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Lithium Manganese-Rich Cathodes Enabling High-Performance, Low-Cost Rechargeable Batteries

— China, Europe, the US, and South Korea Taking Divergent Approaches to Application in EV Batteries —

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Why This Technology?

Cathodes in lithium-ion batteries (LIBs) are critical components that undergo chemical reactions to generate electrical energy. While lithium iron phosphate (LFP) cathodes currently dominate the low-cost segment, lithium manganese-rich (LMR) cathodes—able to achieve higher energy density at comparable cost—are being developed and adopted worldwide as alternatives to LFP cathodes and for application in all-solid-state LIBs.[1] Depending on the direction and degree of future progress, LMR cathodes could transform existing LIB supply chains and reshape the competitive landscape in all-solid-state LIB development.

Summary

- Practical application of lithium manganese-rich (LMR) cathodes is expected within the next few years for their ability to provide high capacity while using little to no cobalt, making them ideal next-generation battery materials combining high performance with low cost.
- In China, where the development of all-solid-state lithium-ion batteries (all-solid-state LIBs) is accelerating, LMR cathodes are highly regarded as a promising candidate for all-solid-state LIBs, and major companies are actively engaged in development. In Europe, the US, and South Korea, efforts are underway to develop and commercialize LMR cathodes through international collaboration as an alternative to LFP cathodes—a sector dominated by China—with a focus on ensuring a stable battery supply.
- While the share of LMR cathodes for EV passenger vehicle batteries in 2035 is projected to remain low at around 3%, China has placed them under export controls in recognition of their future potential. Japan, which seeks to ensure a stable battery supply and pursue the practical application of all-solid-state LIBs, should also closely monitor these developments.

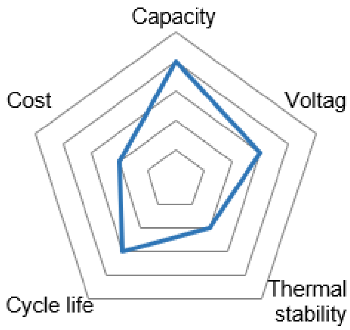
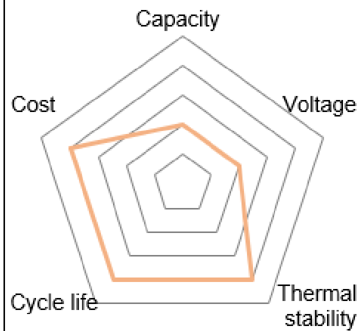
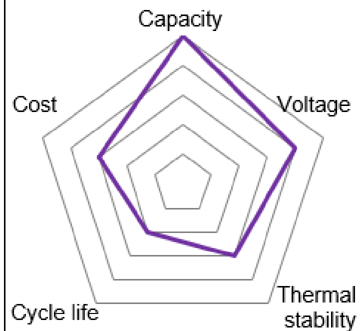
1. What are Lithium Manganese-Rich Cathodes?

1-1. Overview of Lithium Manganese-Rich Cathodes

LMR cathodes make use of a lithium-rich metal oxide cathode material. As it is possible to incorporate a large amount of lithium, they achieve capacities of 250 mAh/g or higher, exceeding that of the current mainstream high-performance cathode materials used in ternary (NMC[2]) cathodes. LIBs using LMR cathodes have the potential to achieve energy densities in excess of 500 Wh/kg, making them suitable for high-performance applications such as in EVs with extended driving ranges. Manganese, an abundant resource, accounts for 30 to 40% of the material composition of LMR cathodes, making it possible to keep material costs at a level comparable to LFP cathodes, which are currently the mainstream low-cost yet lower-performance cathodes. As they require little to no cobalt—

[1] A type of lithium-ion battery in which all components, including cathodes, anodes, and electrolytes, are made of solid materials.
[2] Cathodes primarily composed of nickel, manganese, and cobalt.

Figure 1: Performance comparison between LMR cathodes and current mainstream cathode materials

Cathode material	High-nickel ternary NMC811 (Note)	Lithium iron phosphate LFP	Lithium manganese-rich LMR
Main components	$LiNi_{0.8}Mn_{0.1}Co_{0.1}O_2$	$LiFePO_4$	$xLi_2MnO_3 \cdot (1-x)LiMO_2$ (M=Ni、Co、Mn、0<X<1)
Capacity (mAh/g)	Up to 200	Up to 170	250 or higher
Performance comparison	 The farther from the center, the higher the corresponding performance.		
Advantage	High energy density, compact, and suitable for high-capacity applications	・Delivers high thermal stability and excellent safety. ・Inexpensive due to the absence of expensive metals such as cobalt.	・Delivers high capacity and a wide operating voltage range. ・Inexpensive due to little or no use of cobalt.
Disadvantage	・Thermal stability and safety are inferior to LFP. ・Uses expensive and geographically concentrated rare metals such as cobalt, resulting in high costs and concerns over stable supply.	Its lower energy density requires more space and weight than ternary batteries for the same capacity.	Numerous charge and discharge cycles leads to continuous decline and a shorter cycle life.
Main applications	Used in batteries for mid- to high-priced EV passenger vehicles, drones, and similar applications.	Used in batteries for low- to mid-priced EV passenger vehicles, electric buses, stationary energy storage, and similar applications.	Used in batteries for low- to high-priced EV passenger vehicles, drones, and similar applications.

Note: A type of high-nickel NMC with a nickel-manganese-cobalt ratio of 8:1:1
Source: Compiled by MGSSI based on various public data

an element associated with uneven resource distribution, environmental damage from mining, child labor, and other concerns—LMR cathodes also enable responsible sourcing by battery manufacturers. LMR cathodes are regarded as a promising next-generation cathode material capable of delivering both high performance and low cost (Figure 1) as they combine the advantages of both NMC cathodes and LFP cathodes.

However, practical application still faces challenges. Over the course of numerous charge and discharge cycles, some of the metal oxides in LMR cathodes transition from a layered structure to a spinel structure.[3] As a result, continued use leads to a decline in the battery's operating voltage, ultimately shortening its cycle life compared with the various other LIBs already in practical use. To address this issue, companies around the world have researched measures such as coating the surfaces of material particles with metal oxides, metal doping, and improving manufacturing processes. Of particular note, since 2025, multiple companies have announced technological breakthroughs and plans for mass production, bringing the practical application of LMR cathodes into clearer view.

[3] This spinel structure is represented by the general formula AB_2O_4 and is a crystal structure in which metal ions at tetrahedral (A-site) and octahedral (B-site) positions are bonded to oxygen ions.

1-2. The Future of R&D and Anticipated Applications

In addition to their low cost and high performance, LMR cathodes—with their broad operating voltage range of 2 to 4.8 volts—are being developed with a variety of applications in mind.

Developers are seeking a cathode material for use with the current liquid-based LIBs that delivers higher performance while maintaining costs at a level comparable to existing LFP cathode products. Its use may also be combined with existing cathode materials to complement their performance. For instance, blending it with NMC cathode materials is expected to extend the cycle life and reduce costs per kWh.

For higher voltage ranges, research and development are underway to incorporate LMR cathodes into high-performance batteries. Many first-generation all-solid-state LIB products, likely to be released around 2027 to 2028, are expected to adopt high-nickel NMC cathodes with an operating voltage of 3.7 volts. However, solid electrolytes offer an innately high voltage performance of up to 5 volts, and this feature is not fully utilized when paired with NMC cathodes. Replacing them with LMR cathodes, which can support a maximum operating voltage of up to 4.8 volts, makes it possible to better leverage the solid electrolyte's inherent high-voltage performance of up to 5 volts, while also costing less than NMC cathodes. For this reason, LMR cathodes are regarded as a leading candidate for use in next-generation all-solid-state LIBs.

Chinese companies that hold a significant share of the LIB industry and Western companies that are still in the process of building their battery supply chains are each charting different paths forward for LMR cathode research, development, and commercialization based on their respective positions in the battery industry, as well as on their corporate strategies and national policies. The details are discussed in the next chapter.

2. Noteworthy Trends

2-1. China Pursues Application in All-Solid-State LIBs

China produces the majority of the world's liquid-based LIBs and is also stepping up development of all-solid-state LIBs as they continue to conduct research and development on LMR cathodes as a candidate. As shown in Figure 2, numerous manufacturers of battery materials, batteries, and EVs in China are working to develop LMR cathodes. More than half are focusing on the development of high-voltage, high-capacity LMR cathodes for application in all-solid-state LIBs. Some companies are developing high-performance all-solid-state LIB prototypes that make use of LMR cathodes and next-generation lithium metal as anodes.

Figure 2: LMR development and production trends among Chinese companies

Industry	Company	Timing of announcement	LMR development and production trends
Battery materials	Ningxia Hanyao	April 2023	Has commenced test production. Developing multiple products across the low-, medium-, and high-voltage categories, with the high-voltage (4.45 volt) variant achieving a capacity of 220 to 230 mAh/g.
	Ronbay Technology	December 2024	Engaged in small-scale production of sample products, and has commenced shipping to battery manufacturers and other customers for testing purposes.
	BTR	May 2025	Announced a prototype sulfide-based all-solid-state battery using LMR cathodes with a high voltage (4.8 volts) and a capacity of 300 mAh/g.
	Ningbo Fuli	July 2025	Successfully developed an LMR cathode with a capacity in excess of 300 mAh/g. Developing LMR cathodes for all-solid-state batteries with energy densities of over 450 Wh/kg.
	Chuangneng Huitong	September 2025	Announced several cutting-edge products, including low-voltage, long-life variants and high-voltage, high-capacity variants (4.8 volts, 300 mAh/g).
	Easpring Material Technology	October 2025	Achieved capacities of 280 to 305 mAh/g in tests with all-solid-state batteries, and has commenced shipping samples on the scale of tens of tons.
Batteries	Tailan New Energy	April 2024	Announced a prototype all-solid-state battery using LMR cathodes with a cell energy density of 720 Wh/kg. The anode makes use of lithium metal.
	China Automotive New Energy Technology	July 2025	Announced an LMR cathode battery with an energy density of 366 Wh/kg and 2,000 life cycles, with plans for installation in EVs offering a driving range of over 1,000 km to be launched before the end of 2026.
	Farasis	September 2025	Plans to announce a second-generation sulfide-based all-solid-state battery using LMR cathodes in 2026. The battery has an anticipated energy density of 500 Wh/kg.
EV	Guangzhou Automobile	February 2025	Announced that it will consider adopting LMR cathodes for all-solid-state EV batteries over the long term.
	Chery	September 2025	Announced an all-solid-state battery using LMR cathodes with a cell energy density of 600 Wh/kg. Aims to install the battery in prototype vehicles in 2027 and launch mass production by 2030.

Source: Compiled by MGSSI based on various publicly available materials.

Easpring Material Technology, a leading cathode material manufacturer, has shipped more than a dozen tons of LMR samples to customers in China as well as in Europe, the US, South Korea, and other regions. It is also developing halide-based solid electrolytes compatible with LMR cathodes. While CATL, China's largest battery manufacturer, has yet to announce any prototypes, it is thought to hold the world's largest number of patents related to LMR cathode materials and is actively engaged in developing the technology. Since 2023, CATL, Ningxia Hanyao, Ningbo Fuli, and other startup companies have been carrying out a public-private partnership project to develop low-cost mass production technology for LMR cathodes under the leadership of the Ministry of Industry and Information Technology (the Chinese government ministry equivalent to Japan's METI).

In September 2025, mid-sized automaker Chery Automobile announced a prototype all-solid-state LIB using LMR cathodes. The battery offers a driving range of 1,300 km and has demonstrated a high degree of safety by passing nail penetration tests that evaluate resistance to heat generation and ignition during internal short circuits. It is scheduled to be installed in EVs for launch in 2030. It will be worth watching whether this prompts other Chinese EV manufacturers to follow suit.

2-2. Europe, the US, and South Korea Seek Low Cost and Stable Procurement

In Europe and the US, where there are concerns about dependence on China for battery supply chains, attention is focused on the potential of LMR cathodes to reduce reliance on China due to their low cost and ready availability. In particular, efforts to develop and commercialize LMR cathodes are being accelerated with the aim of replacing LFP cathodes, for which Chinese companies account for 90% of global production (Figure 3).

Figure 3: LMR development and production trends among companies in Europe, the US, and South Korea

Industry	Company	Timing of announcement	LMR development and production trends
Battery materials	Umicore (Belgium)	February 2023	Plans to launch mass production for EV applications in 2026. Potential production sites include existing cathode material plants in South Korea and Poland, as well as a planned facility in Canada.
	POSCO FUTURE M (South Korea)	May 2025	Completed development and prototyping in 2024 in collaboration with EV manufacturers, and has commenced verifications for mass production. Aims to cathodes in the EV sector with LFP cathodes.
	FIREBIRD METALS (Australia)	July 2025	Announced the commencement of in-house development of LMR cathodes, with completion targeted within 18 months. Leverages its expertise in high-purity manganese sulfate (HPMSM).
	Stratus Materials (US)	August 2025	Has commenced shipping samples of second-generation products. In October, announced the joint development of next-generation cathode materials for EVs, together with Ampere in the Renault Group (France).
EV	Ford (US)	April 2025	Achieved a breakthrough in research and development, with installation in actual vehicles anticipated by 2030.
	GM (US)	May 2025	Successfully completed joint development with LGES (South Korea), and the joint venture plans to launch mass production in North America in 2028.

Source: Compiled by MGSSI based on various publicly available materials.

In May 2025, GM announced plans with LG Energy Solution (LGES) to jointly develop and produce LMR prismatic battery cells for EVs, including electric trucks and large SUVs. The two companies, which hold numerous patents related to LMR technology, plan to begin prototyping by the second half of 2027 and gradually commence mass production by 2028 at Ultium Cells, their North American battery joint venture. At the 15th The Battery Show North America, held in Detroit in October 2025, LMR batteries developed by GM and LGES were recognized as the Battery Innovation of the Year, underscoring the high expectations that the North American battery industry has for the technology.

Europe and the US—unlike China—have yet to fully develop domestic supply chains, making cross-border collaboration crucial for companies in these regions for raw material procurement, research and development, and production. It is of particular note that South Korea, which possesses an established battery manufacturing base, is attracting attention as a hub for research, development, and production outside of China.

3. Future Prospects

According to the research firm BloombergNEF[4] (US), the adoption of LMR cathodes is expected to begin after 2027, primarily for use in EV passenger vehicle batteries, and they are projected to account for roughly 3% of all cathodes used in EV passenger vehicle batteries by 2035. Although its projected share is not particularly high at present, further technological advances could make the technology far more important in the future, further increasing its share of the market.

On November 8, 2025, China placed materials and technologies related to high-performance LFP cathodes, NMC cathodes, and LMR cathodes under export controls.[5] It is unusual to impose export controls at the research and development stage or during small-scale pilot production. This suggests the Chinese government's intention to preemptively block the outflow of next-generation battery technologies that could potentially transform the existing battery supply chain.

Further progress in the development of LMR cathodes may also affect the global race to commercialize all-solid-state LIBs. A company's ability to reduce costs—one of the major barriers to the widespread adoption of all-solid-

[4] Source: BloombergNEF「Lithium-Ion Batteries State of the Industry 2025」
[5] Source: Announcement No. 58 [2025] of the Ministry of Commerce and the General Administration of Customs

state LIBs—and ensure high performance is directly linked to its ability to develop competitive products and widen the scope of adoption. While LMR cathode research, development, and commercialization efforts in Japan have not been as active as in China or the US, Japan is working to secure a stable supply of storage batteries (under the Act on the Promotion of Ensuring National Security through Integrated Implementation of Economic Measures) and to promote the practical application of all-solid-state LIBs. In light of this, Japan should closely monitor global trends in LMR cathode development, which could impact the competitive environment.