We raise our global average battery pack price forecasts over 2022E/23E/24E/25E by 18%/26%/15%/8% (rising from US$133/kWh in 2021 to US$164/kWh in 2023E before falling towards US$114/kWh in 2025), reflecting our Commodities team’s latest forecasts for battery metals. While the battery metals bull market appears to have peaked, our new metals forecasts are still higher than our prior assumptions in battery cost curve, leading to revision up in battery price forecasts. The shape of the battery cost path is largely unchanged – ie we continue to see a hiccup in battery cost deflation over 2022/23 but battery innovations and more efficient manufacturing should continue to drive a long-term price decline. Our Autos team also lowers its global car sales forecasts by 3-5% but keeps the EV penetration mix largely unchanged. Overall the greenflation challenge is looking more manageable to us with battery metals cost (especially Lithium) peaking out, battery makers (ex-China) appear to be passing through most of cost inflation to OEMs with our updated model suggesting ex-China battery supply demand could remain tight through 2025, and EV penetration rates are still rising despite higher battery prices given higher fuel savings from elevated oil prices. In this note we address six key debates which we view as top of mind for investors:

1. **How much of battery chemistry improvement is offset by greenflation?**

   With our new battery metal price forecasts still broadly higher than historical 5-year average levels, we calculate overall higher commodity prices offset ~40% of the cost deflation contributed by technology and chemistry improvement over 2020-25.

2. **How would higher battery prices impact EV penetration?**

   More fuel savings from higher oil prices implies cost parity of EVs to ICE in a broader part of the industry could still be achieved by 2025. Longer term, we believe sustainable EV supply growth would require a more diversified battery chemistry mix and recycling of metals from retired batteries.

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# Table of Contents

Thesis in 12 key charts ..... 4

#1: How much of battery chemistry improvement is offset by greenflation? ..... 8

#2: How would higher battery prices impact EV penetration? ..... 12

#3: How are new innovations progressing in solid state batteries? ..... 15

#4: How will supply chain complexity impact new startups, and will the battery industry remain consolidated? ..... 19

#5: Has bargaining power shifted from OEMs to battery makers? When would battery maker margins bottom out? ..... 21

#6: How do we see the competitive positioning and valuation risk-reward of battery companies? ..... 23

Disclosure Appendix ..... 26
3. How are new innovations progressing in solid state batteries? Our tracking suggests many companies are now working on solid state batteries, testing diversified technology routes. Still, multiple challenges exist (eg. scaling up cell layers) and mass production looks less likely before the late 2020s.

4. Will supply chain complexity impact new startups and will the battery industry remain consolidated? Battery supply chain complexity is becoming another barrier for new entrants (in addition to incumbent top players’ technology leadership) suggesting the battery industry will likely remain consolidated this decade.

5. Has bargaining power shifted from OEMs to battery makers? The balance of power appears to be shifting from OEMs to battery makers, especially in the ex-China market where battery supply demand is tight, the battery industry is more consolidated and increasingly most battery materials cost is becoming a pass-through in contracts with OEMs.

6. How do we see the competitive positioning and valuation risk-reward of battery companies? Both LGES and CATL are leading the technology debate, but we note LGES winning more customer mix in tighter battery supply demand regions while CATL remains the cost curve leader.
Thesis in 12 key charts

Exhibit 1: The cost of lithium and nickel account for 10-20% and c.10%, respectively, of global average battery pack prices (during 2022-25E)...

Exhibit 2: ...while the battery metals bull market has peaked, we believe contract lithium hydroxide prices will likely peak in 4Q22

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

Exhibit 3: We raise our battery pack price forecasts on our Commodities team's higher commodity prices outlook

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

Exhibit 4: Along the battery value chain, supply is running tight in anodes, select base metals, and nickel cathodes

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

1 June 2022
Exhibit 5: Battery technology development and recycling will flatten the 2025 cost curve between NCM vs LFP

- **Battery pack cost curve (FOB)**

- **GWh of battery demand**

- **NCM 811**
- **NCM 622**
- **NCM 523**
- **LFP**
- **NCA**

**2021**

**2025E**

**(with recycle)**

NCM refers to Nickel Cobalt and Manganese chemistry; LFP refers to Lithium Iron Phosphate chemistry.

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

Exhibit 6: Even if battery prices rise more than previous expectations, the oil strength will likely support EV sales

**EV premium payback period vs. ICE**

- **Lower Brent ($85)**
- **Higher Brent ($125)**
- **Spot Brent ($105)**

*Toyota Prius achieved a breakthrough in sales after shortening the payback period to 3 years

Source: Goldman Sachs Global Investment Research

Exhibit 7: We keep our EV penetration rates largely unchanged despite the cut to global automobile sales in 2022, 2023

**EV penetration rate scenarios**

- **Bear**
- **Base**
- **Hyper adoption**

**2020**

**2025E**

**2030E**

**2040E**

Source: Goldman Sachs Global Investment Research

Exhibit 8: Global battery supply/demand is expected to loosen going forward, while the ex-China market will likely remain tight...

**Battery supply demand (Global, ex-China)**

Source: Goldman Sachs Global Investment Research
Exhibit 9: ...with the top 6 players still dominating the cell manufacturing market through 2030

Source: Company data, Goldman Sachs Global Investment Research
Exhibit 11: Overall valuation within the EV battery valuechain has declined from higher interest rates and headwinds from higher metal prices...
2023E EV/EBITDA multiple of EV value chain

Exhibit 12: ...and the Korean battery valuechain is now trading at a premium to China
12MF EV/EBITDA by country within the EV battery valuechain

*SKI: Based on implied EV battery business only / estimates for Not Covered Ecopro BM & Posco Chem from Bloomberg, others from GSe

Source: Bloomberg, Goldman Sachs Global Investment Research

Source: Bloomberg
How much of battery chemistry improvement is offset by greenflation?

Higher commodity prices will offset ~40% of the cost deflation contributed by technology and chemistry improvement over 2020-25, on our estimates. While the battery metals bull market appears to have peaked, our new metal price forecasts are still higher than historical 5-year average levels (especially for Nickel). Further, spot and contract lithium prices have diverged meaningfully in recent months, especially for the lithium hydroxide market which is dominated by contract-pricing, and we expect contract prices to lag spot prices by 2-3 quarters. Overall we raise our 2022E-25E global average battery pack price forecasts by 8-26% and expect the battery price to peak in 2023.

The battery metals bull market appears to have peaked, but the level of metal prices also matters. Battery raw material prices have seen some correction but remain at high levels (Exhibit 14). Our global Commodities team recently introduced new lithium carbonate (spot) forecasts of 61/18.5 ($/kg) in 2022/23E. They reflect a strong lithium price in 2022, while we expect the lithium market to pivot towards a prolonged phase of surplus post a significant tightening trend last year. Lithium hydroxide (contract) prices, on the other hand, will likely show a less steep price increase in 2022 (US$35/kg) but a more sustained level in 2023 (US$32/kg) as well from the longer duration of the contract. For nickel, our Commodities team expects the extreme tightness in the battery grade nickel market to sustain this year, and upgraded its 12m price forecast to US$37,500/t (prior: US$25,000/t). While the team does not believe nickel can sustain prices at such high levels in the long run, the persistent tightness in the forward balances and a lack of class 1 supply in the pipeline lead the team to see prices at elevated levels through the next 2-3 years (2023E US$37,500/t vs. prior US$25,000/t).

Exhibit 13: Key metal and component price changes for global average battery pack prices

<table>
<thead>
<tr>
<th>Key metal and component price changes</th>
<th>2021</th>
<th>2022E</th>
<th>2023E</th>
<th>2024E</th>
<th>2025E</th>
<th>Old</th>
<th>New</th>
<th>Change vs. prior</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiOH (contract)</td>
<td>12.2</td>
<td>16.0</td>
<td>17.0</td>
<td>17.0</td>
<td>17.0</td>
<td>35.3</td>
<td>32.3</td>
<td>20.2</td>
</tr>
<tr>
<td>Li2CO3 (spot)</td>
<td>18.8</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>61.0</td>
<td>18.5</td>
<td>12.4</td>
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</tr>
<tr>
<td>Nickel</td>
<td>18,499</td>
<td>22,000</td>
<td>25,000</td>
<td>22,377</td>
<td>22,233</td>
<td>31,000</td>
<td>30,250</td>
<td>27,500</td>
</tr>
<tr>
<td>Cobalt</td>
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<td>54,950</td>
<td>37,987</td>
<td>33,290</td>
<td>42,549</td>
<td>78,500</td>
<td>59,500</td>
<td>48,000</td>
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<td>Manganese</td>
<td>650</td>
<td>676</td>
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<td>716</td>
<td>716</td>
<td>812</td>
<td>739</td>
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<td>Aluminium</td>
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<td>3,450</td>
<td>3,850</td>
<td>2,794</td>
<td>2,586</td>
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<td>3,850</td>
<td>2,829</td>
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<td>Copper</td>
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<td>11,875</td>
<td>12,000</td>
<td>9,397</td>
<td>9,172</td>
<td>11,875</td>
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<td>Iron phosphate</td>
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<td>7,594</td>
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<td>Silicon</td>
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<tr>
<td>Separator</td>
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<td>0.16</td>
<td>0.19</td>
<td>0.18</td>
<td>0.17</td>
</tr>
<tr>
<td>Electrolyte</td>
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<td>12,419</td>
<td>9,935</td>
<td>7,948</td>
<td>6,359</td>
<td>12,419</td>
<td>9,935</td>
<td>7,948</td>
</tr>
</tbody>
</table>

Source: Refinitiv, Wind, Wood Mackenzie, Goldman Sachs Global Investment Research

1 June 2022
Raising our global average battery pack price forecasts by 8-26% for 2022-25E. The cost of lithium and nickel account for c.10~20% and c.10% of global average battery pack prices, respectively. In this calculation, we consider the global weighted average of different types of batteries, inclusive of NCM, LFP, NCA, etc. Following our Commodities team’s forecast revisions, we raise our global average battery pack price outlook to US$160/164/kWh for 2022/23E and US$114/kWh by 2025E (prior: US$136/130/kWh for 2022/23E and US$105/kWh by 2025E). We assess that the rising commodity prices offset c.40% of the cost deflation contributed by technology and chemistry improvement over 2020-25.
Exhibit 18: The cost of lithium and nickel account for 10-20% and c.10%, respectively, of global average battery pack prices.

Exhibit 19: We revise up our global average battery pack price forecasts for 2022-25E...

Exhibit 20: ...on a higher commodities price outlook.

Exhibit 21: Rising commodities prices offset ~40% of the cost deflation contributed by technology and chemistry improvement over 2020-25.

Exhibit 22: Battery technology development and recycling will likely flatten the 2025 cost curve between NCM vs LFP.
Box: Spot and contract lithium prices — which prices matter more for battery makers?

Spot and contract lithium prices have diverged meaningfully in recent months (Exhibit 23), leading to investors questioning which prices matter more for battery makers and how the contract prices are usually calculated.

**Contract prices of lithium hydroxide are more relevant for high-nickel NCM cathodes** (NCM 712, NCM 811, NCM 9/0.5/0.5, Exhibit 24). As per Wood Mackenzie, the lithium hydroxide market is dominated by contract-pricing. This is presumably due to the stringent specification of EV battery grade lithium hydroxide that requires a time-consuming and costly qualification process, which makes it difficult for buyers to purchase from the spot market. For lithium hydroxide supply contracts, there is typically a volume component and a price component, where the pricing is usually based on a basket of spot prices and earlier-month contract prices with a 3-6 months’ lag. In regressions, we find that modeled series using spot prices with no lag and earlier-month contract prices with 2 or 4 months’ lag closely match the historical Korean lithium hydroxide import prices (Exhibit 23).

**Spot prices of lithium carbonate are more relevant for LFP and low-nickel NCM cathodes** (NCM 532). Though it is difficult to pinpoint the exact market share, spot-pricing accounts for a much larger share of the lithium carbonate market than the lithium hydroxide market. This could be because lithium carbonate is used in a wider range of batteries (e.g. portable devices in addition to EVs) and is consumed by a large China-centric market that makes a liquid spot market possible.

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**Supply tightness ahead in anodes.** Among battery components, we continue to see bottlenecks ahead in anode, where there is limited capacity in the pipeline, especially outside of China. We compare the battery demand outlook against the planned production capacity expansions across the various battery component markets, and find future supply of anodes to be relatively more constrained than other components. Based on new capacities announced so far, we assess that the effective utilization of anode capacity would increase from 87% in 2021 to 116% in 2025, indicating severe
supply shortages. 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.

Exhibit 25: Along the battery value chain, supply is running most tight in base metals and anodes...

Exhibit 26: ...from lack of anode capacity additions in the coming years (vs demand)

#2: How would higher battery prices impact EV penetration?

Global demand for autos today sits ahead of supply; EV sales growth still tracking double-digit. Light vehicle production dropped to 77.2mn units in 2021, 19% below 2017’s 95.1mn peak. While the 2021 level is already consistent with prior periods of market correction (-16%, 2007-09, Exhibit 27), our global Autos team sees further uncertainty around both auto production (slow progress resolving semiconductor shortages and delays with parts deliveries) and demand (macro environment in China, the US and India). Across regions, there is evidence in the form of record pricing and low inventories which supports that underlying demand could be higher than present production levels. EV sales continue to be the bright spot in broader car sales — while growth rates have slowed down from the 2021 levels, March sales were still up 29% yoy (Exhibit 28).

TCO (Total Cost of Ownership) analysis points to similar cost competitiveness of EV relative to ICE amid rising energy prices. 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. 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 YTD Brent oil price at US$105/bbl, we find the payback period to drop towards 3 years by 2025. As such, we keep our EV penetration forecasts largely unchanged, but nevertheless 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 as reiterated in our bear case scenario in Exhibit 31.
TCO analysis points to similar cost competitiveness of EV relative to ICE amid rising energy prices. As per our Europe Autos team, despite recent increases in electricity costs, similar increases in oil prices mean that costs for BEVs relative to ICEs have stayed broadly the same (Exhibit 30).

Exhibit 27: The decline in 2021 auto production is already consistent with prior periods of market correction, but uncertainty around both supply and demand leads us to be more cautious on the global autos outlook in 2022E

Exhibit 28: Global EV sales increased 29% yoy in March

Exhibit 29: Even if battery prices fall less than previous expectations, the oil strength will likely support EV sales

Exhibit 30: Despite recent increases in electricity costs, similar increases in oil prices mean that costs for BEVs relative to ICEs have stayed broadly the same

*Toyota Prius achieved a breakthrough in sales after shortening the payback period to 3 years

Source: IHS, Goldman Sachs Global Investment Research

Source: Wood Mackenzie

Source: Goldman Sachs Global Investment Research
Exhibit 31: We keep our EV penetration rates largely unchanged despite the cut to global automobile sales in 2022, 2023...

Exhibit 32: ...leading to a lower number of EV sales

Source: Goldman Sachs Global Investment Research
The greenflation increases the urgency for battery technology innovations which enables cost reductions. Among the new technology routes, solid state batteries caught widespread attention as a strong candidate for the next-generation battery. It is encouraging to us that more companies are working on solid state batteries, testing diversified technology routes. Still, further breakthroughs are needed for challenges such as improving the battery performance at room temperature, scaling up the cell layers to meet OEM requirements, and avoiding operational risks given the hazard which atmosphere air may cause to the Li metal and some solid electrolytes. The solid state battery makers that use Li metal as the anode generally target commercialization close to 2025 or in 2H20s.

The greenflation increases the urgency for battery technology innovations that enables cost reductions. Among the new technology routes, solid state batteries (i.e. batteries that replace the liquid electrolyte and the separator with a solid electrolyte) caught widespread attention as a strong candidate for the next-generation battery. As discussed in “Box: Where does solid state batteries sit in the battery innovation roadmap?”; solid state batteries unlock the potential of Li metal, the anode material of the highest energy density in nature (10 times of the capacity of graphite, Exhibit 33). The Li metal anode can potentially raise the battery energy density from c.200 Wh/kg (commercial batteries) to 400-500 Wh/kg with limited material changes required for the cathode, and towards >1000 Wh/kg with further cathode material changes (e.g. Li-O2 batteries, Exhibit 34).

How are the solid state battery innovations progressing? Many companies are working on solid state batteries, trying to achieve commercialization using different technologies (Exhibit 35-Exhibit 37). The solid state battery makers that use Li metal as the anode generally target commercialization close to 2025 or in 2H20s; others using alternative anodes (e.g. WeLion) are commercializing the products earlier but achieving lower energy density than the Li metal anode batteries (but still c.20% higher than top conventional LIBs). Since most of the benefits and future potential stem from the
battery’s ability to use Li metal as the anode, we categorize the solid state batteries by using or not using Li metal as the anode (as opposed to “solid”/“semi-solid”), and see the eventual adoption of Li metal anode in commercial production as a major milestone.

What are the future breakthroughs needed for solid state batteries? Among the multiple challenges to using Li metal as the anode with a solid electrolyte, we note companies have generally made progress in using solid electrolytes to suppress the Li dendrite issue of the Li metal anode (Exhibit 38). That said, remaining challenges include: 1) some solid state batteries require specific operating temperature and pressure (e.g. the Samsung battery requires 45-60 °C for designed discharge capacity1); 2) the solid state cells have to scale up from 1-4 layers to “dozens of layers” as required by the OEMs; 3) operational risks due to Li metal and solid electrolytes’ sensitivity to the atmosphere air. Given the remaining challenges in designing and/or manufacturing solid state batteries, we see the possibility for a scenario where solid state could exist

1 Lee, et al. (2020) High-energy long-cycling all-solid-state lithium metal batteries enabled by silver–carbon composite anodes
but be costly in the early years and used mostly in premium cars.

### Exhibit 38: Multiple challenges exist to using Li metal as the anode with a solid electrolyte

“?” indicates areas that remain to be addressed by the solid state battery makers

<table>
<thead>
<tr>
<th>Challenge details</th>
<th>Company efforts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unstable form/structure of the anode:</strong> During charging, uneven Li deposition on the surface of the anode tends to form dendritic crystals and dead Li. Unlike in liquid electrolyte batteries, where Li dendrite could puncture the separator and lead to short-circuit of the battery, the mechanical strength of the solid electrolyte may stop the penetration of the Li dendrite (chart c).</td>
<td><strong>QuantumScape:</strong> ceramic electrolyte with high dendrite resistance</td>
</tr>
<tr>
<td><strong>Volume change of the anode:</strong> Ideally all the Li metal will be ionized and transported into the cathode after completing the discharge, causing anode volume changes. Together with Li dendrite, it leads to interface fluctuation of Li metal and the electrolyte, which impedes the Li⁺ ion flow at the interface and limits energy density (chart b &amp; c).</td>
<td><strong>Nissan:</strong> protective films for the Li metal anode</td>
</tr>
<tr>
<td><strong>Li metal sensitivity:</strong> Li metal reacts with moisture and oxygen in the air which may cause fire/explosion.</td>
<td><strong>SES:</strong> utilized composite anode coating as a mechanical barrier</td>
</tr>
<tr>
<td><strong>Side chemical reactions:</strong> chemical reactions at the interface of the electrode and the solid electrolyte causes active material losses.</td>
<td><strong>Samsung:</strong> a thin Ag–C layer can effectively regulate Li deposition, avoiding dendrites and dead Li</td>
</tr>
<tr>
<td><strong>Solid electrolyte sensitivity:</strong> H₂O, O₂ and CO₂ attacks cause degradation in the solid electrolyte.</td>
<td><strong>Samsung:</strong> the soft and elastic mechanical properties of the argyrodite electrolyte facilitates an intimate contact between the electrolyte and the electrodes.</td>
</tr>
<tr>
<td><strong>Operating environment:</strong> May require specific operating temperature or pressure.</td>
<td><strong>QuantumScape:</strong> the soft and elastic mechanical properties of the argyrodite electrolyte facilitates an intimate contact between the electrolyte and the electrodes.</td>
</tr>
<tr>
<td><strong>Scaling up:</strong> From 1-4 layers to dozens of layers as required by the OEMs.</td>
<td><strong>QuantumScape:</strong> the solid ceramic electrolyte is stable to Li metal</td>
</tr>
</tbody>
</table>

---

**Box: Where do solid state batteries sit in the battery innovation roadmap?**

**A solid electrolyte enables the anode material change from graphite to Li metal.** Future high energy-density batteries generally focus on three technological routes (Exhibit 39): 1) early 2020-30: advanced anode batteries (replacing the graphite anode in commercial batteries with Li metal anode or silicon anode to pair with commercial cathodes), 2) late 2020-30: Li-S batteries (further replace the commercial cathodes with sulfur to pair with the Li metal anode) and 3) after 2030: Li-O₂ batteries (pairing oxygen in the atmosphere air as cathode with the Li metal anode). To enable the anode material change from graphite to Li metal used in all these three routes, a solid electrolyte is usually required (not necessarily for silicon anodes²). This is because the Li metal anode tends to generate Li dendrite on the surface of the anode that could penetrate through the liquid electrolyte and the polymer separator, causing short circuit of the battery, whereas the mechanical strength of a solid electrolyte can suppress the dendrite issue (Exhibit 40).

---

² Zhang, et al. (2021) Challenges and Recent Progress on Silicon-Based Anode Materials for Next-Generation
Li metal offers the highest energy density among the possible anodes. Beyond the above-mentioned three technological routes, there are plenty of other possible combinations of cathode and anode materials — the general direction being moving from intercalation materials (e.g. NCM/LFP for cathode; graphite for anode) to conversion/alloy materials (e.g. S for cathode; Si/Li for anode). Among the possible conversion/alloy anode materials, Li metal provides the highest theoretical discharge/charge capacity (Exhibit 41). Conversion/alloy materials (per unit) typically can store a larger amount of lithium than intercalation materials, leading to higher energy capacities. However, such lithium storage requires altering or breaking host material atomic bonds, which could result in large volume changes (e.g. for Si anodes), or a large amount of lithium being deposited on the surface of the host material (Li metal anode’s dendrite issue, Exhibit 42).
#4: How will supply chain complexity impact new startups, and will the battery industry remain consolidated?

Although a number of new startups 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 including incumbent top players’ technology leadership, economies of scale, and their extensive vertical integration, which ensures full control of the supply chain — a competitive strength that becomes more prominent in the face of the raw material supply bottlenecks.

The 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. 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.

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 to top players maintaining leadership over 2022-30. In our view, multiple barriers exist for new entrants, including incumbent top players’ technology leadership, economies of scale, and their extensive vertical integration, which 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 establish long-term raw material access more easily than start-ups can, leveraging their scale and existing relationships 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 43: We estimate global battery players’ announced capacity plans could reach c. 7.4TWh by 2030E...

Global battery players’ announced capacity outlook

Exhibit 44: ...with yield adjusted capacity at 4.6TWh

Global battery players’ yield adjusted capacity outlook

Exhibit 45: Yield adjusted battery capacity on a global level shows loosening battery supply-demand over the coming years

Global key battery players’ yield adjusted capacity outlook vs base demand outlook

Exhibit 46: ...while we expect ex-China supply to remain tight

Key battery players’ yield adjusted capacity (ex-China) outlook vs base demand outlook (ex-China)
#5: Has bargaining power shifted from OEMs to battery makers? When would battery maker margins bottom out?

**Power balance between battery makers and automakers**
Market concentration is higher among battery makers than it is among finished vehicle makers. As of 2021, the top 6 global finished vehicle assemblers accounted for just 56% of total sales, whereas the top 6 battery makers accounted for 84% of sales. This naturally gives the battery makers an advantage when it comes to negotiating prices. Battery makers are adopting price adjustment systems for nickel, cobalt, and lithium to mitigate the impact of greenflation, and some battery makers are expanding their price adjustment system to other materials (copper, mangan, aluminum, etc) as well.

**Korea Battery makers’ price pass-through mechanism**
Korea EV battery makers have made robust contracts for both the raw materials sourcing through strategic partnerships and also long term materials contracts with OEMs. This was witnessed in 1Q22 results with in line to above expectations margins for LGES and Samsung SDI. All three major Korea EV battery players (LGES, SDI, SKI) have already made cathode metals (Nickel, Cobalt and Lithium) as a pass-through to OEMs in the contracts signed over the last few years. LGES management highlighted an expanded pass-through scheme of non-cathode materials (Copper, Aluminum, Mangan) partially to the OEMs. That said into 2Q22 results investors should monitor the time lag of ASP increases and lack of potential offsets from low-cost inventory. Nevertheless, with cathode metals pass-through structures and with the battery metals bull market peaking out, we expect OP margins for battery makers to bottom out into 2Q22.

**China battery makers’ industry structure**
The Chinese EV industry differs from the rest of the world in that the country has incubated a full supply chain of battery materials, with CATL leading the market share but also competing with other domestic local battery makers with large (>20GWh) capacities. In addition, the country’s EV industry is led by BYD which has a 30% vehicle market share and relies exclusively on in-house batteries. Therefore, depending on if a carmaker is volume focused (e.g. SAIC) or cost focused (e.g. Tesla), the tolerance of higher battery prices varies by company. This is in contrast to the EV market outside China where battery-making is more consolidated than carmaking, where a robust pass-through of input costs to automakers is standard practice for major EV battery players. Specifically, the Chinese industry is characterized by:

- **Fragmentation of supply in battery making:** CATL’s market share of domestic EV power battery installation has fallen from 57% in Dec 2021 to 37% in Apr 2022. On an ex-Tesla (bumpy monthly volume due to export demand) and ex-BYD basis, CATL’s market share has fallen from 64% in Dec 2021 to 52% in Apr 2022. Meanwhile, BYD and other smaller battery makers have gained share: BYD’s share went from 15% in Dec 2021 to 29% in Apr 2022, CALB from 5% to 8%, Guoxuan High Tech
from 4% to 6% (source: GGII). In addition, top EV makers are diversifying battery sourcing in order to manage supply chain cost and risk: Xiaopeng, for example, from which CATL has supplied 79% of its batteries in Dec 2021, has diversified the battery supply with the latest split of 52% / 42% / 5% from CATL / CALB / Eve Energy, respectively in Apr (source: GGII).

- **Acceleration of demand in NEV assembly:** The new energy vehicle market in China has tripled in volume from 1mn in 2020 to 3mn in 2021, and we model another +74% yoy growth in 2022E to 5.2mn units. In this rapidly evolving market, carmakers are mostly market share focused and therefore have high tolerance of battery prices. But since the demand is booming and access to battery is strategic to production planning, EV makers are exploring second or third suppliers of power batteries.

- **BYD drives new technologies, such as cell to pack and cell to body, on the back of its integrated battery making + car making:** This is difficult for other EV makers to replicate given they procure battery packs externally and integrate to their chassis – they cannot coordinate the design between battery architecture and car body.

- **Uncertainties of lockdown-related supply and macro-led demand:** The Covid Zero policy has led to the lockdowns of top car manufacturing sites in Shanghai and Changchun.

---

**Exhibit 47: The EV battery industry is more consolidated vs the OEM industry**

Industry concentration (OEM vs battery) in 2021

<table>
<thead>
<tr>
<th></th>
<th>OEM Top 3</th>
<th>Battery Top 3</th>
<th>OEM Top 6</th>
<th>Battery Top 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry concentration (OEM vs Battery)</td>
<td>45.2%</td>
<td>65.1%</td>
<td>55.6%</td>
<td>84.0%</td>
</tr>
</tbody>
</table>

Source: Goldman Sachs Global Investment Research, SNE Research

**Exhibit 48: Korean EV battery makers are actively working on expanding pass-through contracts...**

Price change of raw materials & pass-through of raw materials to OEMs

1Q22 vs 1Q21 price change (YoY)

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Existing raw material pass through</th>
<th>New pass through of raw material / under discussion with OEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiOH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Li2CO3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cobalt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nickel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mangan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: WIND, LME, Company data, Goldman Sachs Global Investment Research
#6: How do we see the competitive positioning and valuation risk-reward of battery companies?

**Strong competitive positioning for LGES and CATL, but valuation risk-reward is not compelling:** LGES is a leader in the European market and is expanding to the US, while CATL is the largest battery manufacturer in China (by mkt share), with plans to export and expand overseas. Both companies have a strong technological edge, with vertical integration through investment and in-house production. CATL leads in terms of cost structure with a concentrated battery supply in China reducing operating and working capital costs. However, we expect the gap in margins and working capital to trend down as LGES (along with LGC) further integrates vertically while CATL expands internationally. LGES leads in terms of diversification towards global top-tier OEMs and higher exposure in the ex-China market where supply-demand is likely to be tighter.
**Exhibit 56: LGES is a leading player in NCM pouch battery while CATL leads in NCM & LFP prismatic battery...**

<table>
<thead>
<tr>
<th>Battery form factor</th>
<th>LGES</th>
<th>CATL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pouch / Cylindrical</td>
<td>NCM/NCMA</td>
<td>Mostly Prismatic (c.1% sales from Pouch)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Battery chemistry (Current)</th>
<th>LGES</th>
<th>CATL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium sulfur (from 2025): High energy density (1.5x vs existing LiIB)</td>
<td></td>
<td>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</td>
</tr>
<tr>
<td>battery with lower cost, tested in unmanned plane</td>
<td></td>
<td>Cell to Chassis: Integrates the battery cell with the vehicle body, chassis, electric drive, thermal management extending driving range to over 1,000km</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Battery chemistry (Developing)</th>
<th>LGES</th>
<th>CATL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid state (Polymer based / Sulphide based: from 2026/2030): High energy density (600Wh/l, 900Wh/l) with high charging speed using solid state electrolyte</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LFP battery: Developing for ESS, R&amp;D for low range EV</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Company data, Goldman Sachs Global Investment Research

**Exhibit 57: ...with both having a diversified supplier base (as of 2021)...**

<table>
<thead>
<tr>
<th>LGES</th>
<th>CATL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Battery materials supplier</strong></td>
<td>Cathode: LG Chem, Poscochem, L&amp;F, Nichia, Umicore</td>
</tr>
<tr>
<td>Anode: Poscochem, BTR, Hitachi, Zichen, Shanshan, Mitsubishi</td>
<td>Anode: BTR, Zichen, Shanshan, Kajjin, XHF, Shinzuom</td>
</tr>
<tr>
<td>Separator: LG Chem JV with Toray, SKIET, Toray, Asahi, Semcorp</td>
<td>Separator: Semcorp, Senior, Sinoma, Mingphu, Toray, SKIET</td>
</tr>
<tr>
<td>Electrolyte: GTHR, Capchem, Tinci, Enchem, Ube, Central Glass</td>
<td>Electrolyte: GTHR, Capchem, Tinci, Kaixin, Shanshan</td>
</tr>
</tbody>
</table>

Source: Company data, SNE Research, compiled by Goldman Sachs Global Investment Research

**Exhibit 58: ...as well as strong vertical integration through in-house manufacturing, JV, investment, etc**

<table>
<thead>
<tr>
<th>LGES</th>
<th>CATL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MOU with the Indonesian government:</strong> LGES to build battery plants in Indonesia, while getting supplies of nickel from 2023 for 10 yrs</td>
<td>Neo Lithium: Through a $6.7mn investment, CATL acquired 8% stake in Neo Lithium (incl. 9% stake acquired in 2021)</td>
</tr>
<tr>
<td>QPM: Through an investment of W12bn, LGES acquired a 7.5% stake in QPM, from which it will get supply of 7k tons of nickel, 0.7k tons of cobalt from 2023 for 6 yrs</td>
<td>North American Lithium: CATL acquired a 43.59% stake in March 2018</td>
</tr>
<tr>
<td>Greatpower Nickel &amp; Cobalt: Through an investment of W35bn, LGES acquired 4.8% stake, from which it will get supply of 20k tons of nickel from 2023 for 6 yrs</td>
<td>Tianyi Lithium: CATL owned 25% of Tianyi Lithium 9 lithium salt producer in China, and invested Rmb 700mn in setting up a JV, of which LGES owns 8.6% stake</td>
</tr>
<tr>
<td>Cobalt Blue: LX International (LG’s group company) owns 6% of Cobalt Blue (company supplies cobalt to LGES)</td>
<td>Zhicun Lithium: In Sep 2021, CATL participated in Zhicun’s (lithium carbonate producer) equity placement and holds a 8.16% stake</td>
</tr>
<tr>
<td>LGC (parent company of LGES) currently provides 25% of LGES required cathode</td>
<td>Pilbara Minerals: CATL bought 8.5% of Australian company Pilbara Minerals, as part of a $561.8mn capital raising</td>
</tr>
<tr>
<td><strong>IV / MOU / Equity stakes</strong></td>
<td>North American Nickel: CATL acquired a 25.4% stake in North American Nickel, which holds 46% of Pilbara Minerals</td>
</tr>
<tr>
<td>Cathode: LGC (parent company of LGES) currently provides 25% of LGES required cathode, and aims to increase this portion to 30-40%</td>
<td>CATL holds 25% of Yongtai. The entity now has capacity of 6k tons of LiPF6 and 400 tons of LiFSi</td>
</tr>
<tr>
<td><strong>In house</strong></td>
<td>Li-ion battery and recycling: CATL's battery recycling plant in Nanjing produces 2k tons of cathode material and 5k tons of anode material per month</td>
</tr>
<tr>
<td><strong>Long term contract</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Recycling</strong></td>
<td></td>
</tr>
</tbody>
</table>

Source: Company data, data compiled by Goldman Sachs Global Investment Research
Exhibit 59: LGES has a more diversified mix of clients, while CATL is more focused on China

LGES vs CATL client mix

Key clients mix (LGES 2025, CATL 2021, China only client mix)

Key EV models

<table>
<thead>
<tr>
<th>Key EV models</th>
<th>Tesla Model 3, Y (China), VW ID.3, 4, GM Hummer, Renault Zoe</th>
<th>Tesla Model 3, Y (China); Nio ES6,8,EC6; Li Auto Li One; Xiaopeng P7,5,G3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geographical mix by capacity location</td>
<td>Europe: 54% (2020), 23% (2025E)</td>
<td>China: 100% (2020), 96% (2025E)</td>
</tr>
<tr>
<td></td>
<td>US: 4% (2020), 47% (2025E)</td>
<td>Europe: 0% (2020), 4% (2025E)</td>
</tr>
<tr>
<td></td>
<td>China: 33% (2020), 24% (2025E)</td>
<td>[Export from China: 32% (2020), 32% (2025E)]</td>
</tr>
<tr>
<td></td>
<td>Others: 8% (2020), 8% (2025E)</td>
<td></td>
</tr>
</tbody>
</table>

Source: Company data, Goldman Sachs Global Investment Research
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<table>
<thead>
<tr>
<th>Rating Distribution</th>
<th>Investment Banking Relationships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buy</td>
<td>Hold</td>
</tr>
<tr>
<td>50%</td>
<td>35%</td>
</tr>
</tbody>
</table>

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