Goldman Sachs | Equity Research

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Global

Batteries: The Greenflation Challenge

Manufacturing batteries is a complex business, with interplay of securing various raw materials and managing the supply chain for a broad range of components that vary over time as the chemistry evolves. Moreover, ever-increasing demand, component shortages and rising raw material prices are now challenging the long-standing consensus that battery prices will continue to decline in the coming decade. To assess the impact of this "Greenflation" and potential supply chain bottlenecks ahead, **we introduce our proprietary battery pack price and cost curve model, supply-demand models across battery components and a bear case battery TAM scenario**.

Five key conclusions from our analysis:

1. We expect **a likely hiccup in battery price deflation over 2022-23**, but battery innovations and more fuel savings from higher oil prices imply **cost parity of EVs to ICE in a broader part of the industry on a TCO basis could still be achieved by 2025.** We estimate battery pack prices to rise from US$129/kWh in 2021 to US$136/kWh in 2022, before falling towards US$105/kWh in 2025.
2. We expect **continued supply tightness in base metals** (e.g. copper and nickel) and see bottlenecks ahead in select battery components **(e.g. anodes and nickel cathodes**) as the component industry is still nascent, geographically concentrated in China and needs to expand capacity more rapidly.
3. For sustainable EV supply growth amid periodic tightness across materials, the industry requires **a more diversified mix of battery chemistry in the medium term** (e.g. we are **raising our LFP market share to 38% by 2030 from 25%**), with **recycling of metals** from retired batteries to play a key role longer term.
4. Greenflation not only leads to margin risks near term, but also raises the battery industry entry barriers since the access to raw materials becomes more difficult. This implies that **the industry structure will likely remain consolidated** and battery cell supply-demand will be running tight outside of China through 2025.
5. **Technology diversification** and **vertical integration** will be the key determinants of long term winners in the battery industry.

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Batteries and 'Greenflation' In numbers

For EVs to reach parity to ICE cars without subsidies, battery pack prices need to fall to **US$100/kWh** (vs. US$129/kWh in 2021).

Rising raw material prices	Component shortages	Increasing demand

to challenge Battery Price deflation

Greenflation

- We estimate battery pack prices to rise from US$129/kWh in 2021 to **US$136/kWh** in 2022E, before falling towards **US$105/kWh** in 2025E.
- Greenflation likely to erode **US$13/kWh** of other cost deflation of **US$45/kWh** over 2020-2025E.
- **0.1-1.2%** change of the NCM 811 battery pack price for every 10% change of different material prices.

Supply chain bottlenecks

- Raw materials: we see continued supply tightness in base metals (e.g. copper and nickel).
- Battery components: we see more constrained supply for anodes and nickel cathodes.
- We are less concerned in the long run since recycling of EV battery metals could supply **39-57%** of lithium, cobalt and nickel demand for batteries by 2040E.

A diversified mix of battery chemistry is thus required

- We expect LFP's market share to rise into 2030, raising our forecast to **38%** by 2030E from 25%.

Greenflation raises the battery industry entry barriers

- This implies that the industry structure will likely remain consolidated and battery cell supply-demand will be running tight outside of China **through 2025**.

Technology diversification and **vertical integration** will be the key determinants of long term winners in the battery industry.

PM Summary

Rising raw material prices are challenging the long-standing consensus that battery prices will continue to decline in the coming decade. For EVs to reach parity to ICE cars without subsidies, battery pack prices need to fall to US$100/kWh (v.s. US$129/kWh in 2021), which is important for sustainable long-term growth in EVs beyond near term support from regulations and subsidies. To assess impact of the "Greenflation", we introduce **our proprietary battery pack price and cost curve model**, where we look into the changing dynamics of each battery component across chemistries before we compile them into one total battery pack price. This model enables us to quantify the cost impact of changes within a certain battery component (e.g. chemistry changes in cathodes and anodes), along the battery supply chain (e.g. utilization increase related cost declines) and across time (e.g. changes in 2022-25 raw material prices outlook). We further introduce the **global supply-demand models across battery components**, which helps us to locate the supply bottlenecks along the battery value chain. **We see the following takeaways:**

#1: "Greenflation" could challenge the pace of battery price decline: We run four commodity price scenarios over 2022-25, and find that the average battery pack price would stay above the 2021 level over 2022-23, in both our base case and the scenario using decade-high material prices. That said, battery innovations, more efficient manufacturing and more fuel savings from higher oil prices imply cost parity of EVs to ICE in a broader part of the industry on a TCO basis could still be achieved by 2025. In our base case, we expect innovations to contribute US$45/kWh battery cost deflation over 2020-2025, of which higher commodity prices could erode US$13/kWh, on net, leading to a US$32/kWh decline in the battery pack price (from US$138/kWh in 2020 to US$105/kWh in 2025); in a scenario of material prices reaching decade-high levels, we note greenflation could erode US$30/kWh of other cost deflation, leading to a 2025E battery pack price at US$123/kWh.

#2: Further supply chain bottlenecks in the medium term, battery recycling key for long term EV adoption: For raw materials, we see continued supply tightness in base metals (e.g. copper and nickel), with the recent Russia-Ukraine situation posing further supply-driven upside risks for copper, nickel and aluminium. Among battery components, we see more constrained supply for anodes and nickel cathodes. While the nickel cathode suppliers have announced sufficient expansions to reduce supply tightness towards 2025, capacity expansions announced for anode so far fall short of demand growth, implying sustained high margins until more investment is attracted. In the long run, we are less concerned with raw material supply given the availability of recycled metals — we estimate the full recycling of EV battery metals could supply 39-57% of lithium, cobalt and nickel demand for batteries by 2040E or 70-80% once EV penetration reaches 100% for 8-10 years, partly realizing self-circulation within EV battery chain.

#3: Increased use of LFP — a more diversified chemistry mix is required for a sustained EV growth: In China, LFP surpassed ternary batteries since last September to become the No.1 battery type; outside of China, LFP is gaining traction, as the patent expiration around 2022-23 removes previous ex-China usage limitations. Given LFP's cost advantage and OEMs' material diversification incentives, we raise our previous forecast of LFP's market share, now expecting it to rise into 2030 before it declines on the increasing importance of batteries' recycling value.

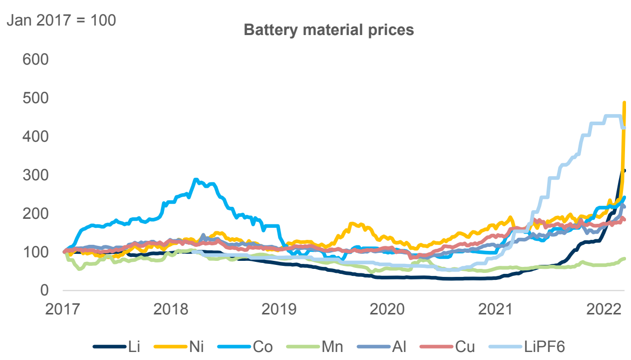
#4: We introduce a bear-case scenario for EV penetration given the greenflation risks: Battery costs account for around 30% of the total EV cost, and a reduction in these costs is essential for EV businesses to become economically viable. With battery costs rising for the first time since the EV shift started accelerating, we see the need to consider the downside risks to EV sales in a scenario where greenflation's impact is larger than our current base case — e.g. material prices to sustain at the decade-high levels for next 5 years, leading to limited economics-driven EV demand from end users. This complements our outlook for EV sales, which now comes in bear, base and hyper-adoption scenarios.

#5: Limited access to raw materials raises the battery industry entry barriers: Although a number of new start-ups are competing for market share in cell manufacturing, we do not see a significant risk for top players to maintain leadership over 2022-30. In our view, multiple barriers exist for new entrants include incumbent top players' technology leadership, economies of scale, and their extensive vertical integration that ensures full control of the supply chain — a competitive strength that becomes more prominent in face of the raw material supply bottlenecks.

From a stock-picking perspective, given the risk of periodic shortages across battery raw materials and components, as well as more diversified battery chemistry view ahead, we believe that vertical integration and technology diversification will be the key determinants of long term winners in the battery industry. **We discuss the company details and their respective material sourcing strategies in the "Stock highlights" section.**

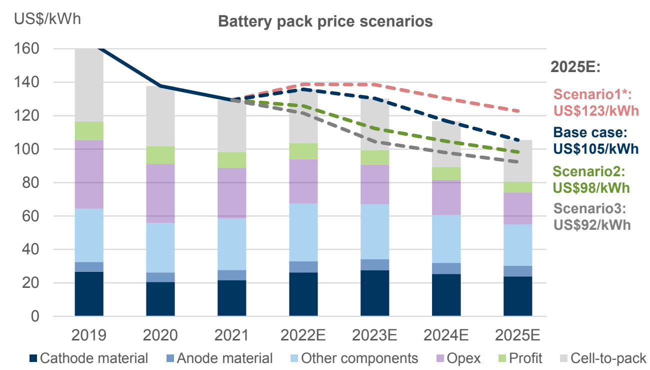
Thesis in 12 key charts

Exhibit 1: Battery raw materials have seen significant price inflation...



Source: Refinitiv, Wind, Goldman Sachs Global Investment Research

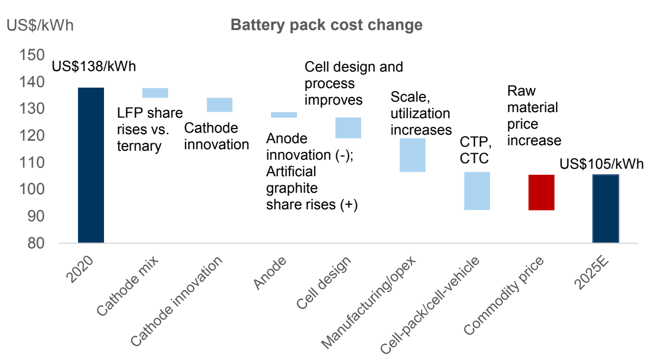
Exhibit 2: ...leading to a likely hiccup in battery price deflation over 2022-23



Material price scenarios: 1) decade-high prices; 2) 5-year averages; 3) 2020 levels

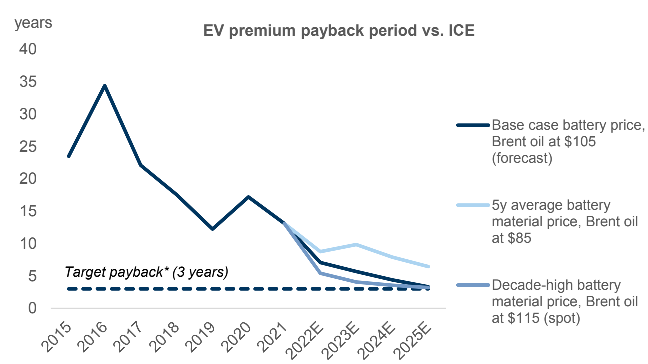
Source: Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

Exhibit 3: Higher commodity prices to erode some of the cost deflation contributed by battery innovations



Source: Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

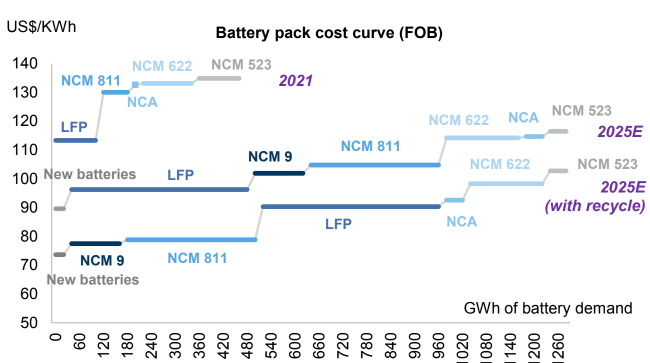
Exhibit 4: Even if battery prices fall less than previous expectations, the oil strength will likely support EV sales



*Toyota Prius achieved breakthourgh in sales after shortening the payback period to 3 years.

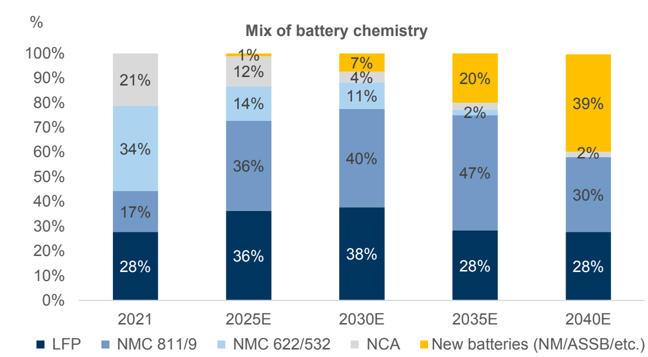
Source: Goldman Sachs Global Investment Research

Exhibit 5: LFP batteries are significantly cheaper than NCM batteries in 2021, but the cost gap narrows towards 2025



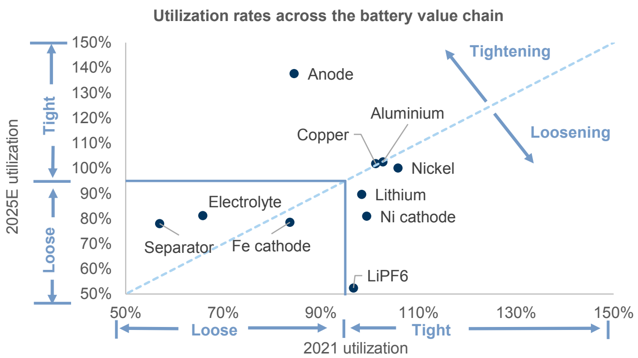
Source: Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

Exhibit 6: We expect LFP's market share to rise into 2030 before it declines on rising importance of recycling value



Source: Company data, Wood Mackenzie, Goldman Sachs Global Investment Research

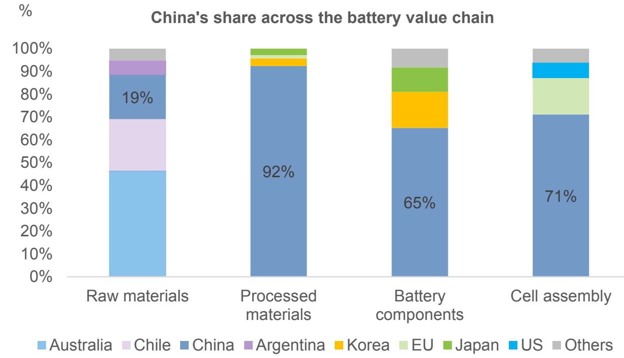
Exhibit 7: Along the battery value chain, supply is running tight in base metals, anodes, and nickel cathodes



Demand / supply for raw materials; demand / capacity for processed materials and components; limited by forecast period, nickel and aluminium using 2023E for 2025E

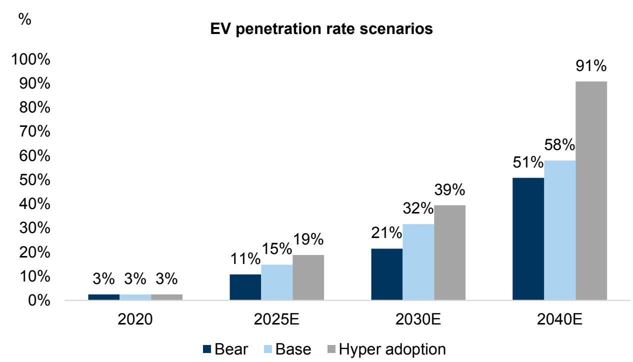
Source: Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

Exhibit 8: China dominates the supply of intermediate battery materials and components



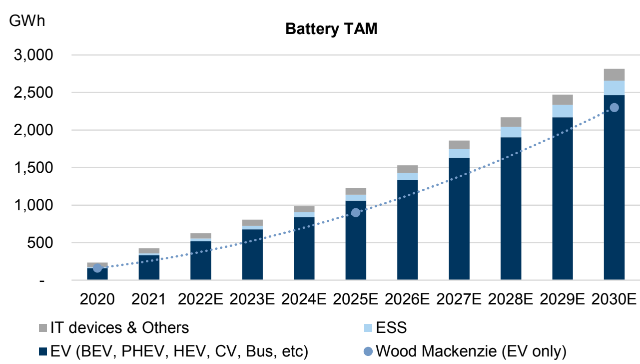
Source: Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

Exhibit 9: We remain positive on EV adoption, but also introduce our bear case scenario due to greenflation risks



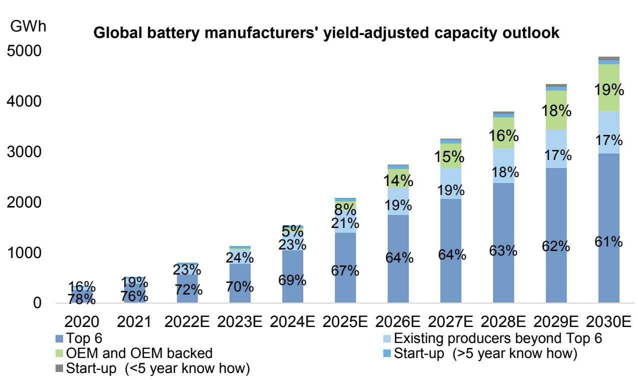
Source: Goldman Sachs Global Investment Research

Exhibit 10: We expect the battery TAM to grow by more than 6 times and reach 2.8TWh by 2030



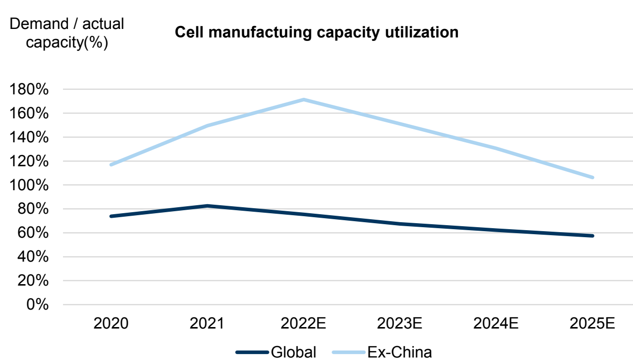
Source: Goldman Sachs Global Investment Research, Wood Mackenzie

Exhibit 11: Top 6 players will still dominate the cell manufacturing market through 2030



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 12: Cell manufacturing industry ex-China will likely remain tight through 2025



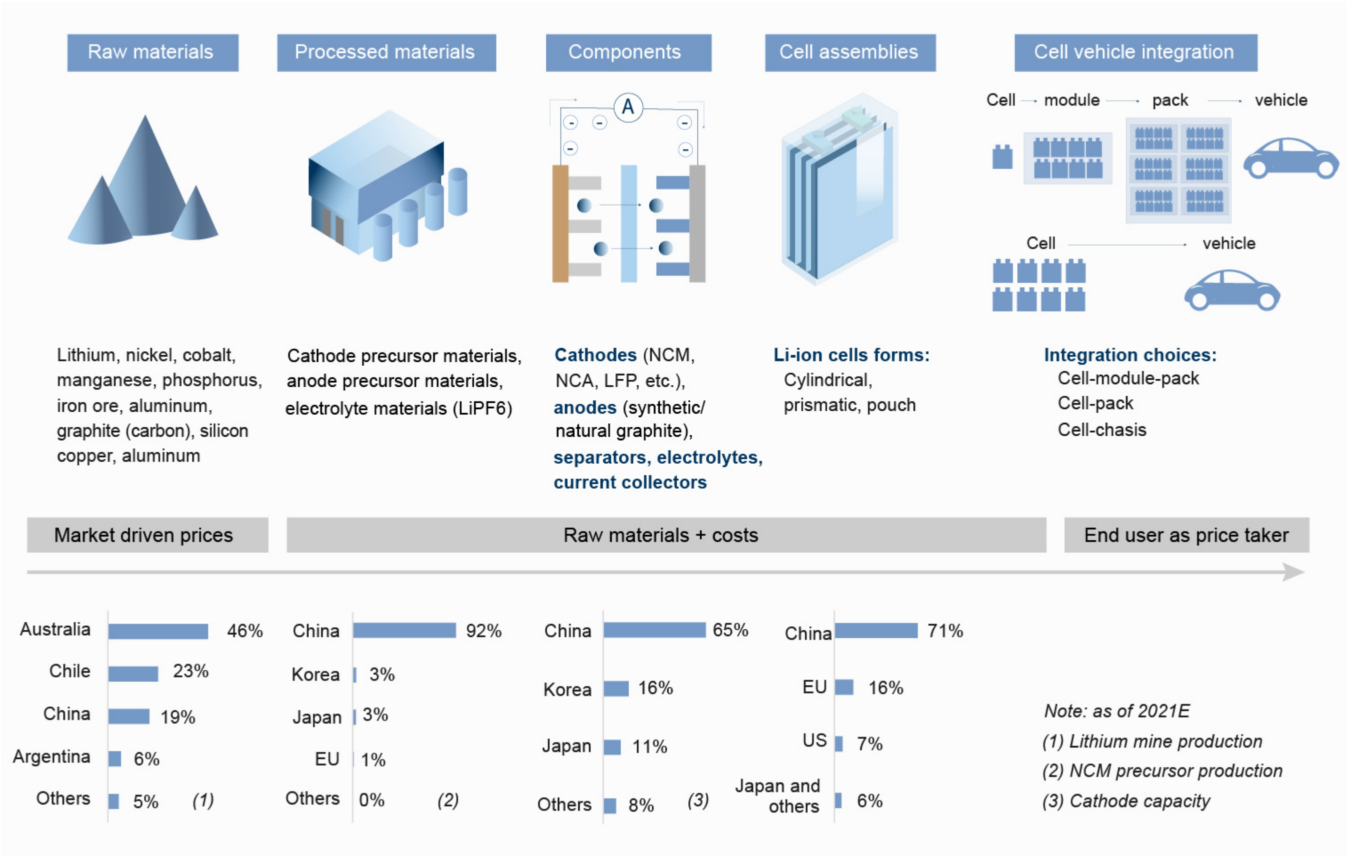
Source: Goldman Sachs Global Investment Research

#1: "Greenflation" could challenge the pace of battery price decline

Rising raw material prices are challenging the long-standing consensus that battery prices will continue to decline in the coming decade. We introduce our proprietary battery pack price model, which points to a likely hiccup in battery price deflation over 2022-23, on the back of higher material prices. We also note the cost savings from battery innovations can be partially offset by factors like increased manufacturing cost of higher nickel cathodes and the increased use of more expensive (but more stable) artificial graphite vs. natural graphite. That said, even if battery prices fall less than previous expectations, the current strength in oil price will likely support EV sales, in our view.

Battery is a complex interplay of multiple components. Battery costs are determined by the total costs of its various components, which are in turn driven by the costs of different raw materials and processing margins at each link of the supply chain. The battery supply chain (Exhibit 13) starts from the mining of raw materials, including lithium, nickel, cobalt, among many others; then, material-processors turn the raw materials into precursor materials for battery components; component-makers further process the precursor materials into different types of cathodes (NCM, LFP, etc.), anodes, separators, electrolytes and current collectors, ready for cell-manufacturers to assemble into battery cells; finally, multiple cells are packaged to reach the desired energy capacity and installed for vehicles. Apart from miners who usually adopt market-driven pricing for raw materials, other participants along the supply chain generally adopt a cost-plus pricing strategy (except for cell makers — like in Korea — where cost pass-through so far is mostly for cathode metals), still largely leaving end users exposed to cost volatility.

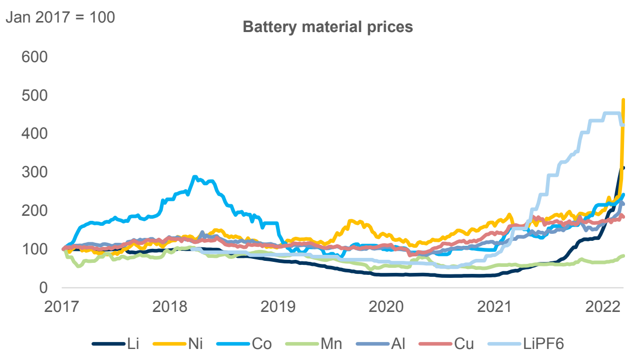
Exhibit 13: Battery supply chain overview: battery is a complex interplay of multiple components



Source: Company data, Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

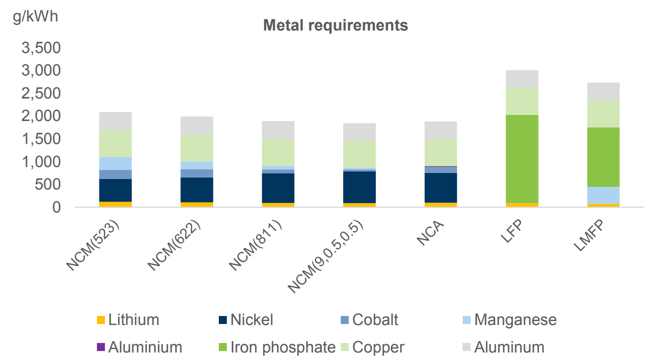
Rising material prices challenge future deflation of battery prices. The fast expansion of battery demand has contributed to tightened raw material markets. Based on the global powertrain outlook and the metal intensity of batteries, we expect the battery demand of the main materials (lithium, nickel, cobalt, manganese) will continue to grow at a 22%/15% CAGR for the next 10/20 years (Exhibit 15-Exhibit 16). Starting from 2021, the broad-based material cost inflation has started to challenge the long-standing consensus that battery prices will continue to decline in the coming decade (Exhibit 14). While the impact of raw material cost inflation varies across the battery chemistry, we illustrate that every 10% change of different material prices leads to 0.1-1.2% change of the NCM 811 battery pack price as an example (Exhibit 17).

Exhibit 14: Battery raw materials have seen significant price inflation through 2021



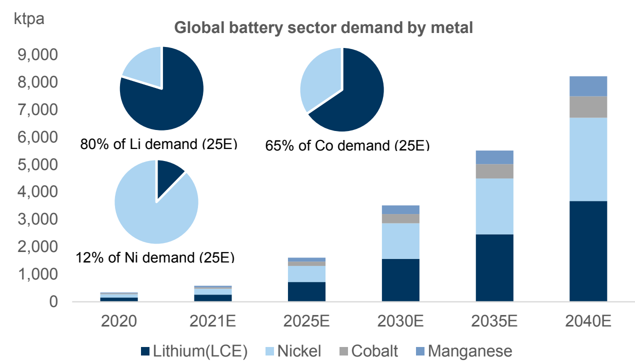
Source: Refinitiv, Wind, Goldman Sachs Global Investment Research

Exhibit 15: Battery production requires c.2000 g/kWh of metals



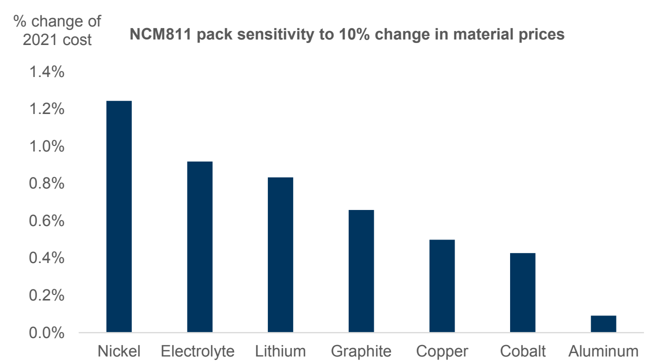
Source: Company data, Wood Mackenzie, Goldman Sachs Global Investment Research

Exhibit 16: We expect battery demand of main materials to grow at a 22%/15% CAGR for the next 10/20 years



Source: Company data, Wood Mackenzie, Goldman Sachs Global Investment Research

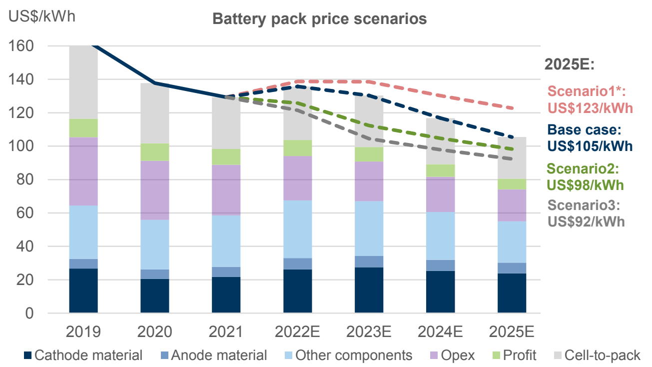
Exhibit 17: Raw material price inflation contributes to higher battery pack prices



Source: Company data, Wood Mackenzie, Goldman Sachs Global Investment Research

A likely hiccup in 2022-23 before battery prices further deflate. We run four commodity price scenarios over 2022-25, and find that the average battery pack price would stay above the 2021 level over 2022-23, in both our base case and the scenario using decade-high material prices (Exhibit 19). Decomposing the base case US$32/kWh average battery price decline over 2020-2025E (from US$138/kWh to US$105/kWh), we note higher commodity prices could erode US$13/kWh of the US$45/kWh cost deflation contributed by other factors (Exhibit 19). Such cost deflation mainly comes from cathode innovation and mix changes, better design (cell design and cell-to-pack / cell-to-vehicle integration) and opex saving on utilization increase. For example, we see the upcoming launch of the larger-sized 4680 cells to improve the cell energy density and lower battery costs on an energy-equivalent basis; that said, larger cells also have demerits including the difficulty of making active materials of uniform thickness and temperature control within cells. To ensure safety, we think automakers will move to adopt larger cells little by little.

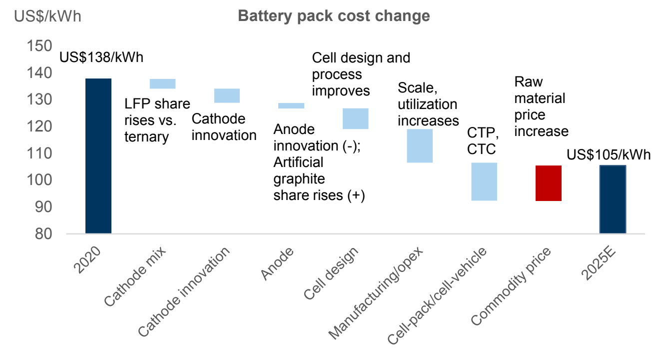
Exhibit 18: A likely hiccup in 2022-23 before battery prices further deflate



Material price scenarios: 1) decade-high prices; 2) 5-year averages; 3) 2020 levels

Source: Company data, Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

Exhibit 19: Higher commodity prices to erode some of the cost deflation contributed by other factors



Source: Company data, Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

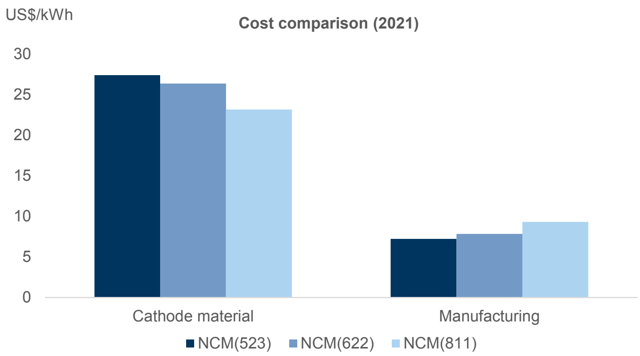
Exhibit 20: GSe battery price vs. targets of OEMs

Time frame	2025	2025	2024	2024	2024-25	New cell2pack	No specific timeline		
	GSe	Tesla	Renault	Stellantis	LGES	BYD	VW	GM (Ultium)	GM (Next gen Ultium)
Cell design / manufacturing	15%	32%	15%	partial			25%	15%	25%
Anode	1%	5%	16%		10-15%		20%	2%	5%
Cathode	6%	12%						9%	10%
Cell-pack / cell-vehicle	10%	7%	5%	partial		20%	5%	15%	21%
Commodity price	-10%								
Total	23%	56%	36%	40%			50%	40%	60%

Source: Company data, Goldman Sachs Global Investment Research

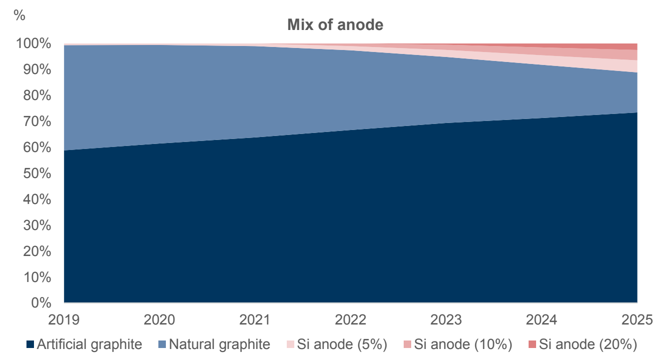
Cost impact of cathode and anode innovations reduced by offsetting factors. Although higher-nickel cathodes improve energy density and reduce cathode material costs, we note the cost saving is partially offset by increased manufacturing costs required for NCM811 vs. NCM523/622 (Exhibit 21). For anodes, cost savings from the energy density improvement (via adoption of silicon in anodes) is largely offset by a rising share of artificial graphite vs. natural graphite, due to favorable features of the artificial graphite like less swelling and longer life cycle (Exhibit 22). Artificial graphite gaining share against natural graphite raises costs in two ways: 1) artificial graphite (320 mAh/g) usually has lower capacity than natural graphite (360 mAh/g), leading to more material needed per cell; 2) artificial graphite is about 20% more expensive than natural graphite.

Exhibit 21: Cost savings from NCM811 cathodes is partially offset by higher manufacturing costs



Source: Wood Mackenzie, Goldman Sachs Global Investment Research

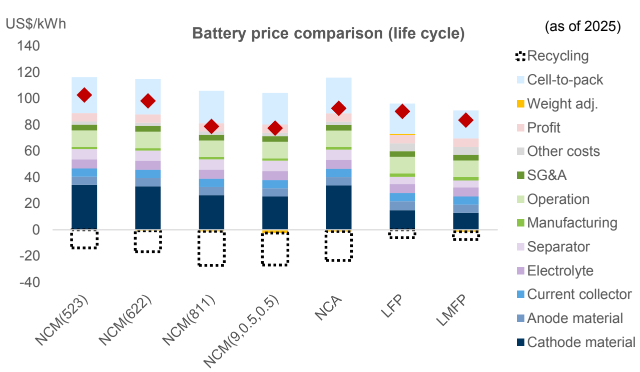
Exhibit 22: Artificial graphite gaining share against natural graphite raises the average cost of anodes



Source: SNE Research, Goldman Sachs Global Investment Research

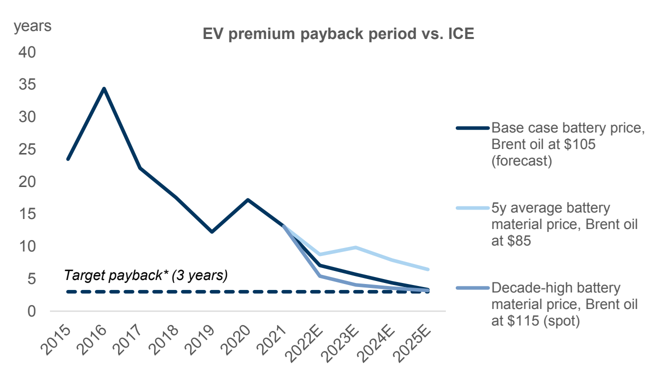
A proprietary battery pack price model. Our 2021-25E battery price outlook and scenarios are based on our proprietary model, where we look into the changing dynamics of each battery component before we compile them into one total battery pack price. We first normalize the cost calculation to a battery pack of a designated energy capacity, which enables energy-equivalent cost comparison of changes within a certain battery component (e.g. chemistry changes in cathodes and anodes), along the battery supply chain (e.g. utilization increase related cost declines) and across time (e.g. changes in 2022-25 raw material prices outlook); we then normalize the battery pack prices to the same driving range, adjusting for weight difference across batteries. Further, to reflect the increasing importance of battery recycling likely for 2025 and beyond, we include the recycling value of dismantled batteries in the life-cycle cost analysis (Exhibit 23).

Exhibit 23: We look into the changing dynamics of each battery component and compile them into a total battery pack price



Source: Company data, Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

Exhibit 24: Strength in oil price supports EV sales against ICE



*Toyota Prius achieved breakthourgh in sales after shortening the payback period to 3 years in 2009.

Source: Goldman Sachs Global Investment Research

Strength in oil price supports EV sales even if battery prices fall less than previous expectations. We believe an EV premium payback period (i.e. the number of years needed for gasoline expense savings to cover the EV cost premium over an ICE) of around 3 years is a threshold for a new powertrain to be widely accepted by consumers.

In the scenario of our base case battery price and Brent oil price at US$105/bbl, we find the payback period to drop towards 3.3 years by 2025, the lowest level since 2015 (Exhibit 24); higher oil price scenarios could bring us closer to the target payback of 3 years, even if one assumes decade-high raw material prices for batteries.

#2: Supply chain bottlenecks could linger in the medium term

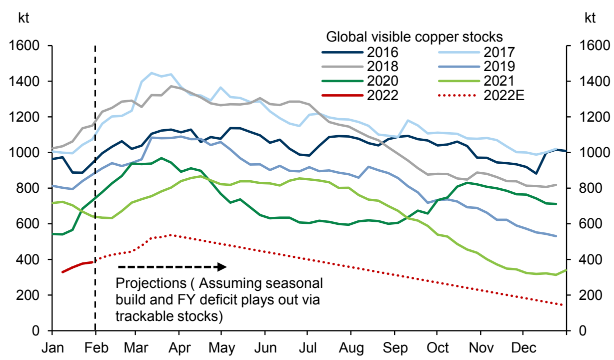
For raw materials, we see supply running tight in the next few years for copper, aluminium, nickel and lithium, with the recent Russia-Ukraine escalation posing further supply-driven upside risks across base metals. By 2024/25, we expect the supply tightness for lithium to ease, whereas the copper market remains in deficit. Among battery components, we see more constrained supply for anodes and nickel cathodes; while the nickel cathode suppliers have announced sufficient expansions to reduce supply tightness towards 2025, capacity expansions announced for anode so far fall short of demand growth, implying sustained high margins until more investment is attracted. Geographically, China currently dominates the supply of intermediate battery materials and components, which will likely sustain for the next few years. Given the increasing importance of batteries from a strategic perspective, as well as the potential trade disruptions and barriers, the battery value chain could gradually diversify away from China-concentrated supply, in our view.

Raw materials: base metals unprepared for the green transition. As our macro team point out, a decade of poor returns and ESG concerns have curtailed investment in new supply growth of base metals. Currently, copper, aluminium and nickel markets are seeing stocks at extremely low levels, supported by a resurgence in demand due to the pandemic stimulus against stagnant supply (Exhibit 25). Our macro team expect the base metal markets to be on track for inventory depletion given the ongoing deficits (Exhibit 26), leading to bullish metal price forecasts — the team's copper, nickel, aluminium forecasts for 2023 are at US$12,000/25,000/3,850/ton, respectively. Further, copper, nickel and aluminium are vulnerable to potential Russia supply disruption risks after recent geopolitical tension, given that Russia accounts for 5-7% of each metal's global supply. For lithium, while supply could remain constrained over 2022-23, our US team colleagues expect the current demand strength and healthy margin opportunity to bring incremental lithium capacity to market by 2024/25, easing the supply tightness (Exhibit 27).

Battery components: supply tightness in anodes and nickel cathodes. We compare the battery demand outlook against the planned production capacity expansions across the battery component markets, and find future supply of anodes and nickel cathodes to be relatively more constrained than other components (Exhibit 28). Based on new capacities announced so far, we assess that the effective utilization of anode capacity would increase from 85% in 2021 to over 100% in 2025, indicating severe supply shortages (Exhibit 29). This will likely translate into a period of strong margins for anode production, driving more investment in anode for new capacities to be brought online over 2024-25. For nickel cathodes, we assess the capacity utilization is near 100% in 2021, but will come down moderately to 81% by 2025 as more planned capacities get commissioned.

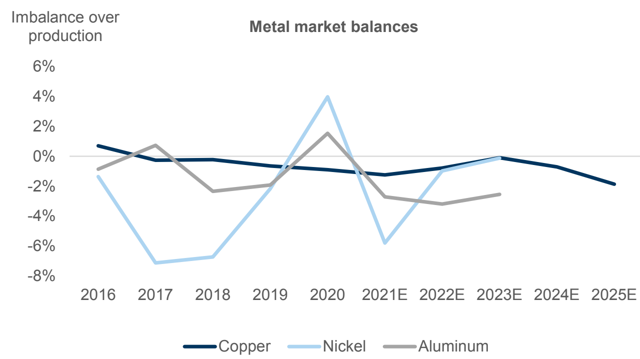
China dominates the supply of intermediate battery materials and components. Geographically, resource-rich countries like Australia benefit from rising mining revenue of battery raw materials, while China currently dominates the production of precursor materials, cell components, and cell assemblies (Exhibit 30). Over the next few years, the rest of world will likely continue to rely on China for the supply of most battery components, judging from the capacity addition plans of the suppliers (Exhibit 31). That said, given the increasing importance of batteries from a strategic perspective, as well as the potential for trade disruptions and barriers, the battery value chain could gradually diversify away from China-concentrated supply, in our view.

Exhibit 25: The global copper market started the year at record low inventories



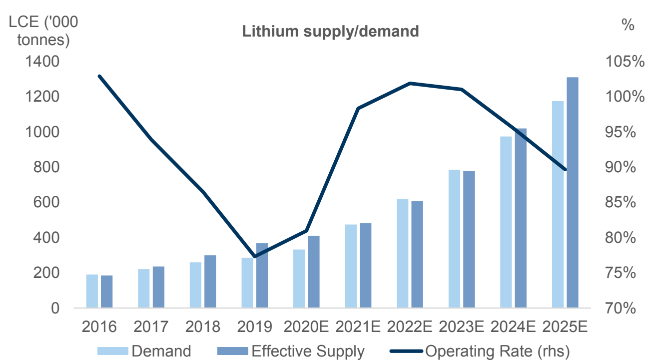
Source: Wind, Goldman Sachs Global Investment Research

Exhibit 26: Our macro team expect the metal markets to be in continued deficits over the forecast period



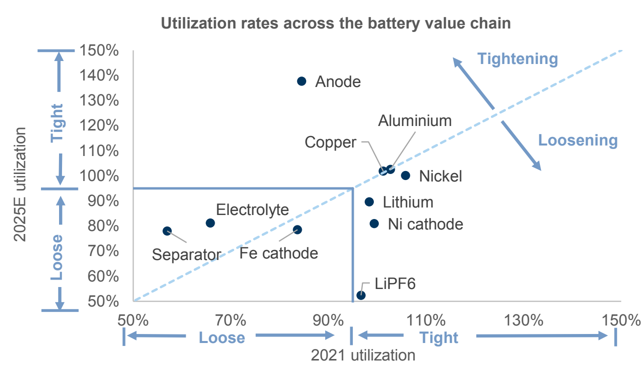
Source: Wood Mackenzie, Goldman Sachs Global Investment Research

Exhibit 27: Lithium supply could remain constrained over 2022-23, but easing towards 2024/25



Source: Goldman Sachs Global Investment Research

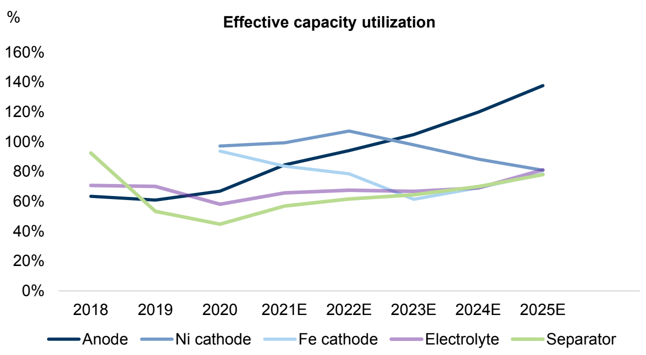
Exhibit 28: Supply is running tight in base metals, anodes, and nickel cathodes



Demand / supply for raw materials; demand / capacity for processed materials and components; limited by forecast period, nickel and aluminium using 2023E for 2025E

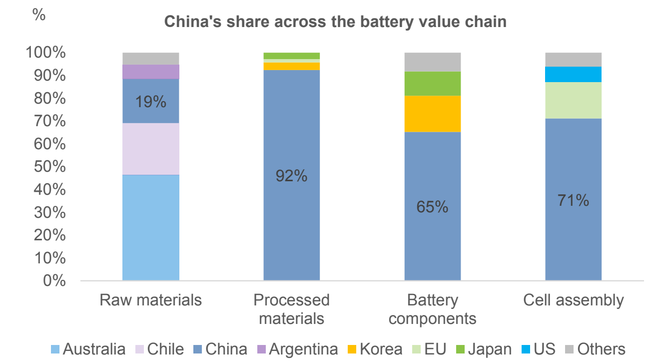
Source: Company data, Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

Exhibit 29: Future supply of anodes and nickel cathodes are relatively more constrained than other battery components



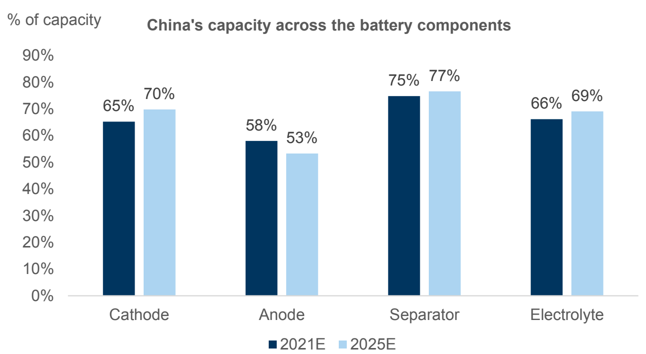
Source: Company data, Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

Exhibit 30: China dominates the supply of intermediate battery materials and components...



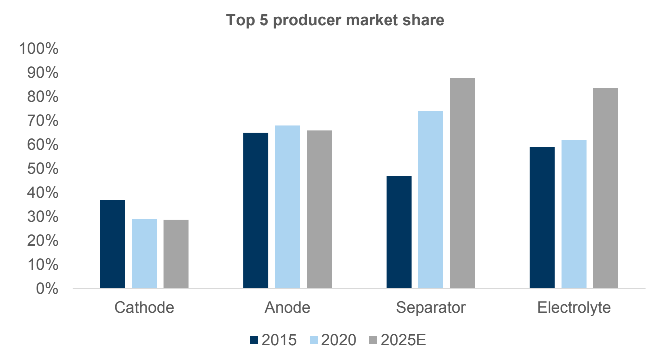
Source: Company data, Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

Exhibit 31: ... and this will likely sustain for the next few years



Source: Company data, Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

Exhibit 32: The cathode market sees relatively low concentration (top-5 suppliers' market share) vs. other components



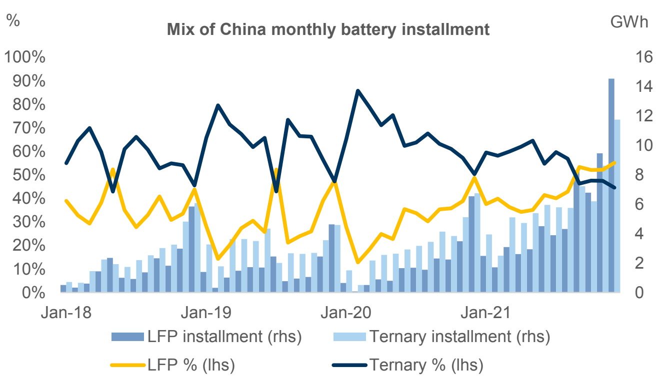
Source: SNE Research, Goldman Sachs Global Investment Research

#3: Increased use of LFP — a more diversified chemistry mix is required for sustained EV growth

In China, LFP surpassed ternary batteries since last September to become the No.1 battery type; outside of China, LFP is gaining traction, as the patent expiration around 2022-23 removes previous ex-China usage limitations. Given LFP's cost advantage and OEMs' material diversification incentives, we now expect LFP's market share to rise into 2030, raising our forecast to 38% by 2030 from 25%. We see small-range EVs among the likely areas for LFP to take off in DMs, due to the lower energy density of LFP vs. NCM. As the battery recycling market matures towards 2030, we expect LFP's market share to start shrinking after 2030 with its cost competitiveness reduced by lower recycling value than NCM, giving way to the expansion of NCM811/9 and other new batteries.

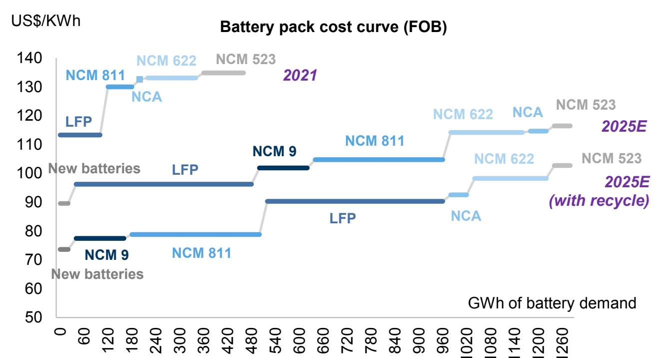
LFP made a come-back in China. The share of LFP batteries in China has been climbing steadily over 2020-21, surpassing ternary batteries since last September to become the No.1 battery type in China (Exhibit 33). A few reasons contributed to the comeback of LFP, including lower costs and higher safety. Specifically, after normalizing the driving range, we assess that LFP batteries are 10-20% cheaper than ternary batteries in 2021, mainly due to the lower cost of iron than nickel/cobalt in the cathode (Exhibit 34). LFP's cost advantage has become increasingly prominent over 2016-22 as China gradually phased out the EV subsidies, which was in favor of the higher-energy-density NCM batteries. As for safety, BYD's nail penetration test for its LFP Blade Battery well-demonstrates the difference — the NCM battery exploded after being penetrated while the LFP Blade Battery emitted neither smoke nor fire.

Exhibit 33: LFP is taking off in China vs. ternary



Source: GGII

Exhibit 34: LFP batteries are at the lower end of the 2021 cost curve



Source: Company data, Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

Some LFP discussions outside of China too. The manufacturing of LFP batteries has been more active in China than the rest of the world, due to the benefit of locally producing and using LFP free of charge. The LFP patents, held by entities in the US and Europe, were invalidated in China in 2011 which allowed free local use of the technology. That said, the patent expiration around 2022-23 will likely drive interest in LFP outside of China, since limitations will be removed 1) for China to export the LFP, and 2) for non-Chinese cell suppliers to produce LFP. We note that a number of OEMs have announced plans to increase the use of LFP, and battery manufacturers have started to plan LFP capacities in the US and Europe (Exhibit 35).

Exhibit 35: LFP is gaining traction outside of China

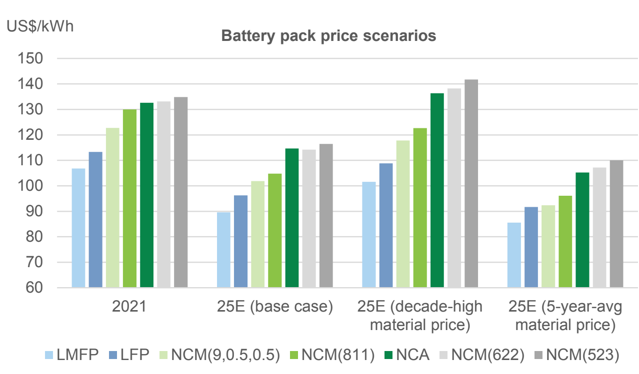
OEM annoucements	Increase usage of LFP?	Current status	Details of stance change	Timeline
Tesla	Yes	Use of LFP for EVs in China	To switch all standard range vehicles to LFP	No specific timeline
VW	Yes	None	To use LFP in upcoming small cars	No specific timeline
Daimler	Yes	None	To use LFP for low price segment	From 2024
Toyota	Yes	None	To launch electric SUVs in China with BYD's blade LFP	By 2022-end
Ford	Yes		To use LFP in commercial vehicles	No specific timeline
BMW	Increased investment		BMW i Ventures invested in an LFP battery startup	First product in late 2022
Hyundai / Kia	Yes	Use of LFP for EVs in China		No specific timeline
GM	No mention	Use of LFP at its JV in China		

Battery producer annoucements	Region	Details	Timeline
Gotion High-Tech	US	The first planned LFP factory in the US	Supply to start by 2023
ElevenEs	EU	To build the first LFP battery gigafactory in Europe	Construction to start from 2024
Freyr	EU	To pursue LFP cathode manufacturing JV	By 2024
Freyr	EU	To build 43/83 GWh of battery capacity in total by 2025/28; a mix of NCM, LFP	2025/28
BYD	EU	To build LFP battery plant (likely blade battery) in Europe	No disclosure

Source: Company data, Goldman Sachs Global Investment Research

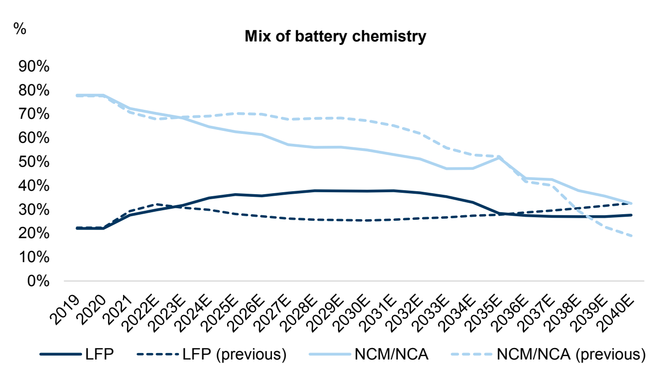
That said, the cost advantage of LFP may narrow. For example, when one considers the recycling value of batteries, LFP's cost advantage is meaningfully impaired by the lower recycling value (Exhibit 34, 2025E cost curve with recycling). Battery recycling benefits both the consumers, via the residual value of the battery, and the suppliers, via lower raw material costs. As more batteries retire and the recycling market matures, we expect battery's recycling value to become an increasingly important consideration for 2025 and beyond. Further, we note the pricing gap between LFP and NCM batteries narrows in lower raw material price scenarios, given that the cost saving from NCM's higher energy density is less offset by the commodity pricing inflation in such scenarios (Exhibit 36).

Exhibit 36: The pricing gap between LFP and NCM batteries narrows in lower raw material price scenarios



Source: Company data, Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

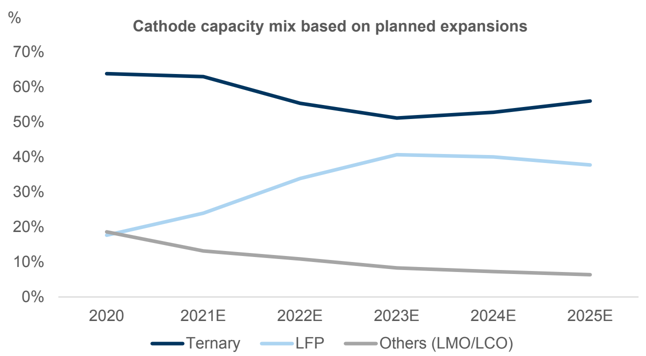
Exhibit 37: We raise our forecast for LFP's market share over 2020-2030s...



Source: Company data, Wood Mackenzie, Goldman Sachs Global Investment Research

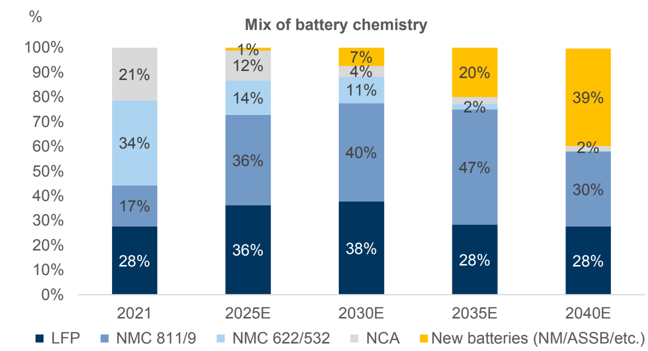
We expect LFP's market share to rise into 2030 before it declines. Over 2022-30, we expect LFP to gain traction due to its cost advantage and OEMs' material diversification incentives to support more sustainable EV supply growth. As such, we raise our forecast for LFP's market share over 2020-30s, cross-checked with suppliers' planned capacity expansions (Exhibit 37-Exhibit 38). After 2030, we expect LFP's market share to start shrinking due to the rising importance of batteries' recycling value, giving way to the expansion of NCM811/9 and other new batteries (Exhibit 39). Among ternary batteries, the more cost-competitive NCM811/9 will rapidly gain market share from NCM622/532, in our view.

Exhibit 38: ... cross-checked with suppliers' planned capacity expansions



Source: Company data, Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

Exhibit 39: LFP's market share to start shrinking after 2030, giving way to the expansion of NCM811/9 and other new batteries



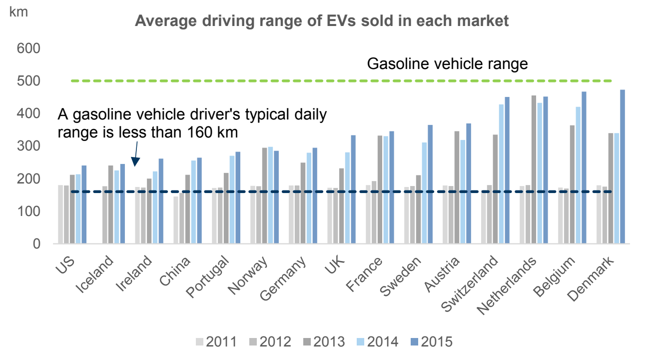
Source: Company data, Wood Mackenzie, Goldman Sachs Global Investment Research

Small-range EVs and energy storage systems are where LFP will take off in DMs. Most daily travel demand can now be met by small-range EVs — the average driving range of EVs (310 km as of 2015[1]) has far exceeded a gasoline vehicle driver's typical daily range of less than 160 km (in US[2], Exhibit 40). That said, most people still want the ability to travel long distances (say for holidays), without having to worry whether there are charging stations along the route. Since LFP has much lower energy density than NCM (Exhibit 41-Exhibit 42), we expect LFP to take off in DMs' small-range EV market, while NCM batteries remain the preferred choice for longer-range vehicles. Further, LFP batteries are more durable and have longer cycle life than ternary batteries, raising the possibility of LFP in energy storage uses (Exhibit 43).

1 Kim, et al. (2017) Does Driving Range of Electric Vehicles Influence Electric Vehicle Adoption?

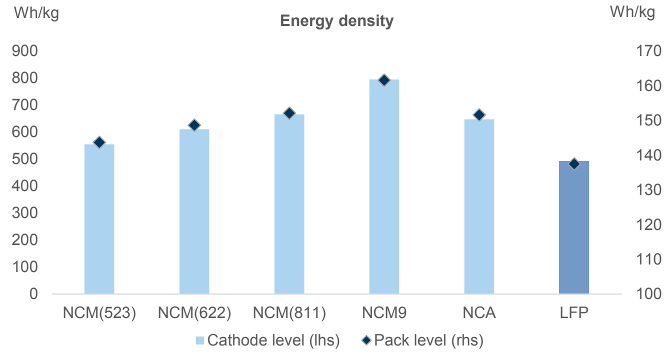
2 Pearre, et al. (2011) Electric vehicles: How much range is required for a day's driving?

Exhibit 40: The average driving range of EVs has far exceeded a gasoline vehicle driver's typical daily range



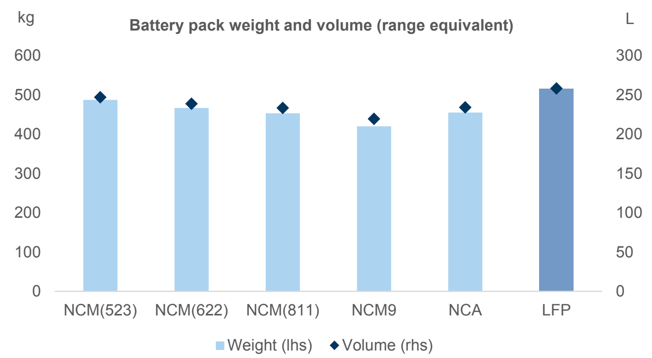
Source: Pearre et al. (2011), Kim et al. (2017)

Exhibit 41: LFP has lower energy density than NCM...



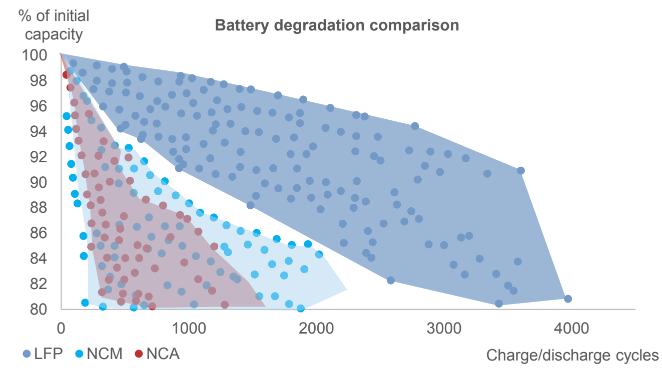
Source: Company data, Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

Exhibit 42: ... leading to heavier battery weight and larger battery space needed per vehicle



Source: Company data, Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

Exhibit 43: LFP batteries are more durable and have longer cycle life than ternary batteries



Source: Preger et al. (2020)

Battery recycling — the future of battery metals

As we have highlighted in EV battery metal recycling: The future of battery metals, we view EV battery metal recycling as indispensable for sustainable EV adoption by addressing the long term supply constraints on resources and reducing dependence on mined metals. We estimate the global EV market could grow by 13x by 2040E or over 25x if EV penetration reaches 100%. Accordingly, we see that battery demand for key metals including lithium and nickel will grow by 12-13x of the current size, and 2x of the current size for cobalt. Under this situation, EV battery metal recycling will gradually become the major source to meet growing battery metal demand - we estimate the full recycling of EV battery metals could supply 39-57% of lithium, cobalt and nickel demand for batteries by 2040E or 70-80% once EV penetration reaches 100% for 8-10 years, partly realizing self-circulation within EV battery chain. Mine reserve life for these minor metals could extend by 100%-240% for lithium, cobalt and nickel with deceleration of mined metals demand compared to no recycling.

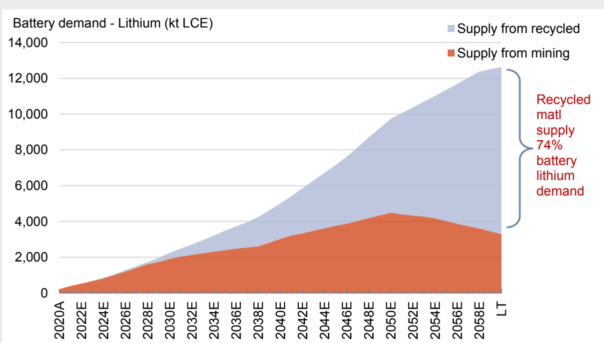
EV batteries typically need to retire from EVs when the capacity falls below 80% of the initial level or after

6-8 years of usage. Retired EV batteries are either recycled to recover raw materials or repurposed for second life applications.

- Retired EV batteries with 40-80% of the initial capacity could potentially be repurposed for second-life application, and use in energy storage or low-speed vehicles, but can't be reused in EV battery any more. Modules and cells will first be disassembled from the battery pack and then go through a series of characterization tests to determine the residual capacity. Cells that meet the minimum requirements for second-life reuse will be re-assembled into modules and battery pack, with the installation of a new battery management system (BMS). Second-life reuse has higher requirements for retired EV battery in terms of consistency in capacity, size, inner structure, economics versus new battery.
- Retired batteries that do not meet the minimum requirements for second-life reuse are recycled. Retired batteries need to be pre-treated first, including discharging, dismantling, crushing, and physical separation. Fine powder called "black mass" is produced after the pretreatment. Black mass will go to recycling stage to recover metals including lithium, nickel and cobalt. Currently, the major processes for recycling treatment that're operating at industrial scale include pyrometallurgical and hydrometallurgical process.

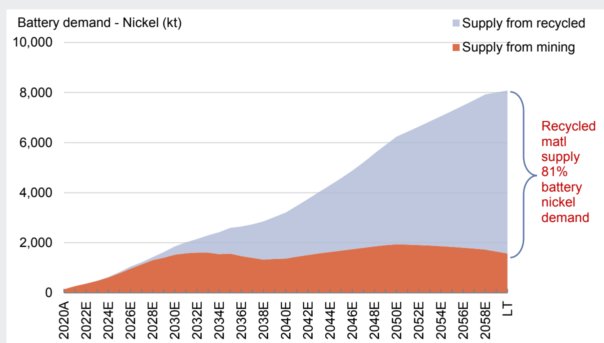
In terms of recycling economics, ternary battery recycling is much more attractive than LFP battery due to 1) higher metal content - lithium usage is higher for most types of ternary battery than LFP, 2) more valuable minor metals left for recycling - ternary battery can recover nickel, cobalt and lithium versus only lithium for LFP battery. Based on 2021 average metal prices, we estimate revenue from recycling NCM811 battery is over 3x of recycling LFP battery. And recycling of retired LFP battery is only at breakeven level in 2021 versus return of nearly 20% for NCM811 recycling. Besides, the incentive for recycling of LFP battery is largely dependent on lithium price movement with lithium accounting for over 50% of recycling revenue.

Exhibit 44: Mined lithium demand from battery - with and without recycling



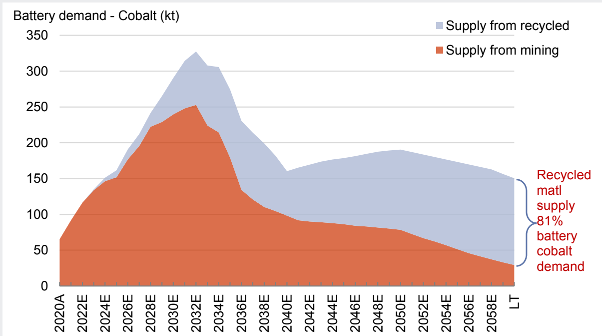
Source: SMM, Goldman Sachs Global Investment Research

Exhibit 45: Mined nickel demand from battery - with and without recycling



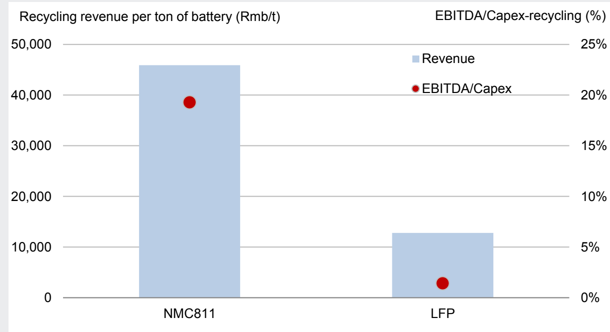
Source: SMM, Goldman Sachs Global Investment Research

Exhibit 46: Mined cobalt demand from battery - with and without recycling



Source: SMM, Goldman Sachs Global Investment Research

Exhibit 47: Recycling revenue and return comparison-NCM811 vs LFP



Based on 2021 average price

Source: Company data, Goldman Sachs Global Investment Research

#4: A bear case scenario for EV penetration given the greenflation risks

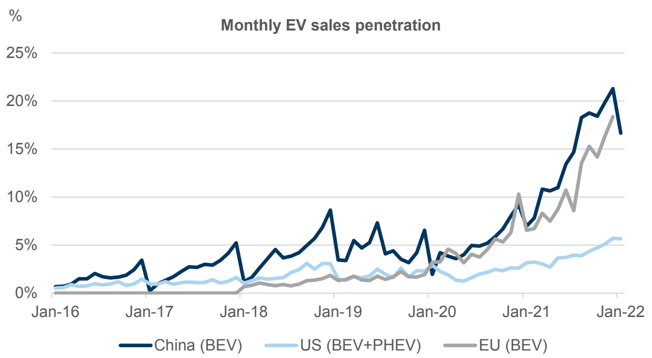
Battery costs account for around 30% of total EV cost, and a reduction in these costs is essential for EV businesses to become economically viable. With battery costs rising for the first time since the EV shift started accelerating, we see the need to consider the downside risks to EV sales in a scenario where greenflation's impact is larger than our current base case — e.g. material prices to sustain at the decade-high levels for next 5 years, leading to limited economics-driven EV demand from end users. This complements our outlook for EV sales, which now comes in bear, base and hyper-adoption scenarios.

Introducing a bear case EV sales scenario to complement our existing base and hyper-adoption scenarios. With battery costs rising for the first time since the EV shift started accelerating, we see the need to consider the downside risks to EV sales in a scenario where greenflation's impact is larger than our current base case — e.g. material prices to sustain at the decade-high levels for next 5 years, leading to limited economics-driven EV demand from end users (Exhibit 49). We regard such EV sales assumptions as highly conservative, as they suggest that regions like the US, Japan and Europe will not be able to meet their targets for carbon neutrality via their automobile sectors. In contrast, our hyper-adoption scenario assumes end users showing a strong preference for EVs, leading to higher demand than the regulation requirements (Exhibit 9). This scenario implies a very high possibility that carbon neutral targets will be met across regions.

CO2 reduction outlook differs significantly across the scenario. In our base scenario, we estimate that the average of CO2/km in the major markets of Japan, the US, Europe, and China would decline from 116 g/km in 2020 to 11 g/km in 2040, representing an average annual decline of 11% (vs. 5%/14% in our bear/hyper-adoption scenario, Exhibit 50). Given that conventional gasoline engine vehicles can only achieve 1-3% annual decline of emission intensity (through higher efficiency), we believe electrification is required to achieve double-digit reductions in automobile CO2 emissions.

Assuming an annual cut in EV subsidies of 20%. As EV sales have expanded, the absolute amount of subsidies offered by governments has increased meaningfully, leading to announcements of subsidy cuts in some regions. Examples include the UK, which announced a 50% reduction in EV grants starting in 2021. China has also decided to withdraw current government EV subsidies altogether at the end of 2022. Meanwhile, in emerging markets (Thailand, Indonesia, etc.), measures such as tax breaks on EVs are being considered to provide an incentive to the next-generation vehicle industry. We estimate that US$2,000-3,000 of government support per vehicle will be needed in 2022-2023 in order to achieve profitability on mass market EVs (vehicle ASP US$25,000-$30,000) and we believe some degree of support will be required through 2022-25 (Exhibit 54). In our base case, we assume an average annual cut in subsidies of around 20% while we watch out for further government announcements.

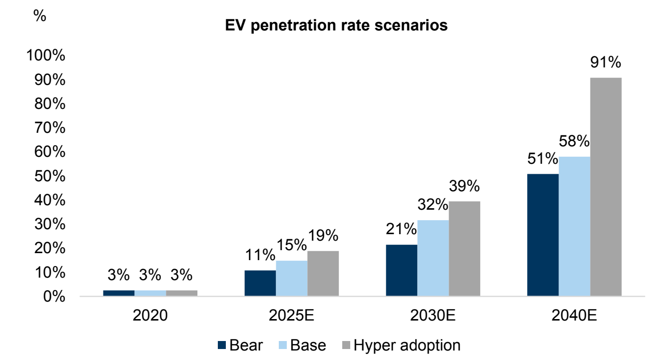
Exhibit 48: EV sales have accelerated over 2021 in key regions (Europe, US, China)



EU BEV penetration rate is from UK, Germany, Norway, Netherlands, Sweden, France, Italy, Spain data

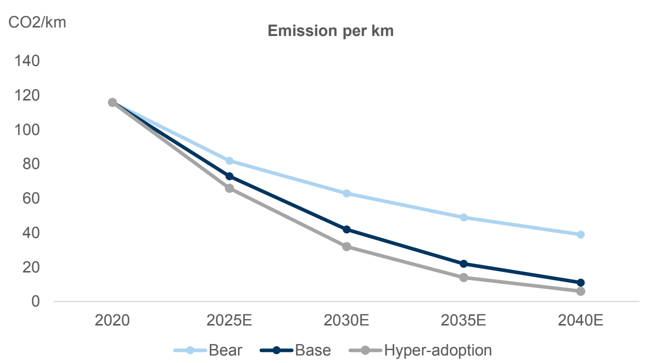
Source: SMMT, KBA, CCFA, UNRAE, RAI, Inside EV, CPCA, Motor Intelligence, Goldman Sachs Global Investment Research

Exhibit 49: We introduce a bear case EV sales scenario to complement our existing base and hyper-adoption scenarios.



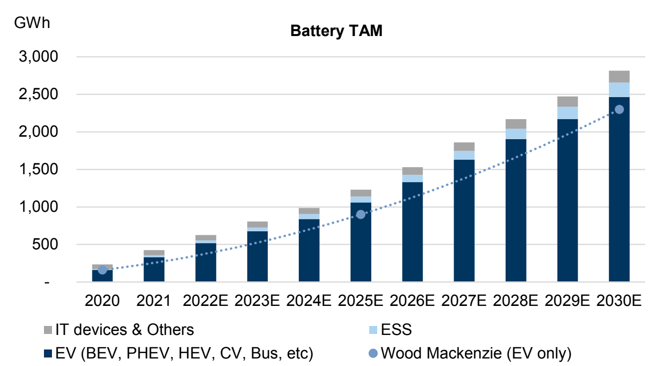
Source: Goldman Sachs Global Investment Research

Exhibit 50: CO2 reduction outlook differs significantly across the scenarios



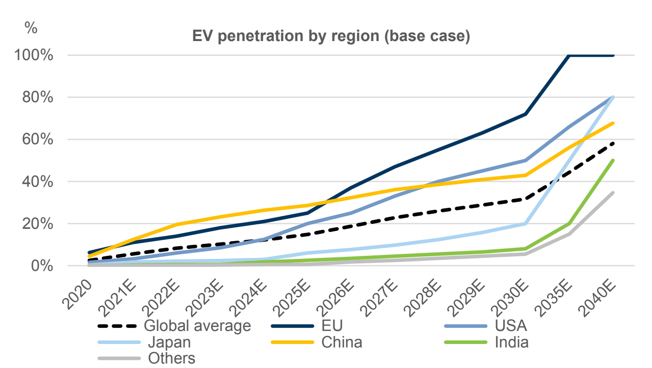
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 51: We expect the battery TAM to reach 2.8TWh by 2030



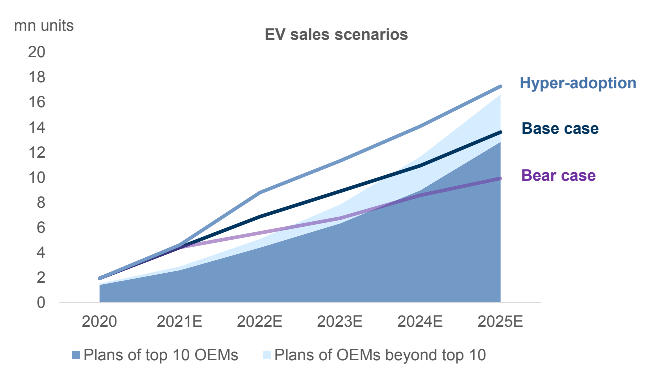
Source: Goldman Sachs Global Investment Research, Wood Mackenzie

Exhibit 52: Our EV sales model considers the different penetration across regions



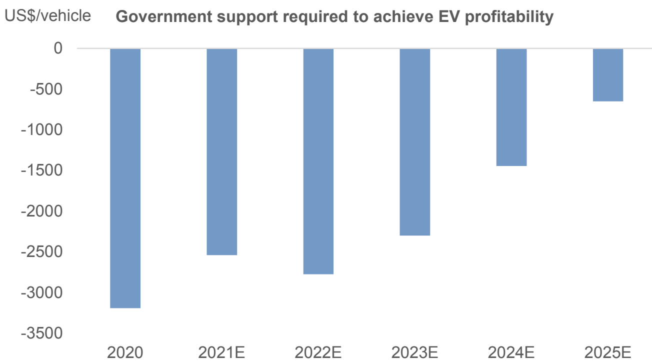
Source: IHS, Goldman Sachs Global Investment Research

Exhibit 53: Our hyper-adoption scenario of EV sales is close to the plans annonnced by OEMs



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 54: Some degree of government support needed through 2025



Source: IHS Global Insight, Goldman Sachs Global Investment Research

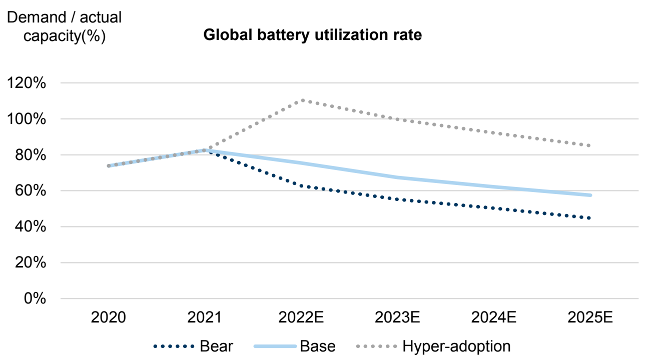
#5: Limited access to raw materials raises battery industry entry barriers

Although a number of new start-ups are competing for market share in cell manufacturing, we do not see a significant risk for top players to maintain leadership over 2022-30. In our view, multiple barriers exist for new entrants include incumbent top players' technology leadership, economies of scale, and their extensive vertical integration that ensures full control of the supply chain — a competitive strength that becomes more prominent in the face of the raw material supply bottlenecks.

Cell manufacturing industry ex-China will likely remain tight through 2025. Although cell manufacturing in general will likely see overbuilt capacity during 2022-25, with the global average utilization declining towards 57% by 2025, we note the ex-China market will likely remain tight with utilization above 100% over 2022-25 (Exhibit 55-Exhibit 56). In this analysis, we consider the company-level capacity expansion announcements, as well as the historical utilization of the respective companies, to incorporate into a yield-adjusted effective capacity outlook for the cell manufacturing industry (Exhibit 57-Exhibit 58).

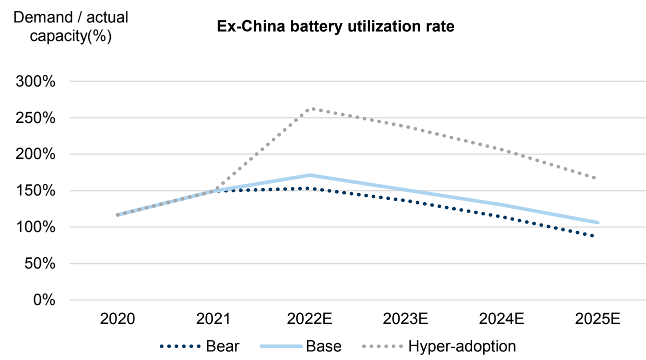
Top cell manufacturers to maintain leadership in ex-China over 2022-30. Although new technologies and startup companies are emerging in cell manufacturing, we do not see a significant risk for top players to maintain leadership over 2022-30. In our view, multiple barriers exist for new entrants include incumbent top players' technology leadership, economies of scale, and their extensive vertical integration that ensures full control of the supply chain. The current raw material bottleneck gives rising importance to vertical integration of cell manufacturers, where the top players can more easily establish long-term raw material access than start-ups, leveraging their scale and existing relationship with the upstream. Further, skilled labor shortage, which is an issue even for the large incumbents (e.g. LG Chem), imposes additional challenges for start-ups to ramp up mass production. As such, we expect non-OEM-backed start-ups to account for only 2-3% of global supply in the coming decade, and the industry to remain consolidated (Exhibit 58).

Exhibit 55: Although cell manufacturing will likely see overbuilt capacity over 2022-25, with the global average utilization declining...



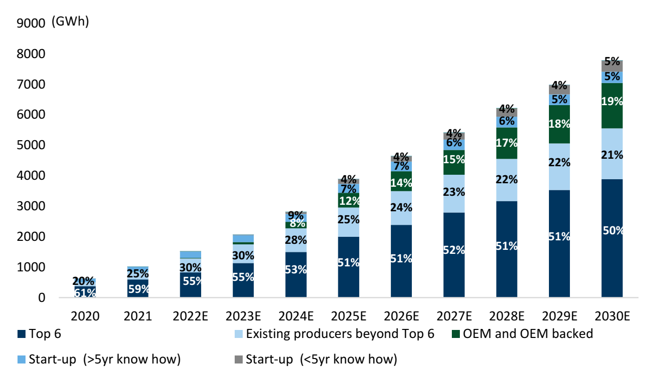
Source: Goldman Sachs Global Investment Research

Exhibit 56: ...ex-China market will likely remain tight with utilization above 100% over 2022-25E



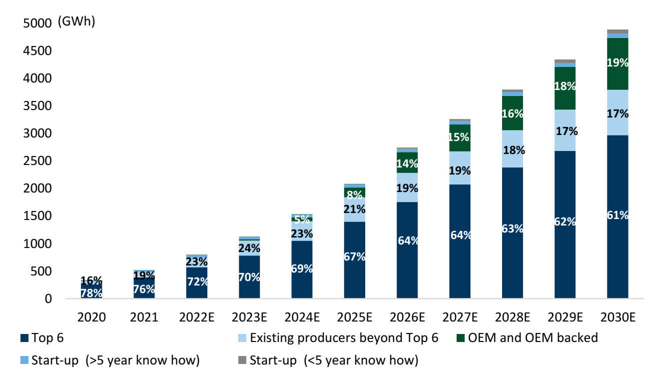
Source: Goldman Sachs Global Investment Research

Exhibit 57: Global battery players' announced capacity plan mounts to near 7.8TWh...
Global battery players' announced capacity outlook



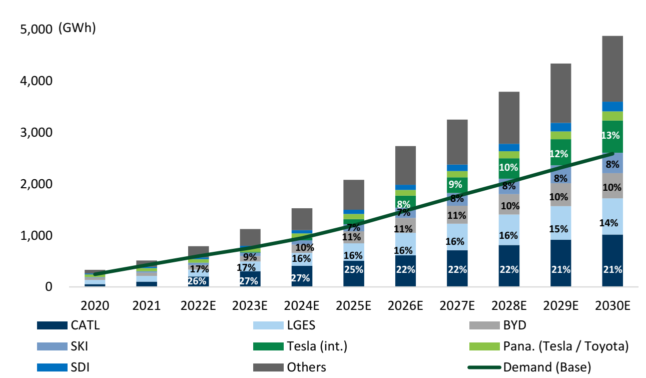
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 58: ...while yield adjusted capacity will lie at 4.9TWh
Global battery players' yield adjusted capacity outlook



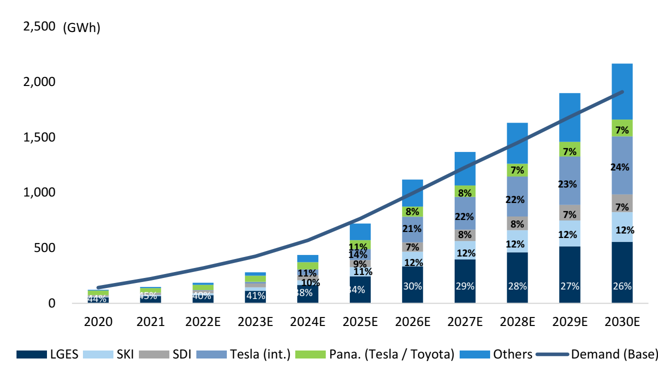
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 59: Yield adjusted battery capacity on global level shows loosening battery SD over the coming years
Global Key battery players' yield adjusted capacity outlook vs base demand outlook



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 60: ...while the ex-China supply will be tight
Key battery players' yield adjusted capacity (ex-China) outlook vs base demand outlook (ex-China)



Source: Company data, Goldman Sachs Global Investment Research

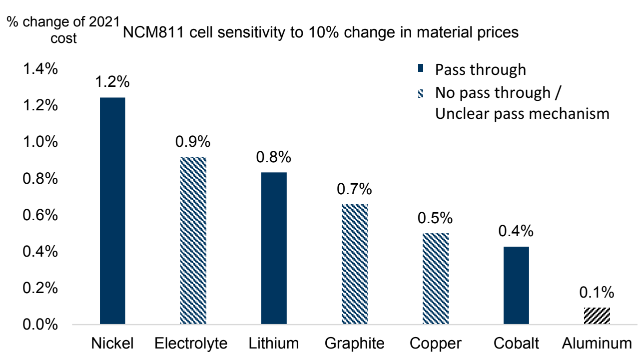
Stock highlights & manufacturers' material sourcing strategy

We believe that vertical integration and technology diversification will be the key determinants of long term winners in the battery industry.

Vertical integration supports profitability and market share. Rising material prices impose downside risks on battery manufacturers' margins, in cases where the material price inflation are not entirely passed-through to the downstream (Exhibit 61). Amid constrained raw material supply, we see vertical integration as an increasingly important strategy for battery manufacturers in order to secure material access as well as to support more resilient margins. Extensive vertical integration can also raise the industry entry barriers and help top players to consolidate their market share (Exhibit 62).

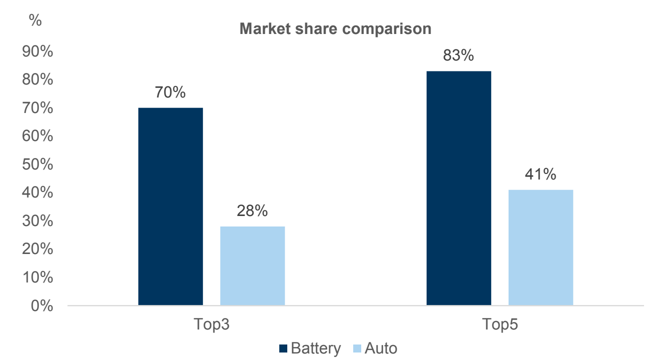
Technology diversification enhances earning sustainability. Among the battery manufacturers, we see LGES and CATL stand out from a technology diversification perspective (Exhibit 64). For different battery chemistries, CATL has exposure to both NCM and LFP; while LGES has been more focused on NCM batteries historically, LFP is among the company's development plan for energy storage systems and small-range EVs. Meanwhile, both companies have laid out plans for next-generation batteries, including CATL's sodium ion batteries and LGES' lithium sulfur/solid state batteries. Further, we note LGES produces multiple forms of cells including pouch and cylindrical cells.

Exhibit 61: Some material price inflations are more difficult to pass-through than others for cell manufacturers



Source: Goldman Sachs Global Investment Research

Exhibit 62: Market concentration is high among battery makers



Source: SNE Research, IHS Global Insight, Goldman Sachs Global Investment Research

Exhibit 64: Among the battery manufacturers, we see LGES and CATL stand out from a technology diversification perspective
LGES vs CATL Technology

	LGES	CATL
Battery form factor	Pouch / Cylindrical	Mainly Prismatic (c.1% sales from Pouch)
Battery chemistry (Current)	NCM/NCMA	NCM & LFP
Battery chemistry (Developing)	**Lithium sulfur (from 2025):** High energy density (1.5x vs existing LiB) battery with lower cost, tested in unmanned plane **Solid state (Polymer based / Sulfide based: from 2026/2030):** High energy density (600Wh/L, 900Wh/L) with high charging speed using solid state electrolyte **LFP battery:** Developing for ESS, R&D for low range EV	**Sodium ion battery (from 2023):** Energy density of up to 160Wh/kg (1st gen) / 200Wh/kg (2nd gen), with charging time in 15 minutes to 80% SOC **Cell to Chassis:** Integrates the battery cell with the vehicle body, chassis, electric drive, thermal management extending driving range to over 1,000km

Source: Company data, Goldman Sachs Global Investment Research

Disclosure Appendix

Reg AC

We, Nikhil Bhandari, Amber Cai, Kota Yuzawa, Joy Zhang, Vinit Joshi, Fei Fang, Giuni Lee, Ryo Harada and Shawn Shin, hereby certify that all of the views expressed in this report accurately reflect our personal views about the subject company or companies and its or their securities. We also certify that no part of our compensation was, is or will be, directly or indirectly, related to the specific recommendations or views expressed in this report.

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