

Global Energy Storage

Global Energy Storage: Is LMR the LFP killer?



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Lithium-Manganese-Rich (LMR) battery technology is being touted as having the potential to disrupt the LFP market. Over the past 5 years, Chinese companies have disrupted the NMC market, with LFP which has gained huge popularity, particularly in China (>60% M/S) given low costs and higher energy density. Recently, Korean companies have announced a new battery chemistry (LMR), which they believe could in turn disrupt the LFP market and give them the upper hand.

LMR battery technology is a balanced approach between LFP and NMC chemistries, but there are challenges. LMR combines the safety and cost-effectiveness of LFP with the high energy density characteristics of NMC. LMR cathodes can achieve specific capacities ranging from 250-280 mAh/g, surpassing NMC cathodes. Consequently, LMR batteries are reported to provide a cell-level energy density of around 300 Wh/kg, with the potential up to 320 Wh/kg through optimization at voltages above 4.7V. In theory, this could yield a 35% improvement over current mainstream LFP battery products in China. However, key challenges for LMR technology include cycle life, voltage stability, and scalability.

Nevertheless, LMR technology offers an alternative for entry and mass-market EVs outside of China, with an established supply chain that minimizes raw material risks. LMR technology does not depend on scarce resources such as nickel and cobalt, which can introduce supply chain vulnerabilities. Additionally, LMR batteries offer better recycling potential at the end of their lifecycle, enhancing future raw material security. While the estimated cost of LMR batteries is higher than that of LFP batteries, they can be produced using retrofitted NMC production lines, significantly reducing the capital investment needed.

Substituting nickel and cobalt with manganese also makes LMR theoretically 20% cheaper than NMC, but still about 15% more expensive than China's LFP. We estimate that the theoretical cost of LMR battery cells is approximately US\$55/kWh (based on manufacturing and material costs in China). In NMC cathode materials, transition metals represent about 60% of the total molar mass, with cobalt or nickel (around US\$20k per tonne) accounting for approximately 50% of the overall molar mass. In contrast, for LMR (NCM307), nickel comprises 19% of the total molar mass, while manganese (US\$2k per tonne) constitutes 40%.

Korean companies are primarily focusing on LMR for the entry-level EV market as an alternative for LFP, while Chinese firms are aiming for higher end applications. POSCO Future M (targeting mass production in 2025), Umicore (2026), and GM in collaboration with LGES (2028) are making progress in commercialization of LMR battery technology. It has a role, but we are skeptical that it will replace LFP, which is good enough for mass market with lower cost. As such, we feel that LMR offers a compromise between LFP and NMC, without offering the true advantages of either. Moreover, with CATL offering hybrid packs of LFP and NMC we feel that this could be the better approach.

BERNSTEIN TICKER TABLE

Ticker	Rating	9 Jun 2025		Price Target	TTM Rel. Perf.	Reported EPS			Reported P/E (x)		
		Closing Price				2024A	2025E	2026E	2024A	2025E	2026E
300750.CH (CATL)	O	CNY 245.58		340.00	15.6%	CNY 11.52	14.88	18.19	21.3	16.5	13.5
373220.KS (LGES)	M	KRW 285,000		307,000	(31.4)%	KRW (4,353.59)	1,884.41	7,639.39	(65.5)	151.2	37.3
051910.KS (LG Chem)	O	KRW 201,500		310,000	(57.7)%	KRW (8,826.00)	11,113	34,678	(22.8)	18.1	5.8
006400.KS (SDI)	O	KRW 170,800		250,000	(67.7)%	KRW 8,916.68	7,675.86	20,795	19.2	22.3	8.2
003670.KS (Posco Future M)	U	KRW 117,600		110,000	(69.4)%	KRW (2,740.96)	158.93	1,353.97	(42.9)	740.0	86.9
247540.KS (EcoPro BM)	U	KRW 92,400		88,000	(69.3)%	KRW (991.00)	(80.00)	405.00	(93.2)	N/M	228.1
002466.CH (Tianqi Lithium)	O	CNY 30.37		47.00	(22.8)%	CNY 4.45	(4.73)	1.22	6.8	(6.4)	24.9
9696.HK (Tianqi Lithium)	O	HKD 25.90		34.00	(21.3)%	CNY 4.45	(4.73)	1.22	5.3	(5.0)	19.5
ASIAx		1,403.70									

O - Outperform, M - Market-Perform, U - Underperform, NR - Not Rated, CS - Coverage Suspended

002466.CH, 9696.HK base year is 2023;

Source: Bloomberg, Bernstein estimates and analysis.

INVESTMENT IMPLICATIONS

The lithium-ion battery industry is dominated by two competing cathode chemistries. High nickel (NMC) and lithium iron-phosphate, or LFP. While Korean companies have focused on high nickel batteries, China has focused more on lower cost (and lower energy density) LFP batteries. This has proved the correct decision. While LFP has a lower energy density than NMC, in many cases they are good enough and can give an EV a range of 600-800km. The advantages of LFP are that they are safer, have a longer cycle time and are considerably cheaper than high nickel batteries. With China dominating LFP technology, Korean battery makers have a dilemma. They could copy Chinese battery makers, although given the scale and technology advantages China has in LFP they will be difficult to compete with. The alternative is to pioneer a new chemistry. From our research, they seem to be doing a bit of both. While most Korean battery makers have plans to start up LFP production, they are also developing a new chemistry LMR. LMR offers a compromise between LFP and NMC, with lower cost than NMC but higher energy density than LFP, which could make it an attractive option for entry level mass market outside of China. Another advantage is that existing (NMC) production lines can be retrofitted to produce these batteries. But there are drawbacks such as lower cycle life, voltage stability, and scalability. As such, we think it is premature to believe that this will be the technology which gives Korean battery makers the edge over LFP. Within our coverage, POSCO Future M is expected to secure mass production technology by 2025. However, given our more skeptical stance, we remain Underperform. LGES is likely to commercialize LMR by 2028 which remains too far away to make a difference and as such we remain Market-perform. Our top pick CATL has no plans for LMR and we continue to believe it will dominate in both NMC and LFP and can offer hybrid packs by combining both chemistries in hybrid battery packs, which gives the upside without any of the disadvantages.

VALUATION COMPS TABLE

EXHIBIT 1: Global battery companies' comparisons

Company	Price 9-Jun	Currency	EV USD mn	Mkt cap USD mn	23A	24A	25E	26E	23A	EV/Sales 24A	25E	26E	Sales Growth 24-25
LGES	285,000.0	KRW	65,551	49,266	42.6	-107.2	241.4	51.4	2.6	3.7	3.4	2.8	9%
CATL	245.6	CNY	142,864	156,536	25.7	22.0	17.3	14.2	2.5	2.8	2.3	2.0	19%
Samsung SDI	170,800.0	KRW	16,704	8,954	6.1	13.0	40.9	9.9	1.0	1.4	1.5	1.2	-7%
Panasonic	1,607	JPY	23,722	26,158	16.9	9.1	11.6	11.1	0.4	0.4	0.4	0.4	7%
BYD	395.0	HKD	138,191	149,579	35.0	27.4	19.3	15.9	1.6	1.3	1.0	0.9	30%
SK Innovation	93,300	KRW	42,698	10,410	24.8	-11.0	-44.3	17.8	0.7	0.8	0.7	0.7	17%
Gotion High Tech	25.9	CNY	12,077	6,492	70.1	55.3	34.8	24.2	2.9	2.4	2.0	1.7	21%
Farasis	13.4	CNY	2,552	2,285	-9.0	-30.6	107.4	26.0	1.3	1.4	1.2	0.9	19%
EVE	45.0	CNY	15,566	12,821	21.4	21.7	17.2	13.1	2.3	2.3	1.8	1.4	30%
Sunwoda	18.6	CNY	7,565	4,769	31.1	20.7	15.5	12.6	1.1	1.0	0.8	0.7	19%
CALB	16.5	HKD	9,866	3,722	45.8	44.1	18.3	12.0	2.2	2.3	2.0	1.6	16%

Company	LTM %	Rel LTM %	LTM High	LTM Low	GPM (%) 24A	OPM (%) 24A	ND/E 23A	24A	23A	EV/EBITDA 24A	25E	26E	25E EV/Capacity (USD M/GWh)
LGES	-46%	-50%	379,500	181,500	14%	2%	31%	40%	19.4	27.3	16.6	11.3	142
CATL	25%	10%	300	166	28%	17%	-63%	-59%	15.2	12.1	10.3	8.6	155
Samsung SDI	-54%	-58%	393,571	157,700	18%	4%	13%	42%	6.4	9.0	9.6	5.8	149
Panasonic	20%	14%	1,919	987	30%	5%	17%	15%	5.0	4.5	4.1	4.1	214
BYD	78%	32%	478	203	21%	6%	-45%	-51%	15.2	9.8	7.6	6.4	231
SK Innovation	-9%	-14%	140,200	80,800	5%	1%	56%	78%	13.4	21.3	12.9	9.0	159
Gotion High Tech	29%	11%	27.6	17.6	18%	3%	111%	125%	34.1	20.8	14.9	12.2	54
Farasis	19%	8%	16.7	8.3	14%	-4%	54%	46%	-23.7	38.8	15.3	11.9	31
EVE	7%	-6%	58.5	30.7	17%	9%	38%	37%	18.5	16.8	12.4	9.9	82
Sunwoda	23%	10%	26.4	13.5	16%	2%	32%	61%	19.1	13.9	10.6	8.6	74
CALB	15%	-16%	20.2	11.0	15%	5%	43%	67%	23.8	17.0	11.4	9.7	51

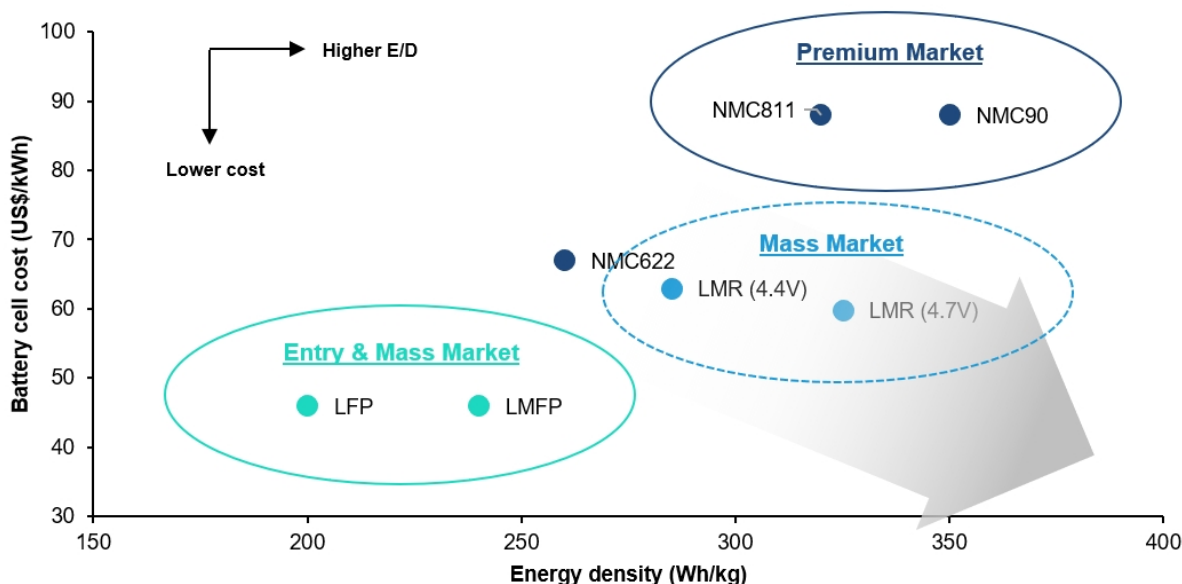
CATL, LG Energy Solution, and Samsung SDI are covered by Neil Beveridge. BYD is covered by Eunice Lee. All other stocks are not covered by Bernstein.

Source: Bloomberg (consensus estimates) and Bernstein analysis

DETAILS

In recent months, there has been increasing investor interest in Korea regarding the advancement and commercialization of Lithium-Manganese-Rich (LMR) battery technology. This technology is being recognized as a cost-competitive alternative that surpasses the performance of LFP batteries, which are predominantly controlled by China. This presents an opportunity for Korean companies to lessen their dependence on China's LFP battery supply chain. As shown in Exhibit 2, the key focus of research and development in battery technology is to improve energy density while also reducing costs. LMR technology appears to effectively balance these two essential metrics, positioning itself as a promising technology for future growth. In this note, we analyze the advantages and disadvantages of LMR battery and evaluate its commercialization potential.

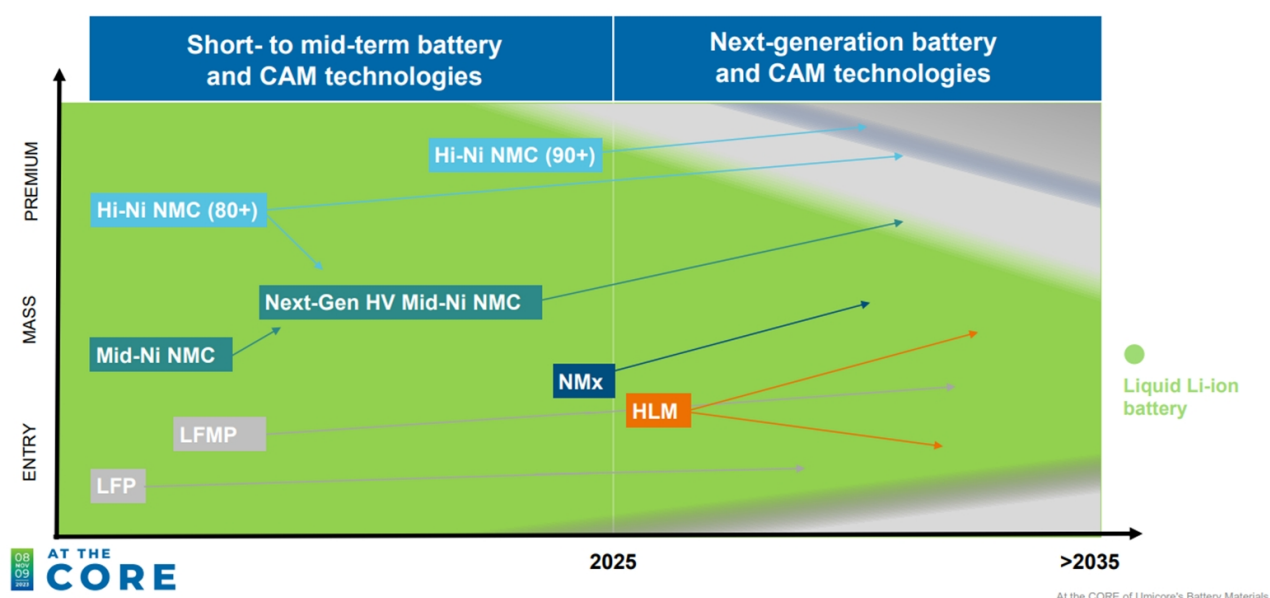
EXHIBIT 2: Compared to current mainstream chemistries, LMR technology appears to effectively balance higher energy density and lower cost



Battery cost based on China battery cell and component spot prices
Source: Company data, Bloomberg, BASF, Bernstein analysis

Currently, there are two main types of high-manganese cathode materials under development: layered Lithium-Manganese-Rich (such as BASF's cobalt-free NCM307) and high-voltage spinel lithium nickel manganese oxide (LNMO), exemplified by Haldor Topsoe's LNMO:TBM-129 product. LMR materials (represented by the formula $x\text{Li}_2\text{MnO}_3 \cdot (1-x)\text{LiMO}_3$, where $M = \text{Ni, Mn, Co}$) provide a capacity improvement over existing state-of-the-art NMC materials. However, stability and cycle life must be significantly improved before commercialization can be expected. The high-voltage LNMO spinel ($\text{LiNi}_0.5\text{Mn}_1.5\text{O}_4$) operates at approximately 4.7 V, but its theoretical specific capacity is limited to 147 mAh/g, offering no advantage in energy density compared to NMC cathodes. Both of these chemistries are expected to be adopted in Western markets for entry-level and mass-market EVs as shown in Exhibit 3. This note will focus mainly on LMR materials.

EXHIBIT 3: For Korean and European battery value chain, HLM (High lithium manganese, or LMR by our definition) and NMx (LNMO) batteries mainly target for entry and mass EVs



Source: Umicore, Bernstein analysis

LMR: A CHEMISTRY THAT BALANCES LFP AND NMC

LMR technology effectively combines the safety and affordability of LFP with the high energy density of NMC, offering a versatile solution for mid-range EV applications. While LFP is dominant in cost-sensitive markets and NMC is essential for premium EVs, LMR leverages the advantages of both chemistries. However, it needs to address challenges related to cycle life, voltage stability, and scalability to achieve large-scale commercialization.

Capacity: LMR cathode materials exhibit the highest specific capacity among mainstream chemistries today. Research indicates that LMR cathodes can achieve capacities between 250 mAh/g and 280 mAh/g, surpassing NMC cathodes, which typically range from 150 mAh/g to 200 mAh/g. The enhanced specific capacity of LMR is attributed to its dual redox mechanisms, utilizing both cationic (transition metal) and anionic (oxygen) redox reactions. Additionally, the lithium-rich layered structure contributes to the increase in capacity. While a higher cathode capacity is linked to increased energy density, it is also essential to consider satisfying voltage and lifecycle performance.

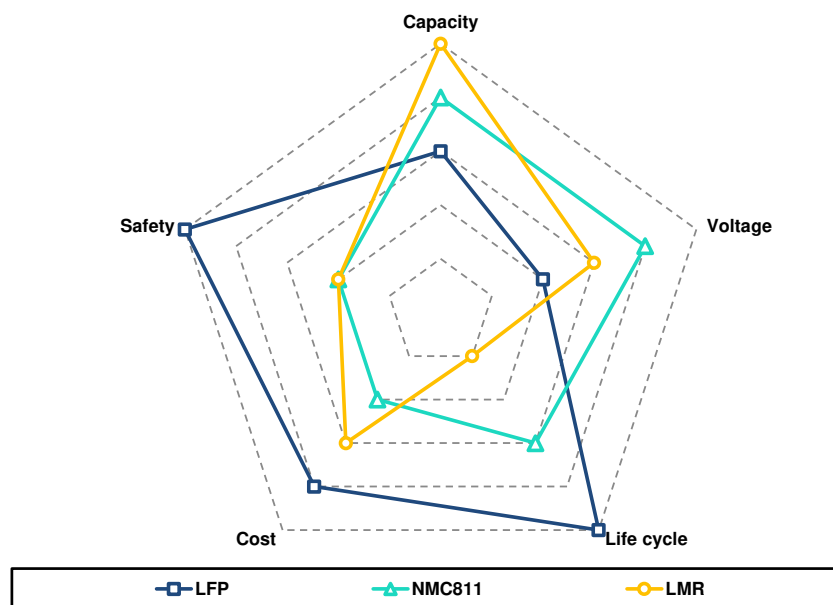
Voltage: Generally, LMR cathode can deliver higher operating voltages compared to traditional commercial cathode materials. However, the crystal structure instability of lithium-rich manganese-based layered oxides—exacerbated by the Jahn–Teller effect of Mn^{3+} —results in rapid voltage and capacity degradation during cycling, limiting their practical application. Addressing this voltage decay is essential for commercialization. Various strategies, such as internal structural stabilization, electrolyte modifications, and surface coatings, are currently being explored to mitigate this issue.

Life cycle: The life cycle performance of LMR has not been commercially validated due to voltage decay concerns. Nonetheless, advancements are being made, as GM reports that its LMR cells now match the lifespan of high-nickel NMC batteries through proprietary coatings and particle engineering. For comparison, the life cycle of NMC battery reaches 1000-2000 cycles and for LFP it can be above 5000 cycles.

Cost: LMR's cobalt-free, manganese-rich composition (60–70% Mn) positions it between LFP and NMC in terms of cost. Based on our estimates, the theoretical cost of LMR battery cells is approximately US\$55/kWh (based on manufacturing costs in China and battery material costs), which is still about 15% higher than LFP batteries, even post commercialization. The abundance of manganese and its lower refining costs help avoid the ethical and supply chain challenges associated with cobalt-dependent NMC. For mid-range EVs, LMR's cost-effectiveness combined with its comparable energy density offers a compelling alternative to premium NMC market.

Safety: LMR batteries present a safety profile that falls between LFP and NMC chemistries. Benefiting from manganese's inherent thermal stability, LMR is less prone to thermal runaway than NMC and generally safer under high-stress conditions. Although LFP is widely regarded as the safest option due to its exceptional resistance to ignition and thermal runaway, LMR is slightly less stable. Furthermore, LMR generates fewer toxic gases than NMC at high states of charge and is less flammable than LFP at low states of charge.

EXHIBIT 4: **In terms of key features and cost, LMR is a chemistry that balances LFP and NMC**



Source: IDTechEx, Bernstein analysis

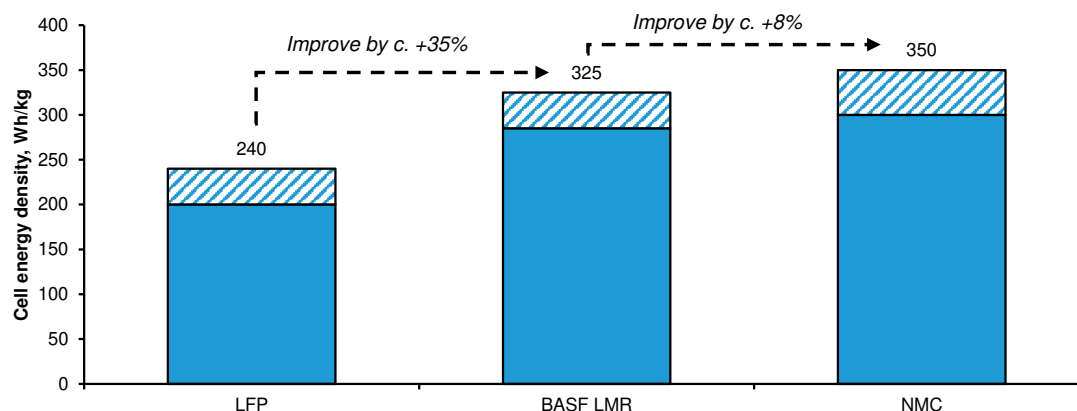
EXHIBIT 5: **There are mainly two types of high-Mn cathode materials in development, including layer-structured LMR, and high-voltage spinel LNMO**

	LMR	NMx/LNMO	LFP	NMC
Chemistry	$x\text{Li}_2\text{MnO}_3 \cdot (1-x)\text{LiMO}_2$; M = Ni, Mn, Co	$\text{LiNi}_{1-x}\text{Mn}_x\text{O}_4$	LiFePO_4	$\text{Li}(\text{Ni}_x\text{Co}_y\text{Mn}_z)\text{O}_2$
Energy density	>280Wh/kg	240-260Wh/kg	200-240Wh/kg	300-350Wh/kg
Cycle life	Not fully reported	2000-3000 cycles	3000-6000 cycles	1000-2000 cycles
Cell cost, US\$/kWh	54	~55	47	68
Safety	High	High	Highest	Moderate
Key materials	Ni, Mn, Co (no / very low)	Ni, Mn	Fe, P	Ni, Mn, Co
Applications	Affordable EVs, aviation	Mid-range EVs	Storage, budget EVs	Premium Evs, electronics

Source: Company data, Bernstein analysis and estimates (cost)

According to the BASF presentation, LMR batteries can achieve an energy density of around 300 Wh/kg. With further optimization to a high voltage exceeding 4.7V, the energy density can increase to 320 Wh/kg. This performance aligns with the expectations of Korean battery manufacturers, who project a 33% increase in energy density compared to LFP batteries, which typically range from 200 Wh/kg to 240 Wh/kg today in China.

EXHIBIT 6: We expect that the energy density of LMR batteries will be 35% higher than that of the current mainstream LFP battery products in China



Source: Company data, Bernstein analysis

We believe that LMR technology presents a potential option for entry and mass-market EVs outside of China, with an established supply chain that minimizes raw material risks. In contrast, the LFP battery value chain has yet to be developed in the West, making it challenging to replicate this technology without access to China's extensive supply of battery components. LMR technology is also well-positioned in terms of raw material availability, as it does not rely on scarce resources like iron phosphate and cobalt, which can pose supply chain risks. Additionally, LMR batteries provide better recycling value at the end of their life cycle, enhancing future raw material security.

While the estimated cost of LMR batteries remains higher than that of LFP batteries, they can be manufactured using retrofitted NMC battery production lines, significantly lowering the capital investment required for production facilities. Despite the cost considerations, LMR batteries offer advantages such as higher energy density, improved performance in low temperatures, and better sustainability metrics. The demand for batteries outside of China is heavily influenced by the cost parity between ICEVs and EV models. As EV adoption increasingly moves toward the mass market, LMR batteries are well-positioned to drive the transition to more sustainable and cost-effective EV battery solutions.

EXHIBIT 7: LMR is the better value proposition versus LFP/LMFP, in particular for Europe and North America

	LMR	LFP/LMFP
Cost	Cost competitive	LF(M)P cost hard to replicate elsewhere due to subsidies in China and massive inventory of iron phosphate
Key Performance / Features	- Higher energy density; - Better performance in cold temperatures; - Better sustainability performance (lower CO₂ generation)	
Manufacturing	Produced on existing NMC production lines	LF(M)P requiring greenfield investments in Europe and N-A
Supply chain	Higher value of recycling at end of life	Recycling of LF(M)P not economical; Raw material availability limitations for iron phosphate

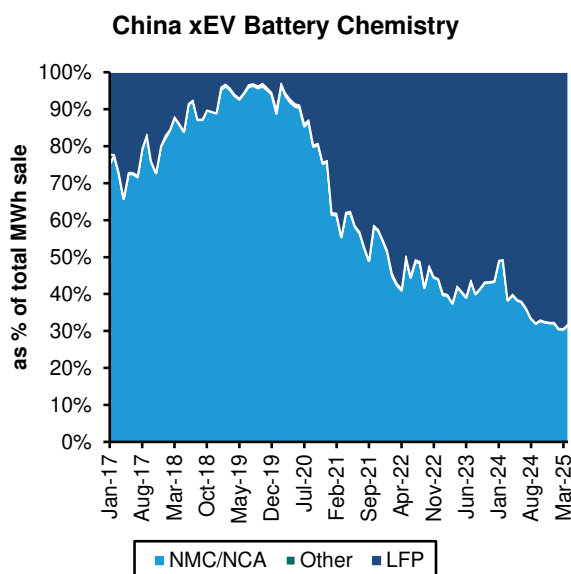
Source: Umicore, Bernstein analysis

Currently, LFP batteries represent 68% of xEV battery installations in China, while their share outside of China is only 14%. Over the past five years, LFP's presence in the chemistry mix in China has surged from less than 5% to nearly 70% today. This raises a natural question: will the West follow China's trend, leading to increased adoption of LFP or other lower-cost chemistries like LMR? The answer appears to be yes, as many Western markets have experienced stagnant EV demand due to higher costs, and

at the same time, an increasing number of European and U.S. OEMs are showing greater interest in LFP and LMR batteries now.

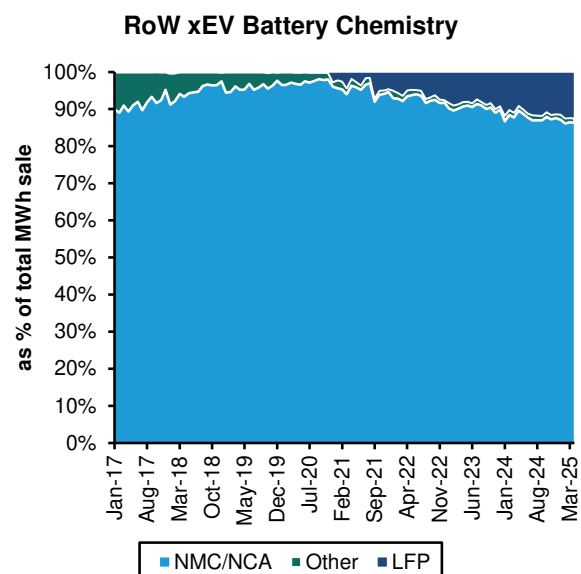
Korean battery cell manufacturers and certain Western OEMs are actively developing both LFP and LMR technologies to address the increasing demand for lower-cost batteries. Currently, it is challenging to determine which technology will be more advantageous. While LFP is a relatively mature technology, LMR has yet to achieve commercial availability on a global scale. However, establishing a supply chain for LFP can be much more difficult, whereas LMR can utilize the existing value chain associated with typical NMC batteries. Both technologies will take time to develop outside of China, but they are expected to fulfill customer demand for more cost-effective EV models.

EXHIBIT 8: NMC accounted for 32% of China's xEV battery installations



Source: SNE, Bernstein analysis

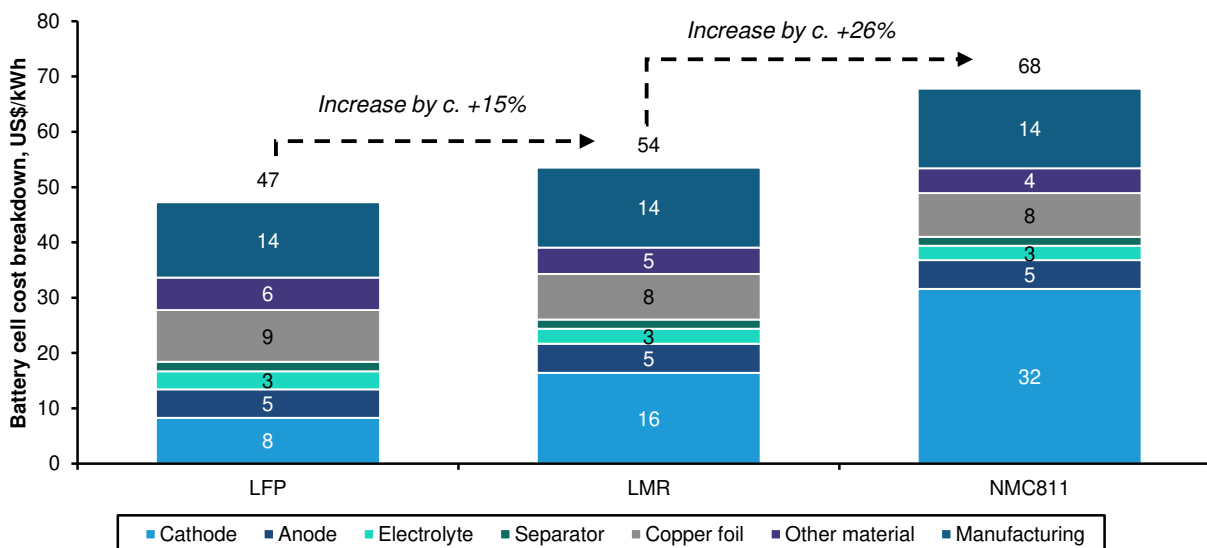
EXHIBIT 9: NMC accounted for 86% of xEV battery installations outside of China



Source: SNE, Bernstein analysis

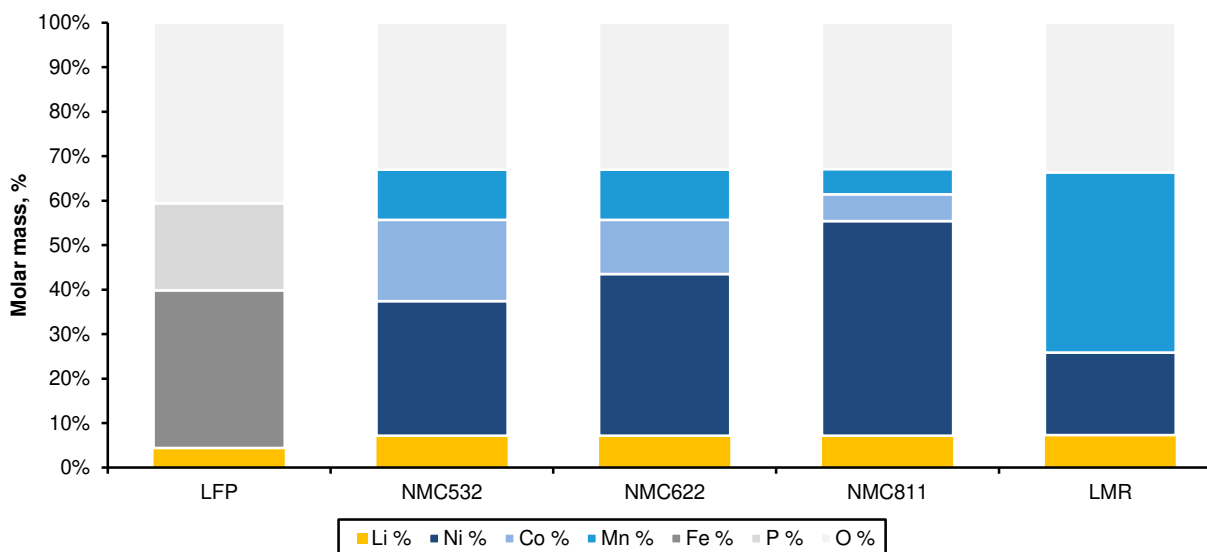
LOWER COST THAN NMC BUT HIGHER THAN LFP

LMR's cobalt-free, manganese-rich composition (60–70% Mn) positions it between LFP and NMC in terms of cost. Based on our estimates, the theoretical cost of LMR battery cells is approximately US\$55/kWh (based on manufacturing costs in China and battery material costs), which is still about 15% higher than LFP batteries, even post commercialization. For mid-range EVs, LMR's cost-effectiveness (20% cheaper than NMC811 at cell levels) combined with its comparable energy density offers a compelling alternative to premium NMC market.

EXHIBIT 10: **We estimate that the cost of LMR battery will be US\$54/kWh, vs. US\$47 for LFP and US\$68 for NMC811**

Source: Bloomberg, Baiinfo, Bernstein analysis and estimates

In essence, the cost savings of LMR compared to NMC arise from substituting cobalt and nickel for the more affordable manganese. Within NMC chemistries, transition metals constitute approximately 60% of the total molar mass, with about 50% of the NMC cathode's weight coming from cobalt or nickel. In contrast, for LMR (NMC307), nickel accounts for 19% of the total molar mass, while manganese makes up 40%. Note the lithium composition in the LMR could be higher, which can increase the cost of LMR battery further.

EXHIBIT 11: **Element composition of LMR, LFP and NMC cathode materials**

Source: Bernstein analysis

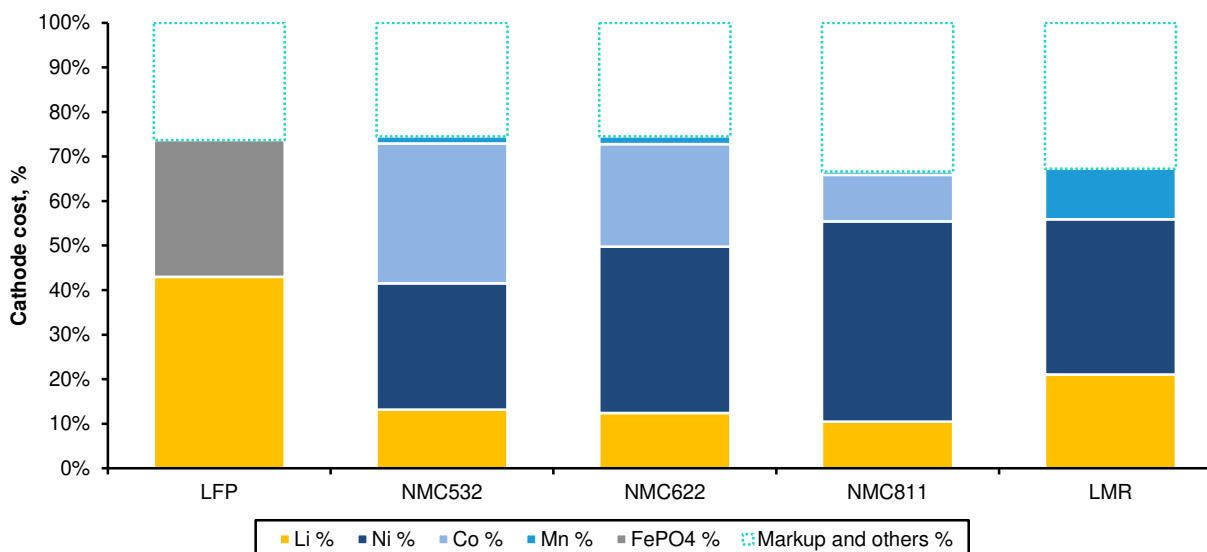
EXHIBIT 12: **Element composition of LMR, LFP and NMC cathode materials**

Molar mass, g/mol	LFP	NMC532	NMC622	NMC811	LMR
Li	6.94	6.94	6.94	6.94	8.33
Ni	-	29.35	35.22	46.95	11.74
Co	-	17.68	11.79	5.89	-
Mn	-	10.99	10.99	5.49	32.96
Fe	55.85	-	-	-	-
P	30.97	-	-	-	-
O	64.00	32.00	32.00	32.00	32.00

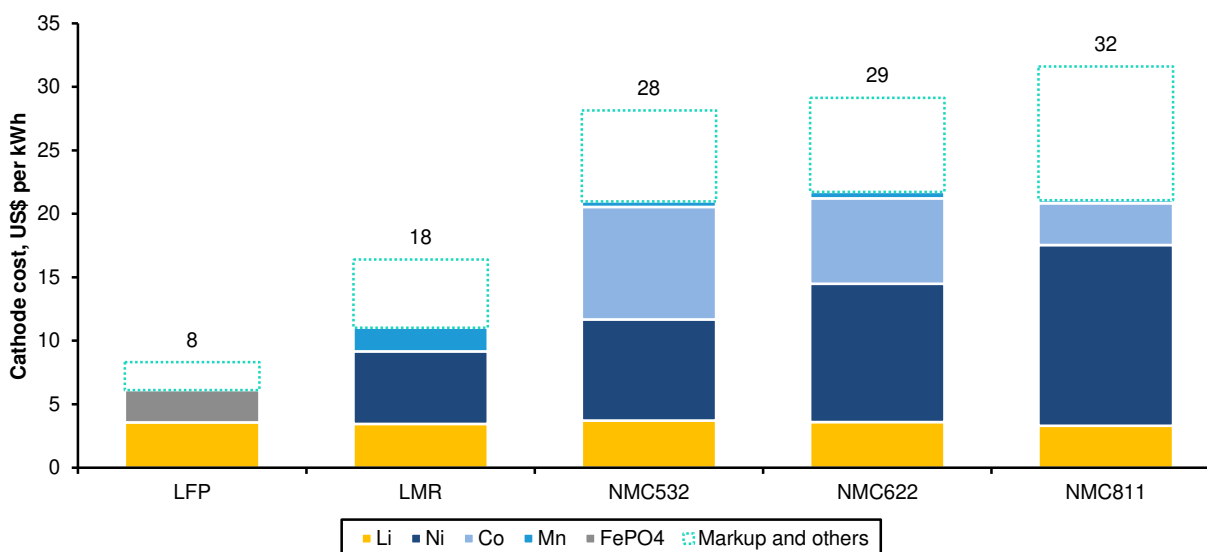
Molar mass, %	LFP	NMC532	NMC622	NMC811	LMR
Li %	4%	7%	7%	7%	10%
Ni %	0%	30%	36%	48%	14%
Co %	0%	18%	12%	6%	0%
Mn %	0%	11%	11%	6%	39%
Fe %	35%	0%	0%	0%	0%
P %	20%	0%	0%	0%	0%
O %	41%	33%	33%	33%	38%

Source: Bernstein analysis

A cost breakdown of key cathode materials as below. The theoretical cost of LMR cathode materials will be US\$18/kWh, which is US\$10/kWh higher than LFP but US\$10-14/kWh lower than NMC chemistries. For LMR cathode materials, we assume a markup of 10% at the precursor level and 30% at the cathode materials level, both based on the spot prices of NMC811 batteries in China.

EXHIBIT 13: **Cost composition of LMR, LFP and NMC cathode materials**

Source: Bloomberg, Baiinfo, Bernstein analysis and estimates

EXHIBIT 14: **We estimate that the cost of LMR cathode will be US\$16/kWh, vs. US\$8 for LFP and US\$32 for NMC811**

Source: Bloomberg, Baiinfo, Bernstein analysis and estimates

EXHIBIT 15: **Cost composition of LMR, LFP and NMC cathode materials**

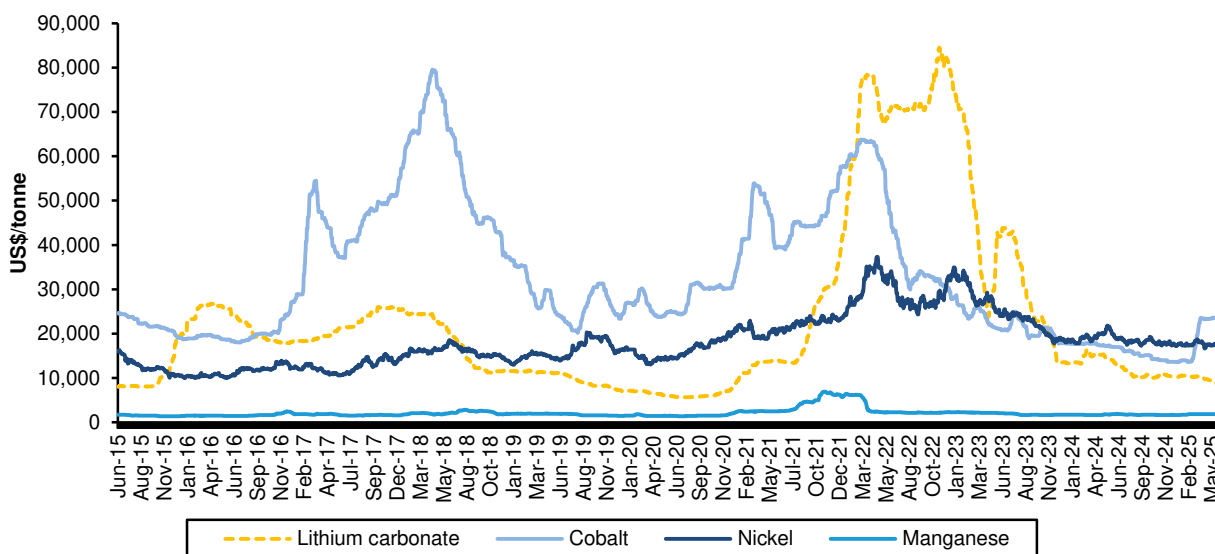
Cathode cost, US\$/kWh	LFP	NMC532	NMC622	NMC811	LMR
Ni	-	7.97	10.89	14.23	6.39
Co	-	8.85	6.71	3.29	-
Mn	-	0.45	0.51	0.25	2.08
FePO4	2.55	-	-	-	-
Li	3.57	3.71	3.61	3.30	3.45
Markup and others	2.19	7.17	7.41	10.54	5.80

Cathode cost, %	LFP	NMC532	NMC622	NMC811	LMR
Ni %	0%	28%	37%	45%	36%
Co %	0%	31%	23%	10%	0%
Mn %	0%	2%	2%	1%	12%
FePO4 %	31%	0%	0%	0%	0%
Li %	43%	13%	12%	10%	19%
Markup and others %	26%	25%	25%	33%	33%

Source: Bloomberg, Baiinfo, Bernstein analysis and estimates

Manganese prices have shown greater stability, particularly since 2023, remaining within the range of US\$1,500 to US\$2,000 per tonne. In contrast, nickel and cobalt prices have experienced more volatility, influenced by supply and demand dynamics, as well as policy changes in key supply countries such as the DRC and Indonesia. For instance, in February 2025, the DRC, the world's largest cobalt producer, imposed a four-month export ban to tackle oversupply and falling prices. This decision has had a significant effect on the global cobalt market, driving prices upward and raising concerns about the future of the DRC's export policies.

EXHIBIT 16: The cost of Manganese is only US\$1.9k per tonne, significantly lower than cobalt (US\$22.5k) and nickel (US\$17.2k)



Source: Bloomberg, Bernstein analysis

COMPANIES

LMR has a long history of research and development, with studies on LMR technology dating back to the 1990s. The focus of this research has primarily been on addressing challenges related to cycle life, voltage stability, and scalability for large-scale commercialization. Since 2024, several battery and cathode manufacturers have announced their mass production plans regarding LMR battery.

POSCO Future M recently announced the successful development of LMR cathode materials and aims to secure mass production within 2025, along with pursuing large-scale orders. Since 2023, POSCO Future M has collaborated with global automakers and battery manufacturers to commercialize LMR technology. Its Technology Research Institute has enhanced energy density, charge-discharge performance, and stability, achieving pilot production of LMR materials in 2024. Recently, POSCO Future M conducted and gained approval for inspections in equipment operation, safety, and environmental fields necessary for LMR production at the request of customers. POSCO plans to leverage existing NMC production lines for LMR manufacturing, minimizing new investment needs.

Umicore plans to commence mass production of high lithium manganese (HLM, LMR by our definition) batteries in 2026. The company's R&D and innovation teams began their work on HLM approximately 10 years ago. Over this period, advancements in battery material technologies have helped overcome initial challenges in HLM development, providing Umicore with valuable insights. When compared to lithium manganese iron phosphate (LMFP) produced in Europe, Umicore anticipates that the energy density of HLM batteries will increase by 28% at the cell level, while costs are expected to decrease by 3%.

GM and LGES are partnering to develop LMR prismatic battery cells for next-generation EVs, with GM aiming to be the first to deploy these batteries in EVs offering over 400 miles of range by 2028. LMR cells utilize a higher proportion of cost-effective manganese, providing a 33% increase in energy density compared to conventional LFP cells while maintaining similar costs. The LMR cells, composed of approximately 35% nickel and 65% manganese with virtually no cobalt, are designed in a rectangular prismatic shape that improves packaging efficiency and reduces the number of required components in battery systems (reducing battery module components by 75% and total pack components by 50%), ultimately enhancing cost-effectiveness. LGES holds more than 200 patents on LMR-related technology. By the end of 2024, GM and LGES coated approximately one ton of LMR cathode at Wallace Battery Cell Innovation Center, testing hundreds of large-format prismatic cells across 18 prototype varieties and 3 cell dimensions, equivalent to 1.4 million miles of EV driving.

Back in 2011, GM invested US\$7MM in Envia, which specializes in manganese-rich cathode technology that promises higher energy density and lower costs for lithium batteries. This collaboration aims to address critical challenges in battery

performance, such as reducing the cost, size, and weight of battery packs essential for GM's EV lineup, including the Chevrolet Volt and future models like the Opel Ampera. The partnership allows GM to utilize Envia's high-capacity manganese-rich cathode materials, which were expected to increase the energy density of lithium-ion cells by up to one-third, potentially leading to significant reductions in battery costs. However, GM ultimately found that the metrics promised by Envia could not be commercialized, as the energy density was lower than expected, and the lifespan decreased by 50% after 400 cycles. After that, GM has been researching LMR technology since 2015 with work acceleration in 2020.

Ford is also developing LMR battery that aims to be mass produced by the end of the decade. Announced by Charles Poon, Ford's director of electrified propulsion engineering, the automaker is already producing a second generation of LMR cells at its Ion Park R&D center in Michigan, touting improvements in safety, energy density, and stability over nickel-based batteries.

BASF has been working on various LMR cathode materials, including NCM217 and NCM307, for several years. In 2018, BASF unveiled its new cathode recipe that would include 70% manganese, 20% nickel and no more than 5% cobalt with mass production in 2021 expected. The company has achieved an energy density of approximately 285 Wh/kg at 4.4V, and with further optimization for high voltages above 4.7V, this can exceed 320 Wh/kg. BASF's products demonstrate a safety profile comparable to mid-nickel NMC systems, allowing for a tailored portfolio that meets diverse requirements.

What initiatives are Chinese companies undertaking in this chemistry? The Chinese battery industry is increasingly focusing on LMR materials, but mainly due to their high specific capacity, which supports the pursuit of high energy density and the practical application of solid-state batteries. In 2024, Chongqing Tailan announced the launch of its automotive-grade solid-state battery, boasting a capacity of 720 Wh/kg. This battery incorporates LMR cathode materials and utilizes composite lithium metal materials for the anode. Another player in the lithium battery sector, Wanxiang A123, revealed in March 2025 that it has enhanced its battery energy density to 860 Wh/kg. Given its prior research advancements, it is likely that the cathode material selected will also be LMR-based. Alongside companies such as Beijing Easpring and Ningbo Ronbay, which have declared their efforts in this field, BTR introduced ultra-high nickel and LMR cathode materials in May of this year to address the demand for high energy density. The LMR cathode is reported to achieve a specific capacity exceeding 300 mAh/g at a high voltage of 4.8V.

EXHIBIT 17: Korean and European companies are actively developing LMR chemistries, while Chinese companies are more focused on LFP

Company	Commercialization Status	Progress	Key Performance / Features
POSCO Future M	2025 (mass production)	- Pilot production completed in 2024. - Using retrofitted NCM lines.	- 33% higher energy density vs. LFP. - Mn-rich (low Co/Ni), cost-competitive with LFP. - High recyclability.
Umicore	2026 (high lithium, manganese CAM)	- Industrialization of HLM (high-lithium, manganese-rich) cathode materials. - Commercial EV use targeted 2026.	- Lower cost than LFP in terms of TCO. - Higher energy density and recyclability than LFP. - Safety comparable to LFP.
LGES/GM	2028 (Ultium Cells JV)	- Pre-production (late 2027). - Validation at GM's Michigan center.	- 33% higher energy density vs. LFP. - Prismatic cells. - 400+ miles range in trucks. - 65% Mn, 35% Ni, virtually no Co.
Ford	Before 2030	- Pilot production of 2nd-gen LMR cells at Ion Park.	- Higher energy density vs. NMC. - Safety profile similar to LFP. - Targets cost significantly lower than current mid-nickel batteries and parity with ICE.
BASF	Not specified	- Development of several manganese-rich products like NCM217 and NCM307.	- 300Wh/kg energy density. - Safety comparable to LFP.

Source: Company data, Bernstein analysis

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