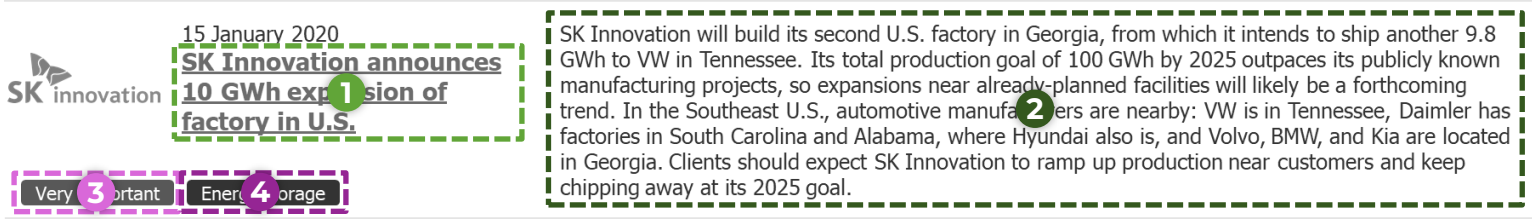
Singapore Battery Consortium Q3 2023 Newsletter

September 2023

SINGAPORE BATTERY CONSORTIUM

Understanding curation of recent industry developments and technology news

Recent industry and technology news are specifically curated based on the relevance to the progression and impact on the battery industry. Each news event is categorized based on importance as rated by Lux's subject matter experts 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
Strategy and regulations	Strategic developments as well as policies with transformational impact on new battery technology developments
Battery developments	Technology developments in electrochemical energy storage, such as Li-ion and solid-state batteries
Electric mobility	Battery deployments for powering road, rail, aviation, and shipping – includes movement of goods and people
Residential energy storage	Hardware and software technologies for commercial and residential battery applications
Stationary storage	Utility-scale and long-duration battery storage for grid services and renewables integration

Supportive government policies and financing has been a boon for the U.S. battery manufacturing industry

U.S. DOE offers loan of USD 9.2 billion to BlueOval SK for battery manufacturing

Very Important | Strategy and regulations

The U.S. Department of Energy (DOE) Loan Programs Office (LPO) announced it had extended a conditional commitment for USD 9.2 billion in loans to BlueOval SK to expand manufacturing capacity. The loan would cover three manufacturing facilities totaling 120 GWh to supply batteries for Ford and Lincoln vehicles. The industry should expect the U.S. to continue offering large initiatives to the battery industry, as it has quickly become a major competitor for such investments, and other governments to mobilize similar types of loan programs.

GM unveils bidirectional EV charger and battery system for the residential market

Very Important | Residential energy storage

GM's system, called Ultium Home, comprises four products: a 19.2-kW charger, a vehicle-to-home (V2H) enablement kit, a 5-kW/10.6-kWh or 7-kW/17.7-kWh battery system, and an inverter/home hub system. Customers can choose from three bundles to enable V2H with or without additional installed storage or install just the battery and home hub. GM doesn't sell a V2H-capable vehicle yet, but with this offering, GM is targeting customers who don't have an EV, allowing them to enter the home energy management system market, differentiating from most automakers except Tesla.

WiTricity offering wireless EV charging tailored for automakers and OEMs

Low Importance | Electric mobility

Through the "FastTrack Integration Program," the company plans to engage with automakers and OEMs to accelerate testing of the company's system [an 11-kW electric vehicle (EV) wireless charger and receiver]. The company claims the program will help test and develop "dealer-installable" or "factory-installed" charging systems for existing or new EVs, respectively, and mentions to "allow for an initial vehicle integration in just three months." Still, it is not clear what the company means by "integration." The industry should watch for automaker announcements about producing vehicles with wireless charging and expect it will be an option rather than a standard feature.

Developers continue to look towards alternative chemistries beyond Li-ion for large-scale energy storage needs

After investment and partnership spree, Umicore takes the next step into solid-state batteries

Very Important | Battery developments

In the last five years, Umicore has invested in Solid Power and Blue Current, bought a license from BASF, and partnered with Idemitsu Kosan to expand its expertise in solid-state batteries. This prototyping facility will provide flexibility to researchers for producing large-format cells. The company highlighted the infrastructure's dry-air capability, which indicates the solid-state electrolyte will be sulfide based. Umicore's interest lies in developing electrode materials rather than electrolytes or peripheral materials. Hence, this facility will build and test battery prototypes with Umicore's different electrodes, such as Li-metal and silicon anode, and electrolyte materials obtained through collaboration.

Volkswagen trades electricity using a second-hand stationary storage battery system

Average Importance | Stationary storage

Volkswagen subsidiary, Elli, conducted a pilot project on energy arbitrage to charge and discharge batteries during peak times. The system used 28 battery systems and 34 cell modules from its e-up! electric vehicle (EV) model. This experience will be used to develop a "smart energy platform," which could integrate EVs and enable vehicle-to-grid (V2G) and vehicle-to-home capabilities. The industry continues to explore V2G monetization opportunities; however, energy arbitrage is not a strong fit for V2G, as it introduces high cycling on the battery and has high regulatory barriers.

Xcel Energy gets go-ahead to replace coal plant in Minnesota with Form Energy's iron-air battery

Average Importance | Stationary storage

Xcel Energy plans to retire its coal-fired plant gradually from 2023 to 2030 and replace it with a solar plant. Form Energy's iron-air battery system of 10 MW/1,000 MWh will be installed as a part of this solar system. The company claims the system costs 10% of the price of Li-ion batteries and could deliver electricity for 100 hours. Form Energy has bagged three projects, totaling of 26 MW, within the last year with utilities across the U.S. and has recently started construction of a manufacturing facility with a production capacity of 50 MW/50 GWh of batteries per year by 2027. However, the company has yet to demonstrate its battery at a pilot scale.

Automakers will need to build charging infrastructure in parallel to electric heavy-duty trucks to tap its full potential

GEM sets its sights on large-scale LFP recycling

Very Important | Battery developments

Green Eco-Manufacture (GEM) will build a 50,000 tonne/y capacity lithium iron phosphate (LFP) recycling facility. In July 2022, the company produced LFP from its first pilot line with a 20,000 tonne/y capacity. It expects to scale to 100,000 tonne/y by 2024. China recently surpassed 60% market share for LFP in mobility, so GEM's scale-up of LFP recycling will be needed. The chemistry has been difficult to recycle due to low-value output products, but if GEM can produce battery-grade LFP precursor material, it will create a valuable business case for the company.

Geely's electric and hybrid electric truck unit Farizon Auto raises USD 600 million in Series A funding

Average Importance | Electric mobility

The funding round, which brings the total funding raised to USD 900 million, was led by Boyu Capital and Yuexiu Industrial Fund and included United Clean Energy among others. Farizon plans to use the funding on R&D and global expansion. It is targeting APAC, the Middle East, South America, and Europe with plans to start selling a light electric cargo van in Europe in 2024. The company will likely find it challenging in Europe due to the presence of local brands. The company should make announcements regarding vehicle releases in the coming months but will need to raise additional funds before bringing a truck to market.

Ampaire acquires Tayln Air to enter the eVTOL space

Average Importance | Electric mobility

While the companies did not disclose the financial details of the acquisition, Ampaire is looking to enter the electric vertical takeoff and landing (eVTOL) aircraft and drone markets for commercial and defense applications. Ampaire plans to deploy its hybrid electric propulsion technology to Talyn aircraft. Talyn has several contracts with the U.S. Department of Defense for both drones and eVTOLs where we will highly likely see deployments before any commercial ones. This gives Ampaire a good footing to enter the eVTOL and drone markets, but any entry into commercial markets will likely occur long after this and the deployment of its hybrid electric regional aircraft.

Electric aviation startups continue to gain traction despite facing regulatory and technical barriers

Wisk completes first public test flight of its autonomous eVTOL

Very Important | Electric mobility

At the EAA AirVenture in Oshkosh, Wisconsin, Wisk flew its fifth-generation autonomous electrical vertical takeoff and landing (eVTOL) demonstrator aircraft. The aircraft transitioned between hover and horizontal flight four times during the test. The company is pursuing FAA type certification for its sixth-generation aircraft, with the goal of commercially deploying by decade's end. Certification is highly prone to delays, especially when autonomy is added to the equation. That said, Wisk is a leader in the space, and being a Boeing subsidiary gives it a wealth of relevant resources to be the first to deploy. In any case, first deployments will be highly restricted to uses like scenic flights or luxury transportation services.

New CEC program will pay BTM storage systems to send power back to the grid in extreme events

Very Important | Strategy and regulations

In the approved Demand Side Grid Support (DSGS) program, the California Energy Commission (CEC) will enable behind-the-meter (BTM) energy storage systems to receive 2 USD/kWh by exporting energy back to the grid during extreme events like wildfires that threaten outages. Unlike the Emergency Load Reduction Program (ELRP), the DSGS can tap assets more frequently (the ELRP is limited to 4 p.m. to 9 p.m.) and will enable participation from batteries across the state of California (not just those in California Independent System Operator territory).

PG&E partners with Schneider Electric to include new V2G capabilities in its DERMS platform

Average Importance | Battery developments

Pacific Gas & Electric (PG&E) has teamed up with Schneider Electric to deploy a distributed energy resource management system (DERMS) platform to improve distributed energy resource (DER) visibility, evaluate and process interconnection requests faster, and manage electric vehicle (EV) charging and vehicle-to-grid (V2G) coordination for EV fleets and residential customers, among other aims. This will be the first time Schneider DERMS implements V2G capabilities and correlates with recent PG&E incentives and pilot projects testing V2G. High penetration of DERs requires increased visibility for utilities, enabling them to leverage asset capabilities to reduce or defer infrastructure upgrades.

Cost reductions and elimination of costly and harmful solvents at the core of interest for dry electrode manufacturing processes

New LFP recycling method uses battery waste to generate electricity

Average Importance | Battery developments

Researchers at Beijing Institute of Nanoenergy and Nanosystems introduced a recycling process that can recover lithium carbonate and lithium iron phosphate (LFP) from redox targeting reactions. From the waste batteries, the researchers recovered casings, plastics, and current collectors to build an energy harvester known as a triboelectric nanogenerator, which can create power from wind energy. Companies like NEU Battery Materials are developing redox targeting reactions to process LFP batteries for faster, less costly recycling, but this new research presents a process that can reduce the energy used to operate the electrochemical recovery of battery materials.

Panasonic

Panasonic signs supply deal with Nexeon for its silicon anodes to be used in EV batteries in 2025

Very Important | Battery developments

Nexeon announced it had signed a supply deal with Panasonic for silicon anodes for its new battery manufacturing facility being constructed in Kansas, U.S., which will be operational in 2025. Panasonic's manufacturing plant will have a capacity of 30 MWh, though it's unclear whether Nexeon will supply for the full capacity. Panasonic will use Nexeon's material for electric vehicle (EV) batteries, reinforcing Lux's expectation to only see silicon anodes commercialized in the later half of the decade.

OAK RIDGE National Laboratory

ORNL's research further confirms dry electrode claims of cleaner and cheaper production

Low Importance | Battery developments

The U.S. Department of Energy's Oak Ridge National Laboratory (ORNL) published the results of anode film testing manufactured through dry processing by Navitas Systems. The research indicates the dry processing method uses no harmful solvents to lower toxicity, reduces the battery's overall weight, saves manufacturing costs, and improves storage capacity. The lab also indicated it is working toward improving binder material and electrochemical performance of batteries integrated with dry-processed materials. Many battery manufacturing companies have shown an interest in dry processing methods, and the government's interest in this is to reduce production time and dependency on other countries and reduce battery costs to accelerate electric vehicle adoption.

Gravitational energy storage remains a longshot despite Energy Vault's flagship system coming online

Archer raises USD 215 million and receives approval to begin test flights

Average Importance | Electric mobility

Archer has raised USD 215 million from Boeing, Stellantis, and United Airlines among others. Boeing's portion will support its new collaboration with subsidiary Wisk, which will become Archer's sole provider of autonomy technology in the future. This collaboration also marks the end of the legal battle between Archer and Wisk. Archer also announced it plans to commence test flights with its Midnight aircraft in the coming months after getting the OK from the Federal Aviation Administration. The company is looking to deploy in the military and commercial domains, where it has partnerships with the U.S. Department of Defense and United Airlines, respectively.

Sion Power introduces its lithium-metal batteries for commercial evaluation in EVs

Very Important | Battery developments

Sion Power has said that it produced 18,000 samples of battery cells ranging from 6 Ah to 20 Ah made of Li-metal anode, high nickel-content cathode, and an electrolyte with a composition between a solid and a liquid. The company claims its 17-Ah large-format cell has a specific energy of 400 Wh/kg. It has started supplying these cells for testing, especially to electric vehicle (EV) OEMs. If Sion Power is at a testing stage in EVs, it indicates its success in research to control the concerns of Li-metal anodes, such as dendrite formation and thermal runaway.

25-MW gravity storage system designed by Energy Vault is commissioned

Average Importance | Stationary storage

After licensing its gravity storage technology to Atlas Renewable and China Tianying last year, Energy Vault announced the commissioning of a commercial-scale 25-MW/100-MWh energy storage system in China. The new system has a round-trip efficiency of 75%, which is expected to hit 80% following undisclosed improvements. After the completion of this project, a subsidiary of China Tianyang will build another 100-MWh system for data center backup. Energy Vault is targeting remote, bulk energy storage, its system has a much larger volumetric energy density compared to that of other electrochemical solutions.

Opportunities exist in advanced batteries as automakers seek to monetize vehicle-to-X as an extension to their EV fleet

Panasonic unveils new energy storage system with V2H capabilities

Average Importance | Residential energy storage

Panasonic will begin taking orders for its new "Eneplat" product that consists of a battery system and an electric vehicle (EV) charger. The system performs energy arbitrage, simultaneously charging or discharging the battery or the EV based on the weather forecast, calculating self-generated solar energy surplus, or issuing alerts related to generation. In a power outage, vehicle-to-home (V2H) backup power can be discharged at 100 V/200 V and 6 kW. Panasonic says the system can increase self-consumption from 50% to approximately 90% and offers storage capacity ranging from 3.5 kWh to 13.4 kWh

Wallbox and Kia America partner to realize residential backup power via EV charger

Average Importance | Residential energy storage

Through a partnership between Wallbox and Kia America, owners of a Kia EV9 will be able to implement vehicle-to-home (V2H) capabilities with the new version of the Wallbox bidirectional electric vehicle (EV) charger Quasar 2. Wallbox claims to provide an 11.5-kW discharge power, which is 1.2 times bigger. Utility customers should see this announcement positively, bringing vehicle-to-grid (V2G) technology commercialization closer, and charger OEMs should explore possibilities to partner with automakers to develop V2G and V2H systems together, focusing primarily on reducing product costs.

Eos Energy wins nearly USD 400 million loan from DOE to scale production

Very Important | Stationary storage

U.S. Department of Energy (DOE) awarded a USD 398.6 million conditional loan offer to Eos Energy to scale production of its zinc-hybrid battery chemistry. The conditional funding will account for up to 80% of Eos Energy's USD 500 million project to build semiautomatic commercial manufacturing of its battery systems. Eos Energy claims over 2.2 GWh in finalized orders but has struggled with delivery of units due to production design challenges.

Technology choice for long-duration storage will greatly hinge on the size of the system and target applications

U.S. DOE grants USD 325 million in funding for long-duration energy storage projects

Very Important | Strategy and regulations

Nine projects will receive up to USD 286 million for demonstration of long-duration energy storage (LDES), and six projects will receive up to USD 39 million for technology development at national labs. The demonstration projects include second-life batteries from ReJoule and Smartville, Urban Electric Power's zinc manganese oxide battery, Invinity Energy Systems' vanadium redox flow battery, Redflow's zinc bromide flow battery, Eos Energy's zinc hybrid battery, Energy Dome's compressed CO2 energy storage system, Echogen's pumped thermal energy storage system, and Form Energy's iron-air battery.

Honeywell and ESS Tech to collaborate on iron flow batteries

Average Importance | Battery developments

Honeywell has announced it will collaborate with ESS Tech Inc. and buy USD 27.5 million worth of ESS common stock. The collaboration includes a purchase target of up to USD 300 million for ESS technology, with USD 15 million prepaid, access from ESS to Honeywell IP on flow batteries, and joint development of new flow battery technology. Although this collaboration serves as positive validation of ESS' technology and will provide a massive customer base for system deployment, it's a major walk-back from Honeywell's own flow battery development.

EnergyHub partners with GE to increase capabilities of its DERMS platform as a grid interface

Very Important | Stationary storage

EnergyHub has partnered with GE to integrate GE's GridOS software for grid optimization with EnergyHub's distributed energy resources management system (DERMS) for DER aggregation and control. The partnership aims to provide utilities with better DER visibility and management, opening up new revenue streams primarily from energy storage systems. Interfacing with the grid through the GridOS platform will enable EnergyHub to perform better DER scheduling for market participation, which could translate into larger revenues and better optimization of power flows that are required to reduce grid congestion thanks to the fast deployment of DERs.

EV Battery Pack Materials Innovation

Today’s battery packs are increasing in complexity with no standard pack design between manufacturers

By 2030, one-half of all new vehicles sold will have an electric drivetrain, representing nearly USD 300 billion in value. In the same timeframe, new regulations will emerge, and charging infrastructure will boom. Many automakers haven’t finalized technology decisions regarding next-generation battery packs. To successfully navigate this complex area within such a short window, partnerships will be paramount

EV battery packs are a rapidly evolving technology, and big divergences in design, materials, and assembly are common.

Cells. These are the individual batteries in the pack. Cells have different cathode chemistries and form factors.

Modules. Cells are typically grouped into units called modules, which often integrate sensors, thermal management, and electrical connections.

Packs. Modules are grouped to form the overall battery pack. This includes the structure of the pack, active cooling systems, and components like TIMs or BMSs.

Image source: Nissan Motors

Pack-level innovation has enabled a wider range of cell chemistries in battery EVs with a focus on eight key innovation areas

Substantial price spikes in critical metals like nickel and cobalt made the advanced chemistries far more expensive than LFP. At the same time, companies such as CATL and BYD made great strides with pack-level innovations. The BYD Blade is a great example of this: It uses 200-Ah cells (roughly an order of magnitude larger than Tesla cells) in a cell-to-pack (C2P) configuration, supported by advances in thermal management to ensure these large cells stay cool. This allowed BYD to dramatically increase the overall energy density of the pack by eliminating nonenergy-storing components, offsetting the weaknesses of the LFP chemistry while maintaining the benefits of lower cost, better durability, and higher safety.

Pack-level innovations are increasing in importance and in turn has sparked a wave of interest and activity from a broad range of players including established battery pack component suppliers, large materials and chemicals companies, and early-stage startups with a wide range of novel technologies.

Key Innovation Areas in Battery Packs	
Busbars and electricals Conductive and insulative materials to transport current throughout the battery pack	**Safety and fire-retardant materials** Specialty materials that can prevent, shield, or put out fires associated with thermal runaway
Battery management systems The “brain” that controls battery charging, discharging, sensors, and range calculations	**Sensors** Point-source or simulated measurements of key metrics like voltage and current, temperature, and presence of coolant or gases
Structural materials The battery case, fasteners, seals, adhesives, and other structural members	**Cooling systems** The equipment and connected fluid circuits that actively pull heat out of the battery pack
Thermal interface materials The physical interface that transfers heat from a given component to its heat sink	**Design and simulation** Software tools to simulate and generate new designs, novel materials, and safety tests

Each area of battery pack innovation has a different landscape and distinctly different set of drivers, barriers, and opportunities

Four global megatrends are the primary drivers of battery pack innovations.

- **Consumer demand for faster charging.** Auto industry experts claim that shorter charge times (as close to gas refueling as possible) are more important than range for most customers.
- **Fire safety regulation.** Fire safety regulations continue to tighten with several countries enacting rules such as the 5-minute safety window.
- **Sustainable materials and production.** Companies are developing new sustainable materials and manufacturing methods as a response to needs for a regional supply chain and cleaner production.
- **Critical materials shortages.** Lithium, nickel, cobalt and rare earth metals are increasingly under supply pressures for battery electronics, pack materials, and other vehicle components.

While global megatrends are influencing the broad innovation landscape for EV battery packs, each component has its own unique innovation outlook. Lux assessed each battery pack component based on the market opportunity, innovation activity, and external pressures.

Component	Low	Medium	High
Market opportunity	USD 1 billion to USD 5 billion	USD 5 billion to USD 10 billion	> USD 10 billion
Innovation activity	Comparatively lower than other battery pack components	Average amongst battery pack components	Comparatively higher than other battery pack components
External pressures	Aligned with two global megatrends or less	Aligned with three global megatrends	Aligned with all four global megatrends

Electrical equipment is placed under increasing demand as EV performance and capabilities continue to improve

As automakers continue to develop machines with longer ranges and faster charging capabilities, low- and high-voltage networks will bear the brunt first. Current busbars are a step better than cylindrical wires, but will continue to see improvements in flexibility, coatings, and continuity; companies like Aptiv, Impact Innovations, and Interplex are advancing this work.

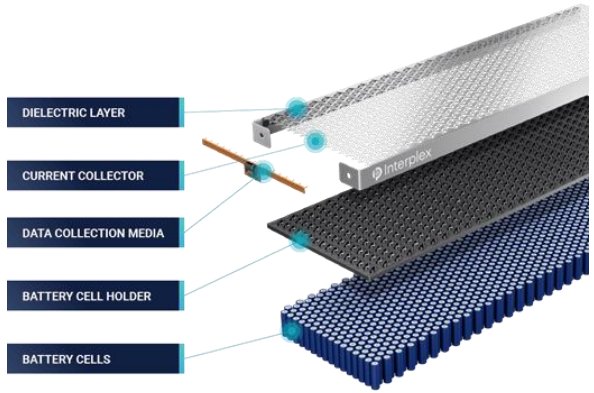
As vehicle autonomy progresses, it will be important to ensure that high-voltage electronics in the pack don't interfere with other electronic systems. Companies like Henkel, Kitagawa, Schlegel, and Laird now offer TIMs, heat sinks, and other materials with electromagnetic interference (EMI) shielding built in. Meanwhile, the thermal conductivity gap for higher-performance EV power electronics is attracting newcomers like Carbice to develop purpose-built, high-performance TIMs.

Primary driver: Consumer demands

Primary barrier: Materials performance

Materials opportunity: Metallic and dielectric coatings, high-voltage and heat-resistant polymeric connector materials, flexible printed circuits, multifunctional materials

Component	Rating
Market opportunity	**Low** – USD 3 billion
Innovation activity	**Medium**
External pressures	**Medium** – Regulation, fast charging, critical materials shortage



Interplex's Cell-PLX interconnects

Cell interconnect methods like wire harnesses, flexible circuits, and wire bonding limit energy density or are slow to assemble; Cell-PLX can be quickly integrated with cylindrical, pouch, or prismatic cells at a wide range of current densities and pack configurations.

Image source: Interplex

Increasing regulatory scrutiny underlying drive for the adoption safety and fire-retardant materials

Early fires and recalls have damaged the public's perception of EV safety and caused major headaches for automakers. This led Chinese and Indian governments to roll out comprehensive fire safety regulations in the last two years; companies should expect other countries to follow suit. To meet emergent requirements, automakers will need to implement physical fire barriers as well as better sensing and BMSs.

For materials, automakers today can choose from various intumescent foams, aerogels, and fire-retardant plastics from companies like Saint-Gobain, Jios Aerogels, and SABIC, respectively, although regulation may obviate existing options. Materials companies have work to do here, and battery makers should plan to overshoot any minimum targets to ensure future needs are met.

Primary driver: Regulation

Primary barrier: Materials performance

Materials opportunity: Multifunctional (mechanical and thermal) gap pads, intumescent materials, hot gas valves, ceramics, encapsulants, flame-retardant coatings

Component	Rating
Market opportunity	**Medium** – USD 9 billion
Innovation activity	**High**
External pressures	**Medium** – Regulation, sustainability, fast charging

Aspen Aerogels' PyroThin

Existing gap pads provide mechanical performance but don't contribute during thermal runaway events; PyroThin is the same thickness as most mechanical pads but can withstand up to 1,400 °C while saving 5–10 kg, ensuring no power sacrifice for improved fire safety.

Image source: Aspen Aerogels

Implementation of battery management systems may alleviate some battery pack materials challenges

While physical fire barriers provide a critical window for passengers to escape during a fire safety event, they do nothing to prevent a cell entering thermal runaway to begin with. For this, one must rely on advanced BMS features like active current control, gas detection and venting, more accurate sensors, and wireless communication between the BMS, cell controllers, and sensors. Companies like Texas Instruments, Bosch, and ADI are active here.

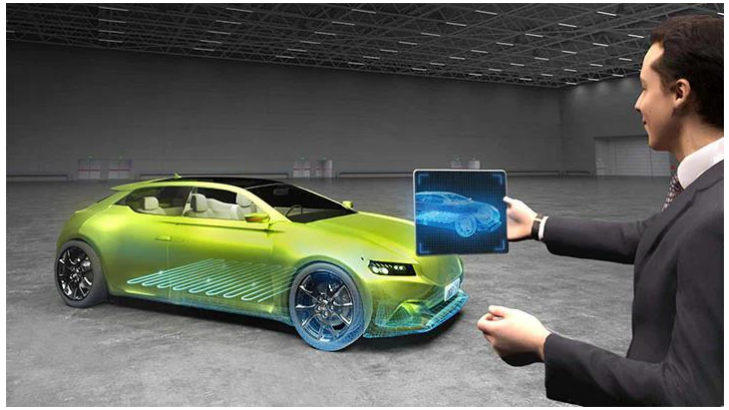
Given advancements in AI, cloud-based systems, and digital twins, BMSs can now shoulder day-to-day performance optimization over a vehicle's lifespan. For instance, companies like Infineon and NXP offer features like independent cell control, over-the-air software updates, and predictive algorithms. These upgrades enable the BMS to avoid or self-balance during outlier events while improving the treatment and lifespan of the battery.

Primary driver: Fast charging

Primary barrier: Lack of partnerships

Materials opportunity: Digital twins, AI- or cloud-based models, cell-level control, wireless communication, electromagnetic interference shielding

Component	Rating
Market opportunity	**High** – USD 15 billion
Innovation activity	**High**
External pressures	**Low** – Regulation, fast charging



NXP and Electra's BMS

NXP Semiconductors and Electra Vehicles have joined forces to offer an AI-based BMS that leverages cloud-based digital twin models to predict and control the battery in real time. They claim this adaptive cell modeling system can improve state of charge (SoC) and state of health (SoH) calculations by 12%.

Image source; NXP Semiconductors

Deployment of advanced battery sensors can unlock addition range and serve as a security measure for fire threats

Most EVs on the road today use wired, periodic sensors to approximate cell-level values for SoC and SoH metrics. Given the regulatory landscape as well as failures of these imprecise systems, battery makers are moving toward wireless, cell-level detection of all critical metrics. In addition to current and temperature sensors, future battery packs will have more pressure, humidity, and gas sensors, supplied by companies like Sensata, TE Connectivity, and Amphenol.

Additionally, large sensor errors (up to 10%) limit range and charging speed and can lead to cell imbalances that cause fires. Research persists on sensors with high dynamic range and high specificity, like ultrasound sensors from Titan Advanced Energy Solutions, while BMS makers like Nexceris employ AI-based sensor models and the Internet of Things (IoT) to simulate metrics remotely.

Primary driver: Technology

Primary barrier: Materials performance

Materials opportunity: Wireless sensors, high specificity (mA range) with high current thresholds (hA range), ultrasound, AI-based sensor models, coreless (nonferrous) sensors

Component	Rating
Market opportunity	**Medium** – USD 6 billion
Innovation activity	**Low**
External pressures	**Low** – Regulation, fast charging

Nexceris and Honeywell's Li-ion Tamer

Nexceris and Honeywell put their strengths together to release the Li-ion Tamer — a proactive, gas sensor-based detection system that both helps prevent thermal runaway and materials failure modes, optimizing battery pack lifespan. They claim this provides a 30-minute window of safety for fire events.

Image source: Nexceris

Battery structural materials offer high potential in addressing market and regulatory needs

Underpinned by the global EV metals shortage, auto- and battery makers are planning to recover batteries for second lives. This has implications for structural components like adhesives, seals, and casing materials, since batteries must be designed for easy disassembly or shredding (depending on second-life usage). Expect to see more natural fiber-based composites from players like Helicoid or Bcomp and multifunctional materials from players like Henkel, Tesa, or Parker Lord.

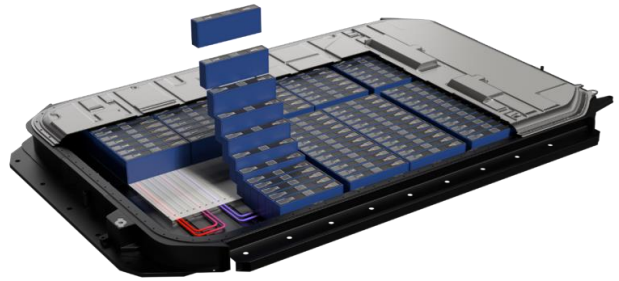
Despite momentum in C2P, every OEM will make unique decisions based on regional policy, incentives (like China's incentive for swappable batteries), and infrastructure. Expect modularity and design for circularity to play central roles in the future because regardless of regional variations, supply chain and sustainability concerns will be alleviated.

Primary driver: Critical materials shortage

Primary barrier: Sustainability

Materials opportunity: Recyclable adhesives, seals, and resins for housings, composite materials for housings, multifunctional materials, materials informatics, novel alloys, coatings

Component	Rating
Market opportunity	**High** – USD 30 billion
Innovation activity	**Medium**
External pressures	**High** – Regulation, fast charging, sustainability, critical materials shortage



Henkel's dielectric coating

For cell-to-x configurations, where cells must be semi-structured and bonded directly to one another, current interface options are too weak; Henkel's product is strong enough to contribute structurally, is thinner than polyethylene terephthalate alternatives, and ensures the same voltage breakdown strength.

Image source: Henkel

As battery chemistries and pack designs change, cooling systems will need to evolve and adapt

Hotspots and inefficient thermal conduction pathways are serious issues for today's packs. As automakers mull major structural changes like C2P or novel chemistries, the knock-on implication is how to keep new packs cool. Despite the current ubiquity of cold-plate cooling, we anticipate a multitude of future solutions, primarily split between optimization of existing systems and rollout of new cooling systems.

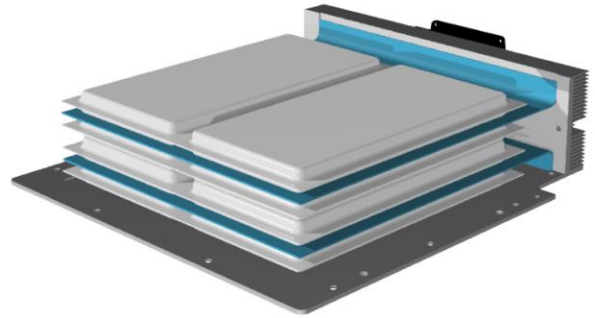
For automakers that stick with cold-plate or air-cooled systems, expect to see high-performance TIMs, phase-change materials (PCMs), heat pipes, or design optimization, with solutions from players like Carbice, Kulr, Calogy Solutions, or Gamma Technologies, respectively. For more energy-dense chemistries or to enable ultrafast charging, using a liquid immersion system from newcomers like Carrar, Wattalps, or e-Mersiv will be the quickest route.

Primary driver: Consumer demands

Primary barrier: Technology

Materials opportunity: Sustainable hoses, tubes, and nonflammable dielectric fluids, phase change materials, heat pipes, thermal fillers, design optimization

Component	Rating
Market opportunity	**High** – USD 60 billion
Innovation activity	**High**
External pressures	**Medium** – Regulation, fast charging, sustainability



Calogy Solutions' Uni.T

Calogy's Uni.T is a passive heat pipe that when used in conjunction with existing air- or liquid-cooled systems, can keep ΔT across all cells less than or equal to 1 °C. The plate itself can also be used as a structural member for C2P systems; Calogy also produces complete LFP packs with Uni.T installed.

Image source: Calogy Solutions

Thermal interface materials will become multi-functional and enable future design requirements of battery packs

Many EV subcomponents generate heat, including cells, inverters, and power electronics. At every junction of the heat-producing system and heat sink lies a TIM. And while the race for lowest thermal conductivity takes place among fire-retardant materials suppliers, there is a race among TIM providers like Parker Lord, DuPont, 3M, and Saint-Gobain to both increase thermal conductivity and add secondary functions like structural rigidity for C2P architectures.

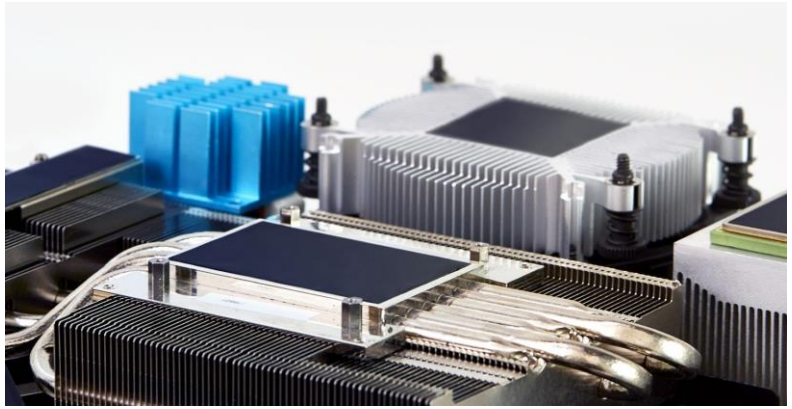
Regardless of pack design decisions, common TIMs like silicones and greases often require rework, contribute to outgassing, and lack the conductivity and durability needed to function efficiently at high power densities. Therefore, purpose-built, high-performance TIMs like those offered by U-MAP, Kulr, or Carbice will be the most enabling for future design requirements.

Primary driver: Cell-to-pack architectures

Primary barrier: Materials performance

Materials opportunity: Carbon nanotubes, de-bondable thermal interface materials, phase change materials, multifunctional TIMs (electromagnetic interference or structural)

Component	Rating
Market opportunity	**Low** – USD 3 billion
Innovation activity	**Medium**
External pressures	**Low** – Fast charging, sustainability



Carbice's Ice Pad

Satellite makers have historically assembled two side by side due the high likelihood of TIM rework with liquid TIMs; Carbice brings its experience solving this problem for the space industry to automotive players with carbon nanotube TIMs that provide low thermal resistance and high conductivity.

Image source: Carbice

Further developments in simulation and design software will uncover novel battery pack solutions

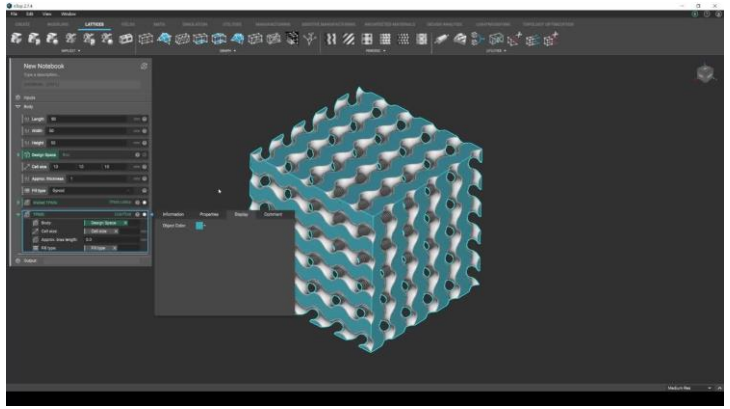
Computer-aided engineering (CAE) software has come a long way in recent years, with a plethora of suppliers like Siemens, SimScale, Dassault, Gamma Technologies, Comsol, or Ansys offering computational fluid dynamics, thermal simulation, finite element analysis, and digital twins for battery modeling. Generally, these tools are not considerably different from one another. Instead, there are three key areas where software will trigger major design improvements: accelerated wear testing, generative design (GD), and materials informatics (MI). Every battery undergoes dozens of extreme tests that can take years (for second-life batteries); simulations could have an outsized impact here. For similar unexpected improvements, GD-based CAE tools from nTopology or Neural Concept will uncover optimized structural and thermal pathways, while MI tools from Synopsis and Citrine will lead to novel thermal, electrical, structural, and multifunctional materials not in existence yet.

Primary driver: Consumer demands

Primary barrier: Materials performance

Materials opportunity: Generative design, thermal modeling software, materials informatics, digital twins

Component	Rating
Market opportunity	**Low** – USD 5 billion
Innovation activity	**Low**
External pressures	**High** – Regulation, fast charging, sustainability, critical materials shortage



nTopology's thermal design tool

GD algorithms can be applied to thermal optimization too; Puntozero used nTopology's software to redesign its cold plate cooling system to achieve 25% weight reduction and a 300% increase in heat transfer surface area by employing shark-inspired flow guides.

Image source: nTopology

Several battery pack innovation areas have inadequate innovation activity despite strong market opportunities

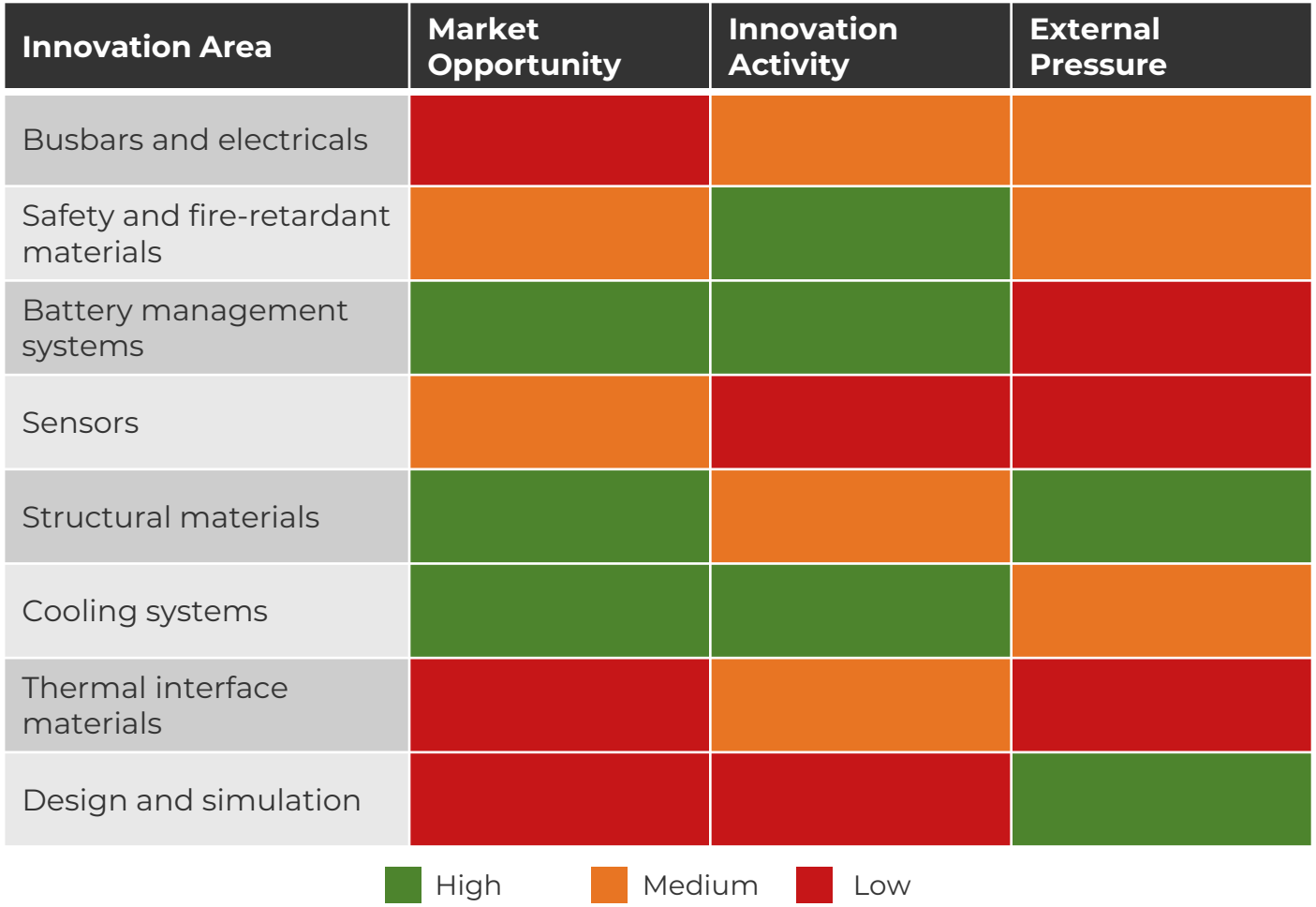
Electrical systems have both short-term needs like fire safety and fast charging and long-term opportunities like enabling advanced driver autonomy systems.

Sensors will increase in prominence over the next decade, offering market share to both materials and electronics companies.

Structural materials improvements are driven by every megatrend; materials companies and simulation players should partner for quicker development.

Thermal interface materials may play a reduced role in future C2P designs, but their performance will need to be improved. TIMs will continue to play a critical role in other power electronics.

Simulation and design tools, purpose-built for EV simulation, testing, and optimization, will offer step-change improvements to pack designs aligned with all four megatrends.

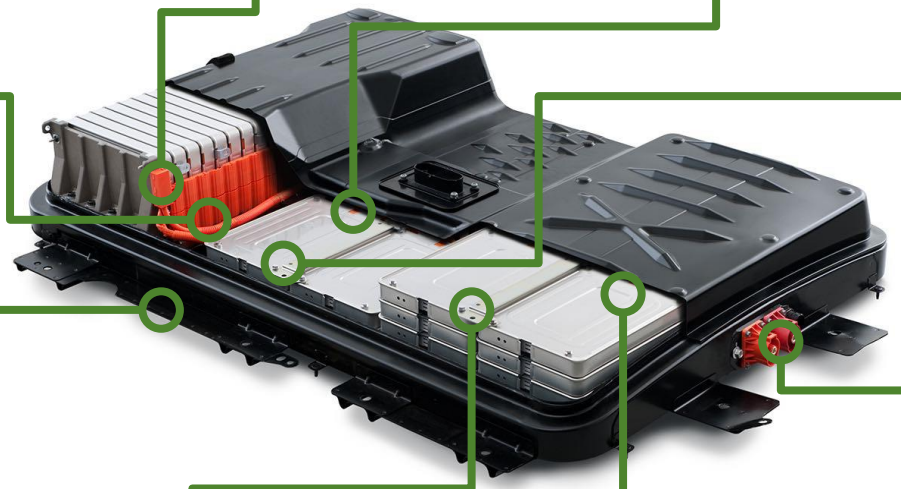


Materials innovations are poised to play a vital role in the evolution of the EV battery pack

Electrical systems are deeply integrated and fail operational; advanced materials support radar systems' move to 77 GHz

Phase change material heat sinks and heat pipes complement a single, integrated cooling loop for the battery and cabin

Battery management systems provides over-the-air updates and uses AI to optimize state of charge and state of health calculations



Wireless, high-specificity sensors are connected via IoT

Materials informatics drives selection of novel, recyclable fiber-reinforced polymers or alloys

Automated battery testing is commonplace to speed up development and regulatory approvals

Fire-retardant materials and hot gas valves work in concert with BMSs to stop thermal runaway in its tracks, meeting more stringent regulation

Thermal interface materials are universally multifunctional, providing electromagnetic interference shielding, mechanical strength, and/or adhesion

*FRPs, fiber-reinforced polymers

Solid-state batteries would be the most disruptive innovation to battery pack design along with several other emerging technologies

Solid-state batteries

"Beyond lithium" generates a lot of R&D activity for auto OEMs — if solid-state batteries take over, it will mean a complete pack redesign for most players. Fire safety will become far less of an issue for solid-state-based packs.

Multi-material additive manufacturing

Multi-material additive manufacturing could theoretically enable bottom-up construction of the entire battery pack.

Hybrid chemistry and voltage splitting

Voltage splitting and hybrid chemistry packs will greatly disrupt current plans. Given the extra weight, a hybrid pack might mean a range extender for a truck or minivan.

Phase change materials

Phase change materials have been talked about for years but still haven't made it into vehicles at scale. Laird and Kulr offer commercially ready options, and increasing demand for low energy solutions could drive adoption.

AI-powered design software

Generative design and materials informatices, when applied to battery packs, will obviate preexisting designs, and first movers here will gain a lot of momentum.

Immersion cooling

Like phase change materials, this technology is borrowed from the computing industry and could take off in the right battery ecosystem as it helps enable ultrafast charging.

Document prepared by Lux Research

Our mission is to advise leaders about commercially viable science and technology to enable sustainable innovation. We deliver research and advisory services to inspire, illuminate, and ignite innovative thinking that reshapes and grows businesses. Using quality data derived from primary research, fact-based analysis, and opinions that challenge traditional thinking, our experts focus on finding truly disruptive innovations that are also realistic and make good business sense. The “Lux Take” is trusted by innovation leaders around the world, many of whom seek our advice directly before placing a bet on a startup or partner — our clients rely on Lux insights to make decisions that generate fantastic business outcomes. We pride ourselves on taking a rigorous, scientific approach to avoid the hype and generate unique perspectives and insights that innovation leaders can’t live without.

VISIT

www.luxresearchinc.com

READ

www.luxresearchinc.com/blog/

CONNECT

LuxResearch

FOLLOW

@LuxResearch

EMAIL

questions@luxresearchinc.com