Semi-Solid-State Battery Technology

—Driving the Development of Solid Electrolytes, High-Performance Anodes, and Other Technologies for All-Solid-State Batteries—

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Why This Technology?

Semi-solid-state batteries are positioned between liquid-based lithium-ion batteries (LIBs), which use flammable liquid electrolytes, and all-solid-state batteries. They offer higher safety and energy density than liquid-based LIBs while having lower mass-production challenges compared to all-solid-state batteries. As a result, battery companies worldwide are working to implement semi-solid-state batteries as an interim solution until all-solid-state batteries become commercially viable. The implementation of semi-solid-state batteries is driving the development and integration of solid electrolytes, high-performance cathodes, and anodes, not only accelerating all-solid-state battery development but also holding the potential to expand market share of semi-solid-state batteries beyond just serving as an interim solution, depending on performance and cost.

Summary

- By utilizing solid electrolytes and high-performance anodes, semi-solid-state LIBs can achieve an energy density exceeding 300 Wh/kg, which is considered the upper limit of liquid-based LIBs. The hurdle for mass production is also low because they can be manufactured on existing liquid-based LIB production lines.
- Many Chinese companies are developing semi-solid-state batteries with oxide-based solid electrolytes for EV applications. Some next-generation battery startups in the US and other regions are entering the semi-solid-state battery sector, targeting aerospace and other high-added-value applications.

1. Semi-Solid-State Battery Technology

1-1. Semi-Solid-State Batteries

There is no clear definition of a semi-solid-state battery. As shown in Figure 1, they are generally classified as solid-liquid hybrid type, which utilizes both liquid and solid electrolytes, and gel polymer type or clay type, where electrolytes and electrode materials are gelled or made clay-like.

Figure 1: Definition and classification of semi-solid-state batteries

Classification	Definition	Characteristics	Representative companies
Solid-liquid hybrid type	A technology that uses different electrolytes for the cathode and anode, such as employing a solid electrolyte on the anode side and a liquid electrolyte on the cathode side	Enables the use of high-performance anodes, achieving higher energy density. Offers higher safety while utilizing existing liquid-based LIB manufacturing technologies	WELION (China), SES AI (US)
Gel-polymer type, clay type	A type where conventional electrolytes are gelled or where electrolytes are mixed into the electrode materials on the cathode or anode to form a clay or gel-like structure	Lowers the risk of leakage and ignition compared to conventional liquid-based batteries by reducing fluidity	Kyocera (Japan), 24M Technologies (US)

Source: Compiled by MGSSI based on various data

The solid-liquid hybrid type can leverage existing LIB manufacturing processes and offers higher energy density than liquid-based LIBs, making it a focus of development and implementation, particularly among Chinese companies. The gel polymer and clay types offer higher safety, lower raw material costs, and simplified manufacturing processes. A representative company in the space is 24M Technologies (US), which has developed a thick-film electrode using clay-like materials in a simple structure. By eliminating binders and reducing the volume of current collectors and separators, the company has increased energy density per unit volume of battery cells.

1-2. Performance and Main Benefits

Figure 2 shows a comparison of key materials and performance between semi-solid-state LIBs, liquid-based LIBs, and all-solid-state LIBs.

Figure 2: Comparison of liquid-based LIB, semi-solid-state LIB (Note 1), and all-solid-state LIB

	Liquid-based LIB	Semi-solid-state LIB	All-solid-state LIB
Cathode	NMC (Note 2), LFP (Note 3)	NMC, high-nickel NMC (Note 4), LFP	NMC, high-nickel NMC, LMR (Note 5)
Anode	Graphite, silicon-based	Graphite, silicon-based, lithium metal	Graphite, silicon-based, lithium metal
Separator	Required	Required	Not required
Electrolyte	Comprises more than 10% of battery weight. Includes lithium ion salts, flammable organic solvents, and additives.	Mixture of solid electrolytes and a small proportion of liquid electrolyte (less than 10% of battery weight)	100% solid electrolytes (mainly sulfide, oxide, and polymer)
Energy density	Up to 300 Wh/kg	300 Wh/kg or more	350 - 500Wh/kg
Voltage range	2.7 - 4.2V	2.7 - 4.2V	5V or more
Safety	Risk of ignition	Higher than liquid-based LIB	Highest
Implementation stage	Implemented	Initial stage	Expected implementation after 2027
Cost	Low	High	High
Advantages	Mature technology; low-cost large-scale production possible	Higher performance and safety than liquid-based LIBs; some existing liquid-based LIB production lines can be used.	Significantly higher performance and safety compared to current liquid-based LIBs possible
Disadvantages	Uses organic electrolytes, posing ignition risk; energy density nearing its limit	Performance is inferior to all-solid-state batteries; ignition risk not fundamentally eliminated.	New materials with higher performance are under development. Large-scale mass production technology is still being established as manufacturing process differs from liquid-based LIBs.

Note 1: Example based on solid-liquid hybrid type
Note 2: NMC: A ternary cathode material primarily composed of Nickel (Ni), Manganese (Mn), and Cobalt (Co)
Note 3: LFP: Lithium iron phosphate ($LiFePO_4$) cathode
Note 4: High-nickel NMC: A ternary cathode with a high nickel content
Note 5: LMR: Lithium-rich manganese-based cathode
Source: Compiled by MGSSI based on various data

Generally, batteries with liquid electrolyte content of 10% or less of the total battery weight are classified as semi-solid-state LIBs. By reducing the use of liquid electrolytes, semi-solid-state LIBs lower the risk of ignition. Additionally, the use of solid electrolytes and high-performance anodes is expected to enable an energy density exceeding 300 Wh/kg, which is considered the upper limit of liquid-based LIBs. Another advantage is that semi-solid-state LIBs can be manufactured using existing liquid-based LIB production lines, making mass production easier. However, semi-solid-state LIBs use an electrolyte containing a small amount of flammable organic solvent, meaning that the risk of ignition under abnormal heat conditions cannot be completely eliminated. Additionally, the increased cost of solid electrolytes and high-performance anode materials is expected to be a bottleneck for widespread adoption. For example, the semi-solid-state LIB package adopted by Chinese EV startup NIO is estimated to cost 1.7 to 2.2 CNY/Wh (approx. 36 to 46 JPY/Wh[1]), which is significantly higher than mainstream nickel manganese cobalt (NMC) batteries at around 0.73 CNY/Wh (approx. 15 JPY/Wh). Due to this high cost, NIO has opted not to sell the battery but to provide it exclusively on a rental basis.

2. Notable Trends

As of 2024, many Chinese companies, along with some US and South Korean firms, have announced plans to implement semi-solid-state LIBs (Figure 3).

Figure 3: Development status of semi-solid-state batteries by major companies

Battery manufacturer	Mass production	Main component			Cell energy density (Wh/kg)	EV battery pack development status		
		Cathode	Anode	Electrolyte		Capacity (kWh)	Range (km)	Partnerships, etc.
WELION (China)	2023	High-nickel NMC	Si/C anode	Oxide and polymer-based	360	150	1,000	Installed in the NIO ET7, a premium model from the Chinese EV startup NIO
	2025	High-nickel NMC	Si/C anode	Oxide and polymer-based	300	n/a	600 - 1,000	Planned for a new model from, Lutetium Wei Technology, an EV subsidiary of JAC (a mid-sized Chinese state-owned automaker)
GanFeng Lithium (China)	2023	NMC	Graphite	Oxide-based	240 - 270	90	530	Installed in export EV models from SERES (China)
	TBD	NMC	Li metal	Oxide-based	400	n/a	n/a	This is its second-generation semi-solid-state battery under development
Qingtao Energy Development (China)	2024	High-nickel NMC	Si/C anode	Oxide and polymer-based	368	130	1,000	Installed in IM L6 from SAIC Motor (China). Developing a second-generation version using oxide, halide, and polymer electrolytes
Dongfeng Motor (China)	2025	NMC	Graphite	Oxide-based	350	n/a	n/a	Plans to implement in own vehicles
	TBD	High-nickel NMC	Li metal	Unknown	405	n/a	n/a	
FARASIS (China)	2025	NMC	Si/C anode	Unknown	300 - 400	n/a	n/a	Strategic partnership with FAW (China) and JAC (China)
24M Technologies (US)	2025	NMC	Si-based / Li	Unknown	391	n/a	1,600	Proprietary dry electrode, cell & packaging technology, and electrolyte/separator integration
QuantumScape (US)	2025	LFP/NMC	Li metal	Oxide-ceramic	300	n/a	n/a	Mass production planned in collaboration with Volkswagen (Germany)
Enpower Greentech (US)	2025	NMC	Li metal	Sulfide-based	292 - 320	n/a	n/a	Targeting industrial, drone, eVTOL*, and other applications
LG Energy Solution (South Korea)	2026 - 2027	Unknown	Unknown	Oxide and polymer-based	n/a	n/a	n/a	Adopting a bipolar structure
SVOLT (China)	2026	NMC	Graphite	Sulfide-based	266	n/a	n/a	For vehicles with large-capacity battery packs
Talent New Energy (China)	2027	NMC	Graphite	Oxide-based	n/a	n/a	n/a	Development with Changan Automobile (China)
StoreDot (Israel)	2028	High-nickel NMC	Si-based	Organic-inorganic composite solid electrolyte	400	n/a	n/a	Joint development with Polestar (Sweden). Aiming for 100 miles (about 160 km) of range with a 3-minute charge
Gotion (China)	TBD	NMC	Graphite	Unknown	360	160	1,000	Said to be developing in collaboration with EV and eVTOL (electric vertical takeoff and landing) companies
ZENERGY (China)	TBD	NMC	Si-based	Unknown	300 - 330	170	1,000	Conducting EV tests and collaborating with eVTOL companies
LISHEN (China)	TBD	High-nickel NMC	Si-based	Oxide-based	402	n/a	n/a	Development underway for long-range EVs and eVTOLs

Note: eVTOL：Electric Vertical Take-Off and Landing aircraft
Source: Compiled by MGSSI based on various company materials

[1]Exchange rate: 1 CNY = 21 JPY

Chinese companies, which already hold a significant share in the liquid-based LIB market, perceive breakthroughs in all-solid-state batteries by foreign companies as a major threat, as they could disrupt the market where liquid-based LIBs remain the dominant product. However, Chinese battery manufacturers lag behind Japan and South Korea in solid electrolyte development, making it difficult to compete in the race for all-solid-state battery commercialization. Accordingly, they are adopting a two-step strategy: first, implementing semi-solid-state batteries, which have relatively low mass-production hurdles, to enhance their technological capabilities, and then ultimately achieving all-solid-state battery commercialization. Also, many Chinese companies are focusing on oxide-based solid electrolytes, which offer high stability and safety. However, these electrolytes have low ion conductivity and rigid material properties, making it challenging to bond them with active materials, thereby delaying full commercialization of all-solid-state batteries. Semi-solid-state batteries that incorporate liquid or polymer electrolytes can overcome these challenges more easily, enabling earlier practical implementation. Envisaging use in EVs, many Chinese companies are working alongside EV manufacturers to implement semi-solid-state batteries using oxide-based electrolytes, which offer longer driving ranges than liquid-based LIBs.

Some next-generation battery technology startups in the US and other regions are entering into semi-solid-state battery development, leveraging their proprietary technologies such as solid electrolytes and high-performance lithium metal anodes, while also preparing for the full-scale roll-out of all-solid-state batteries in the future. The expected applications for these semi-solid-state batteries under development extend beyond EVs to include high-added-value sectors such as eVTOL and aerospace applications.

On the other hand, sulfide-based solid electrolytes, in which Japanese companies lead globally, have high ionic conductivity and soft material properties, making it largely unnecessary to develop them into semi-solid-state batteries, as they are often directly implemented as all-solid-state batteries.

3. Future Prospects

According to the Chinese market research firm GGII, China's semi-solid-state battery shipments in 2024 are expected to reach 7 GWh (million kWh), equivalent to 117,000 EV[2], and grow to 65 GWh by 2030. While it remains to be seen how much market share can be expanded due to cost-related and other challenges, industry efforts are driving the development of solid electrolytes, high-performance anodes, and other technologies that can later be applied to all-solid-state batteries, while also contributing to the prolongation of the existing liquid-based LIB industry, ultimately benefiting the evolution of the Chinese battery industry. On the other hand, unlike Chinese companies, which focus on incremental improvements, Western, Japanese, and other foreign battery companies aim to differentiate themselves through higher performance, making the creation of demand for high-performance batteries a key competitive factor.

Furthermore, if future technological advancements enhance the safety and cost-effectiveness of semi-solid-state batteries, they could secure a stable market share in the mid-to-long term, potentially delaying the adoption of all-solid-state batteries. As a result, close attention should be paid to the implementation and technological development of semi-solid-state batteries.

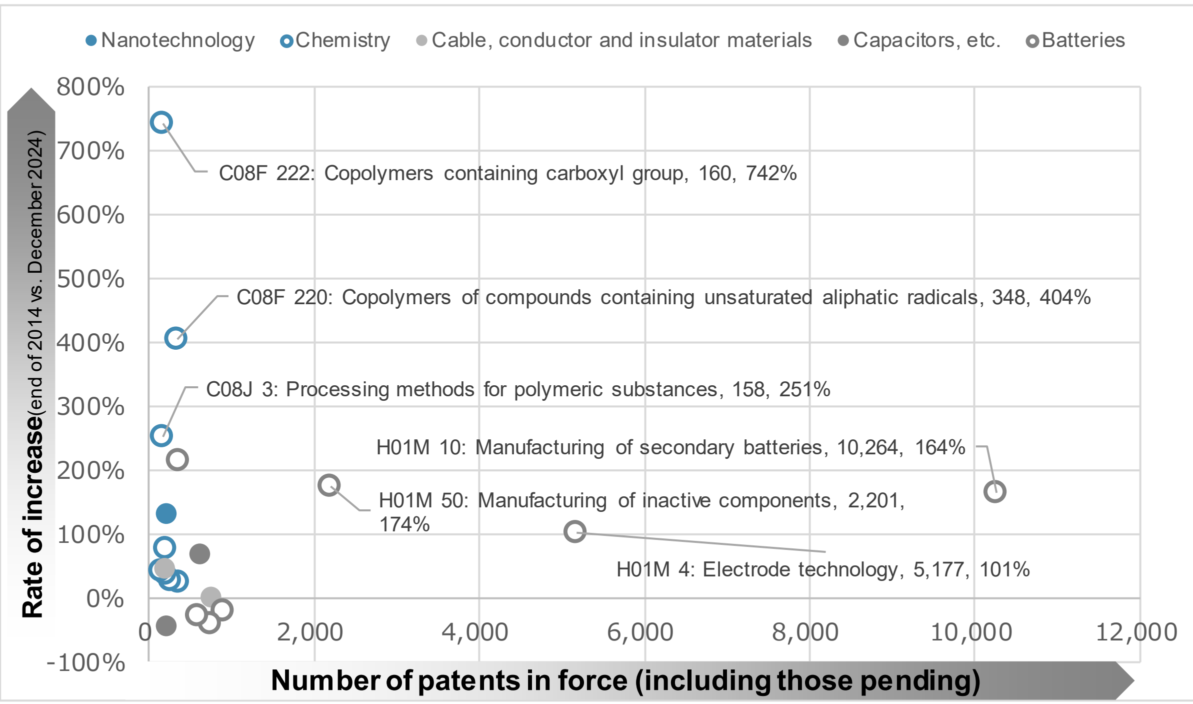
[2] Assuming a battery package capacity of 60 kWh.

IP Analysis of Semi-Solid-State Battery Technology

Keywords closely related to this technology, such as “(semi) polymer,” “gel,” and “electrolyte,” as well as International Patent Classification (IPC) codes related to secondary batteries, were identified (11,030 in force as of December 2024, including pending applications[3]), and an analysis was conducted based on technology classifications and top players.

Figure 4 compares the number of patents in force related to semi-solid-state batteries and their growth rates. The horizontal axis represents the number of patents in force, while the vertical axis shows the growth rate by comparing the number of patents as of December 2024 with those at the end of 2014. The results indicate that interest is increasing, particularly in secondary batteries and electrodes.

Figure 4: Number of patents in force and growth rate (by technology category)

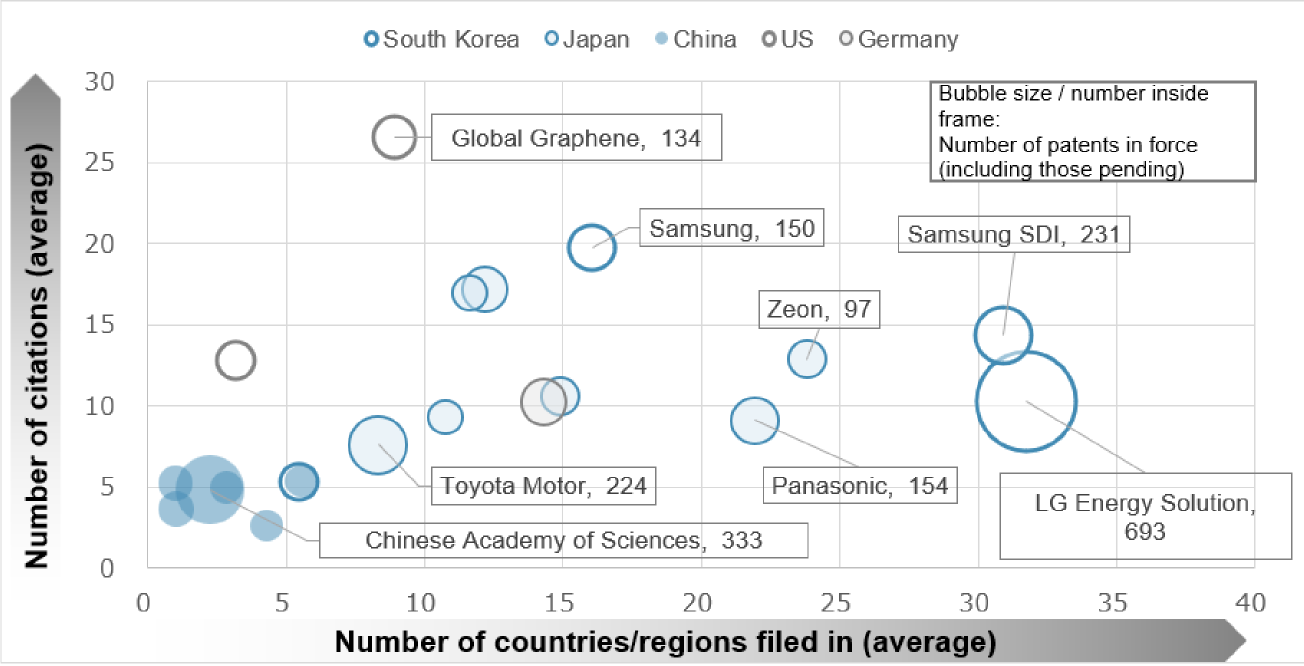


Source: Compiled by MGSSI based on data from LexisNexis PatentSight

Figure 5 compares the top players in terms of the number of patents related to semi-solid-state batteries. The bubble size represents the number of patents in force, the horizontal axis indicates the average number of countries or regions where applications were filed, and the vertical axis represents the average number of citations, reflecting the technological impact. The results reveal that LG Energy Solution (South Korea) leads significantly, surpassing the second-ranked company by a wide margin in patent count, demonstrating its aggressive investment in R&D. The company is also engaged in intellectual property activities in battery technology, such as strengthening patent protection, enforcing patent infringement measures, and leading a patent pool initiative to ensure fair patent licensing.

[3] The total number of patents includes both filed patents and granted patents that have completed the examination process and are enforceable as intellectual property rights.

Figure 5: Number of patents in force, number of countries/regions filed in, and number of citations (by top players)



Source: Compiled by MGSSI based on data from LexisNexis PatentSight