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Global Automobiles

Electric Vehicles: What's Next VII: Confronting Greenflation

Battery costs now account for around 30% of total EV cost, and a reduction in these costs will be essential if EV businesses are to become viable. Currently, however, prices for battery materials are rising as a result of so-called greenflation. In this report, the seventh installment of our *Electric Vehicles: What's Next* series, we outline our new forecast for a slower pace of decline for automotive battery prices through 2025, and we consider the outlook for the EV and automotive battery markets under three scenarios (bear, base, and hyper-adoption). With costs rising for the first time since the EV shift started accelerating, we see a greater need for vehicle assemblers to step up technological innovation, which may mean increased adoption of LFP batteries, the use of larger cells, and the development of all-solid-state batteries. We also focus on EV pricing strategies that make use of improving total cost of ownership (TCO) for EVs against a backdrop of rising crude oil prices. We highlight Tesla, VW, BYD, and Toyota, in view of their vertically integrated business models and unique technology strategies.

Raise battery price outlook on greenflation

Electric vehicle (EV) sales are rising sharply amid an accelerating carbon-neutral policy drive. Global EV sales in 2021 were 4.4 mn vehicles, up 127% yoy, and we forecast sales will grow 56% yoy in 2022 to 6.9 mn vehicles. Automotive battery demand has also risen sharply, and as a result prices for battery-related inputs and components have increased, with so-called greenflation spreading to automotive batteries. In this context, we raise our forecast for battery cost per kWh (weighted-average price factoring in the cathode composition). Specifically, we revise our 2025 battery cost forecast to US$105, from US$100 previously. We also lower our annualized cost forecast for 2021-2025 to 5%, from 6% previously. While we think some of the increase in input costs can be offset by shifting to relatively low cost lithium iron phosphate (LFP) batteries, an increase in overall cost is unavoidable, in our view.

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EV profitability a short-term downside risk

The cost of the battery accounts for an extremely large 30% portion of the price of a mass-market electric vehicle. We estimate that reductions in battery costs will bring this proportion down to a steady 15-20% during 2030-2040. This is on par with the current 18% cost proportion accounted for by the powertrain (engine + transmission) in a gasoline-powered vehicle. Recent increases in the price of batteries will naturally put pressure on the profitability of EVs by 100-200bp. However, if the price of EVs could be increased from a TCO standpoint, deterioration in profitability could be kept to a minimum. We believe an overly pessimistic medium-term view on EVs is unwarranted.

Focusing on the power balance between battery makers and automakers

Market concentration is higher among battery makers than it is among finished vehicle makers. As of 2020, the top five global finished vehicle assemblers accounted for just 41% of total sales, whereas the top five battery makers accounted for 83% 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, but they are not using the system for electrolytes, anode materials, copper, and aluminum. We think it stands to reason that vehicle assemblers will try to redress the power balance with battery manufacturers by seeking to put in place vertically integrated business models.

Medium-term EV demand outlook unchanged

The medium-term EV sales outlook is unlikely to change much given the global carbon-neutral drive. While we assume some changes in EV prices and demand in the near term due to higher battery prices, we maintain our view that the global EV sales weighting will rise from 3% in 2020 to 15% in 2025 and then 32% in 2030. We forecast a further rise to 58% in 2040. Given a useful life of 10 years for the average vehicle, this suggests developed nations aiming for net-zero by 2050 would need to achieve relatively high EV sales as of 2040 (because the EV ratio of owned vehicles is more important for carbon neutrality). We continue to forecast EV sales weightings in 2040 of 80% in the US, 80% in Japan, and 100% in Europe.

EVs and Battery Greenflation

Global EV sales **+56% yoy** to **6.9 mn** vehicles in 2022E.

Expect global EV sales weightings **15%** in 2025E, **32%** in 2030E, and **58%** in 2040E.

2040E sales weightings: US **(80%),** Japan **(80%),** China **(68%),** Europe **(100%)**.

Greenflation in Batteries

Battery costs account for **~30%** of total EV cost, expected to go down to a steady **15-20%** by 2030-2040.

We revise 2025E battery cost forecasts to **$105/kWh** (from $100/kWh), likely a **100-200bp** negative impact for EV margins.

Impact of Greenflation on EV sales ratio

2025:

11% (bear case); 15% (base case); 19% (hyper-adoption)

2030:

21% (bear case); 32% (base case); 39% (hyper-adoption)

Focus on rising gasoline prices and technological innovation

Payback period could shorten to three years in 2023 if crude oil prices increases to **$120/bbl**, accelerating the shift to EV.

Increased adoption of LFP batteries, the use of larger cells, and the development of all-solid-state batteries needed to counter greenflation.

Vertically integrated Business models to benefit

Top 5 global finished vehicle assemblers accounted for **41%** of total sales vs. **83%** for top 5 battery makers (2020).

Tesla, BYD, VW, Toyota committed to vertically integrated structures that include battery cell production.

Raise battery price outlook; EV margins could fall temporarily

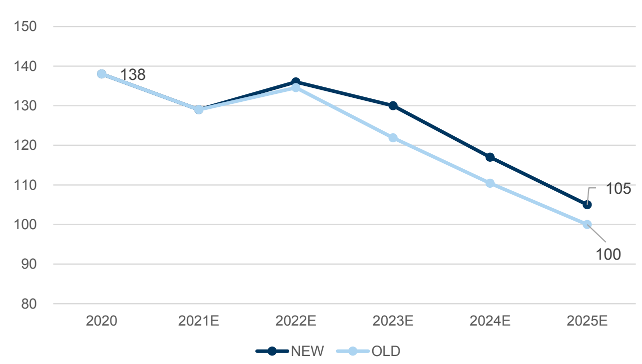
Raise battery price outlook on greenflation

Electric vehicle (EV) sales are rising sharply amid an accelerating carbon-neutral policy drive. Global EV sales in 2021 were 4.4 mn vehicles, up 127% yoy, and we forecast sales will grow 56% yoy in 2022 to 6.9 mn vehicles. Automotive battery demand has also risen sharply, and as a result prices for battery-related inputs and components have increased, with so-called greenflation spreading to automotive batteries. In this context, we raise our forecast for battery cost per kWh (weighted-average price factoring in the cathode composition). Specifically, we revise our 2025 battery cost forecast to US$105, from US$100 previously. We also lower our annualized cost decline forecast for 2021-2025 to 5%, from 6% previously. While we think some of the increase in input costs can be offset by shifting to relatively low cost lithium iron phosphate (LFP) batteries, an increase in overall cost is unavoidable, in our view.

Multiple conceivable scenarios for battery prices

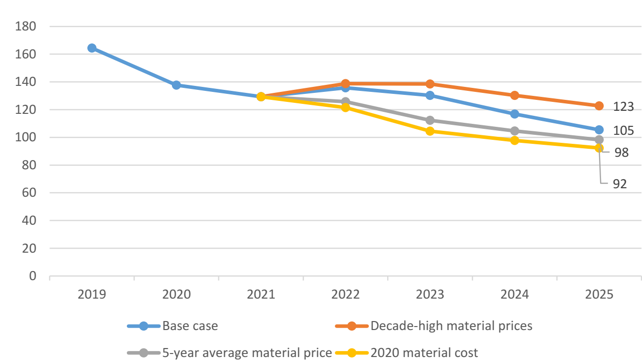
We estimate battery cost according to input prices. Our baseline scenario calls for US$105/kWh in 2025. However, our risk scenario using past highs for input prices (over the last decade) is for US$123/kWh and thus a limited decline from battery costs in 2021 (US$129/kWh). On the other hand, scenarios based on past five-year average input prices and input prices as of 2020 show battery cost falling to US$98 and US$92, respectively. In these cases, benefits yielded by improving the energy mix for cathode materials would contribute fully. We think battery cost would need to decline to US$100/kWh for general EVs to break even.

Exhibit 1: The pace of decline in battery prices has slowed
Forecast for weighted-average battery prices



Source: SNE, Goldman Sachs Global Investment Research

Exhibit 2: Input costs are a major swing factor
Battery price scenario analysis

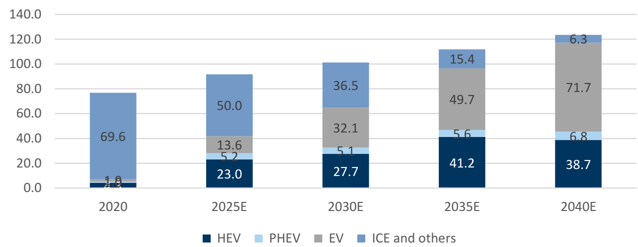


Source: SNE, Bloomberg, Goldman Sachs Global Investment Research

Medium-term EV demand outlook unchanged

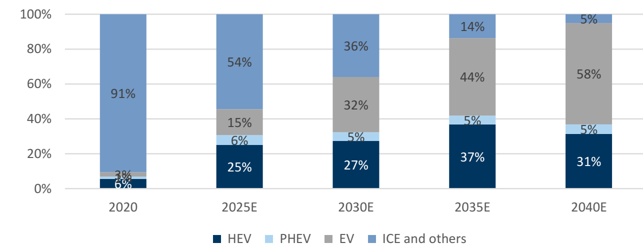
The medium-term EV sales outlook is unlikely to change much, given the global carbon-neutral drive. While we assume some changes in EV prices and demand in the near term due to higher battery prices, we maintain our view that the global EV sales weighting will rise from 3% in 2020 to 15% in 2025 and then 32% in 2030. We forecast a further rise to 58% in 2040. Given a useful life of 10 year for the average vehicle, this suggests developed nations aiming for net-zero by 2050 would need to achieve relatively high EV sales as of 2040 (because the EV ratio of owned vehicles is more important for carbon neutrality). We continue to forecast EV sales weightings in 2040 of 80% in the US, 80% in Japan, and 100% in Europe.

Exhibit 3: EV sales are growing structurally
The number of vehicles sold globally (unit: mn)



Source: IHS Global Insight, Goldman Sachs Global Investment Research

Exhibit 4: We think the EV sales weighting could rise to 58% in 2040
Global EV sales ratio



Source: IHS Global Insight, Goldman Sachs Global Investment Research

Bear case should also be kept in mind

We see a need to consider the downside risks to EV sales if greenflation were to have a strong impact on battery prices (bear scenario). We also outline an upside risk scenario in which EV sales accelerate (hyper-adoption scenario).

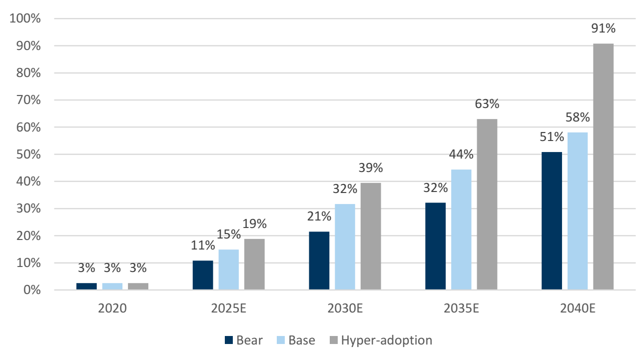
Bear scenario: In this scenario, we assume an EV sales ratio of 11% in 2025, well below our base scenario assumption of 15%, and a ratio of 21% in 2030 vs. our base case assumption of 32%. In our bear scenario, we assume that automakers will focus only on complying with CO2 regulations in each country, and that consumers do not actively shift to EVs. Although governments have not announced clear CO2 reduction targets through 2040, we assume that they will require an annual reduction of around 5% to reach net-zero by 2050. Our bear scenario EV sales ratio for 2040 is 51% overall, with ratios of 49% in the US, 52% in Japan, and 71% in Europe. We regard these assumptions for EV sales as highly conservative, as they suggest that these countries will not be able to meet their targets for carbon neutrality via their automobile sectors.

Hyper-adoption scenario: In this scenario, we assume that the 2025 EV sales ratio will be 19%, well above our base case assumption of 15%. For 2030, we assume an EV sales ratio of 39% vs. our base assumption of 32%. Our hyper-adoption scenario is predicated on consumers showing a strong preference for EVs, rather than just a regulatory-driven increase in EV sales. As a result, this scenario would see CO2 reduction targets significantly exceeded in each region in 2025-2030. Our hyper-adoption EV sales ratio assumption for 2040 is 91% overall, with ratios of 90% in the US, 96% in Japan and 100% in Europe. This implies a very strong possibility that carbon neutral targets will be met.

CO2 reduction outlook differs significantly depending on the scenario

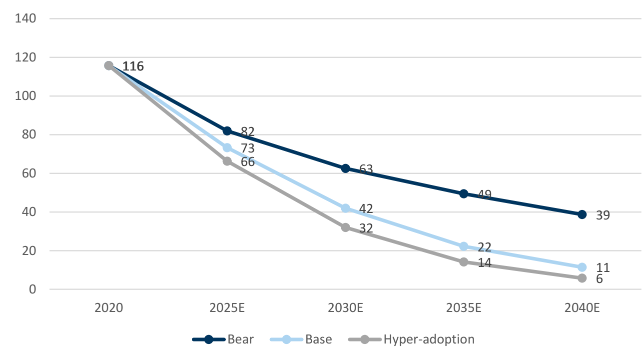
In our base scenario, we estimate that CO2/km in the major markets of Japan, the US, Europe, and China (simple average) would decline from 116 g/km in 2020 to 11 g/km in 2040, representing an average annual decline of 11%. With an average annual decline of just 1-3% possible in conventional gasoline engine vehicles (through increased engine thermal efficiency, multi-stage transmissions, etc.), it goes without saying that double-digit (%) reductions in CO2 emissions from automobiles will not be possible without electrification. In our bear scenario, CO2/km would decline by 5% per year, while in our hyper-adoption scenario it declines by 14%.

Exhibit 5: Our bear scenario assumes the minimum level of EV sales to meet environmental regulations
Assumed EV sales ratios for each of our scenarios



Source: IHS Global Insight, Goldman Sachs Global Investment Research

Exhibit 6: CO2 reduction outlook differs significantly depending on the scenario
CO2 per km outlook (g/km)

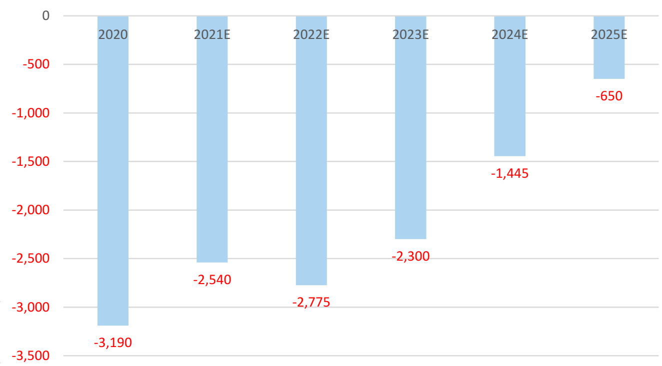


Source: Company data, Goldman Sachs Global Investment Research

Varied stance on EV purchase subsidies

For EVs, with their relatively low levels of profitability, subsidies offered by national governments make a difference to sales. As EV sales expand, total subsidies inevitably increase, which has led to the announcement of cuts to subsidies in some regions. Examples include the UK, which announced a subsidy cut from GBP2,500 to GBP1,500 per vehicle starting in December 2021. China also decided to withdraw current government EV purchase subsidies altogether at the end of December 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 $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 $25,000-$30,000) and believe some degree of support will be required until 2025. In our baseline scenario, we assume an average annual cut in subsidies of around 20%, and we need to watch for announcements that would take the level of subsidies above or below this level.

Exhibit 7: Some degree of government support needed through 2025
Government support/vehicle (USD) required to achieve EV profitability



Source: IHS Global Insight, Goldman Sachs Global Investment Research

Exhibit 8: Subsidies are being cut in some markets
EV support schemes in major regions

	Subsidy
China	Until the end of 2022: Rmb9k ($1,400) subsidy for EV with driving mileage in 300-400km, Rmb13k ($2,000) subsidy for EV with driving mileage >400km, Rmb5k ($800) subsidy for PHEV. Only applicable to NEV with MSRP lower than Rmb300k or NEV that use battery swapping technology.
USA	Tax credit: Currently offered to consumers of up to $7,500 per EV (This scheme begins to phase out once an OEM has sold 200k EV in the US). The Build Back Better Framework (not legislated yet) initially included lifting the 200k unit OEM cap, and instituting a base $7,500 credit per new BEV (assuming a battery pack of 40 kWh or higher) with an additional $4,500 credit for vehicles with final assembly in a US union facility, and an additional $500 for EVs with battery cells manufactured in the US ($12,500 total credit at the high end). It also suggests EVs would have to be assembled in the US to qualify for any credit from 2027.
Japan	$5,000 for mini cars, $8,000 for normal cars. Total budget limitation of $350mn and the subsidies amount to 50k EVs annually (1% of new auto sales in Japan). This policy only applies to 2022 EV sales.
Korea	$7,000 for cars under $55k, $3,500 for cars between $55k-85k. Subsidy for total of 164.5k cars annually (up from 75k units in 2021). Above are subsidies by the national government; there is scope for other subsidies by the local governments.
India	2019-24: Federal subsidy up to US$3,800 on mass market EV like the Tata Nexon priced at US$19,000 (approx. 20% of car price). Total budget limitation of USD 1.35 billion. Electric cars must cost less than US$20,000 at ex-factory level to be eligible for subsidies.
Germany	2019: EUR4k for BEV, FCV; EUR3k for PHEV and EREV. 2020-2025: if MSRP is less than EUR40k, EUR9k for BEV, EUR6.75k for PEHV; if MSRP is EUR 40-65k, EUR8k for BEV and EUR5.625k for PHEV.
UK	35% of MSRP (no more than GBP2.5k) for cars with zero tailpipe CO2 emission and minimum no-emission travel range of 112km (70 miles). Cars must have an RRP <GBP35k to be eligible. It was announced that the subsidy would be reduced to GBP1.5k to the maximum and cars must have an RRP <GBP32k to be eligible from Dec 2021.
France	Max subsidy of EUR6k for vehicles emitting =<20gCO2/km & price EUR45k or less. Max subsidy of EUR3k for vehicles costing EUR45-60k. Max subsidy of EUR2k for vehicles emitting >21 and =<50gCO2/km & price EUR50k or less. If ICE car scrapped in parallel with purchase of vehicle emitting =<50gCO2/km & price =<EUR60k, max subsidy of EUR5k, based on income.
Spain	MOVES III incentive scheme; 2021-23: Up to EUR7k for BEV and EUR5k for PHEV if an ICE car is scrapped in parallel; up to EUR4.5k for BEV and EUR2.5k if no ICE car is scrapped. Max vehicle price EUR45k. Electric range must be at least 90km for max subsidy.
Italy	Ecobonus: max EUR6k for cars emitting =<20g/km and price <50k. Up to EUR2.5k for PEHV with CO2 emissions between 21 and 60 g/km if an ICE car is scrapped in parallel; EUR1.5-4k if no ICE car is scrapped.

Source: Various materials, Goldman Sachs Global Investment Research

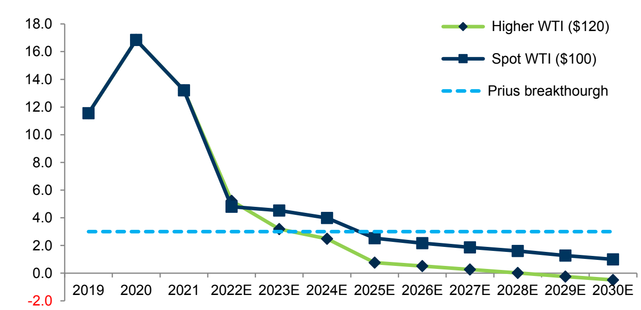
Rising gasoline prices could boost relative value of EVs

Despite the negative effects of increased battery prices and lower subsidies on EV sales, greenflation is also likely to have a positive impact as higher gasoline prices, resulting from higher crude oil prices, make EVs relatively more competitive. According to a total cost of ownership (TCO) analysis, with fuel costs as the variable, the annual fuel cost reduction from switching to an EV from a gasoline vehicle at a crude oil price of $100/bbl comes to roughly $850. Looking back to the period when the Toyota Prius saw a surge in penetration, this occurred when the price premium on hybrid cars was the equivalent of three years' worth of fuel cost reductions (i.e., three-year payback period). Assuming declining costs of EVs/batteries and crude oil prices remaining at current levels, we calculate that the payback period is likely to shorten to within three years by 2025. If the crude oil price increases further to $120/bbl, for example, we calculate that the payback period will reach three years in 2023, potentially accelerating the shift to EV two years earlier than expected.

EV profitability a short-term downside risk

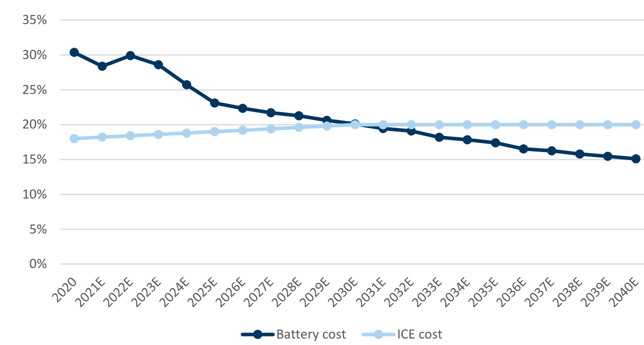
The cost of the battery currently accounts for an extremely large 30% of the price of a mass-market electric vehicle. We estimate that reductions in battery costs will bring this proportion down and stabilize at 15-20% during 2030-2040. This is on par with the current 18% cost proportion accounted for by the powertrain (engine + transmission) in a gasoline vehicle. Recent increases in the price of batteries will naturally put pressure on the profitability of EVs. However, if the price of EVs could be increased from a TCO standpoint, deterioration in profitability could be kept to a minimum. We believe an overly pessimistic medium-term view on EVs is unwarranted.

Exhibit 9: Turning point for EVs expected in 2023-2025
Payback period on EVs



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 10: Battery cost to reach ICE powertrain level in 2030
Cost as a percentage of vehicle price



Source: Company data, IHS Global Insight, Goldman Sachs Global Investment Research

Exhibit 11: Expecting shift to electric to accelerate

Our estimates by powertrain

	2020	2021E	2022E	2023E	2024E	2025E	2026E	2027E	2028E	2029E	2030E	2035E	2040E
EV sales ratio													
Total	**3%**	**6%**	**8%**	**10%**	**12%**	**15%**	**19%**	**23%**	**26%**	**29%**	**32%**	**44%**	**58%**
USA	2%	3%	6%	9%	13%	20%	25%	33%	40%	45%	50%	66%	80%
Japan	0%	2%	2%	2%	3%	6%	8%	10%	12%	16%	20%	50%	80%
China	4%	12%	20%	23%	26%	29%	32%	36%	39%	41%	43%	56%	68%
EU	6%	11%	14%	18%	21%	25%	37%	47%	55%	63%	72%	100%	100%
India	0%	0%	1%	1%	2%	3%	4%	5%	6%	7%	8%	20%	50%
Others	0%	0%	0%	0%	1%	1%	2%	3%	4%	5%	6%	15%	35%
Hyper adoption	**3%**	**6%**	**11%**	**13%**	**16%**	**19%**	**24%**	**28%**	**31%**	**34%**	**39%**	**63%**	**91%**
Bear	3%	6%	7%	8%	10%	11%	13%	16%	18%	19%	21%	32%	51%
EV sales (mn)													
Total	**1.9**	**4.4**	**6.9**	**8.9**	**10.9**	**13.6**	**17.5**	**21.7**	**25.3**	**28.6**	**32.1**	**49.7**	**71.7**
USA	0.2	0.5	0.9	1.4	2.1	3.4	4.0	5.3	6.4	7.2	8.0	10.6	12.8
Japan	0.0	0.1	0.1	0.1	0.1	0.3	0.4	0.4	0.6	0.7	0.9	2.2	3.5
China	0.9	2.5	3.9	4.7	5.3	5.8	6.6	7.4	8.0	8.6	9.1	12.5	15.8
EU	0.7	1.3	1.8	2.6	3.2	3.9	5.8	7.5	8.8	10.1	11.5	16.0	16.0
India	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.3	0.4	0.5	1.6	4.9
Others	0.1	0.0	0.0	0.1	0.1	0.2	0.6	0.8	1.2	1.6	2.0	6.8	18.7
Hyper adoption	**1.9**	**4.6**	**8.8**	**11.3**	**14.1**	**17.3**	**22.0**	**26.6**	**30.4**	**34.2**	**40.0**	**70.4**	**112.2**
Bear	1.9	4.4	5.6	6.8	8.6	9.9	12.2	15.2	17.3	19.2	21.8	36.0	62.8
LiB demand (GWh)													
Total	**160.3**	**330.8**	**518.6**	**675.1**	**838.3**	**1,059.8**	**1,330.8**	**1,628.6**	**1,903.6**	**2,170.3**	**2,464.3**	**3,977.0**	**5,962.6**
Hyper adoption	**160.3**	**385.2**	**756.1**	**992.5**	**1,246.0**	**1,569.3**	**1,965.8**	**2,363.5**	**2,714.7**	**3,084.3**	**3,622.2**	**6,421.7**	**10,257.8**
Bear	160.3	330.8	446.3	546.3	692.5	823.4	982.2	1,179.4	1,338.8	1,486.1	1,682.6	2,934.6	5,100.3
	2020	**2021E**	**2022E**	**2023E**	**2024E**	**2025E**	**2026E**	**2027E**	**2028E**	**2029E**	**2030E**	**2035E**	**2040E**
Powertrain outlook													
HEV	4.3	7.2	12.4	17.1	20.1	23.0	23.5	23.8	24.4	25.7	27.7	41.2	38.7
PHEV	1.0	2.2	3.5	4.2	5.0	5.2	5.2	4.9	5.1	5.2	5.1	5.6	6.8
EV	1.9	4.4	6.9	8.9	10.9	13.6	17.5	21.7	25.3	28.6	32.1	49.7	71.7
ICE and others	69.6	65.0	59.7	57.2	53.9	50.0	47.4	45.0	42.5	39.9	36.5	15.4	6.3
Powertrain ratio													
HEV	6%	9%	15%	20%	22%	25%	25%	25%	25%	26%	27%	37%	31%
PHEV	1%	3%	4%	5%	6%	6%	6%	5%	5%	5%	5%	5%	5%
EV	3%	6%	8%	10%	12%	15%	19%	23%	26%	29%	32%	44%	58%
ICE and others	91%	82%	72%	65%	60%	54%	51%	47%	44%	40%	36%	14%	5%
NEV (EV+PHEV)													
NEV	2.9	6.6	10.4	13.1	16.0	18.8	22.7	26.7	30.4	33.8	37.2	55.3	78.5
NEV ratio	4%	8%	13%	15%	18%	20%	24%	28%	31%	34%	37%	49%	64%
(China NEV)	1.1	3.2	5.2	6.3	7.2	7.9	8.7	9.5	10.3	11.0	11.6	15.6	18.7
(China NEV ratio)	6%	16%	26%	31%	36%	39%	43%	46%	49%	52%	55%	70%	80%

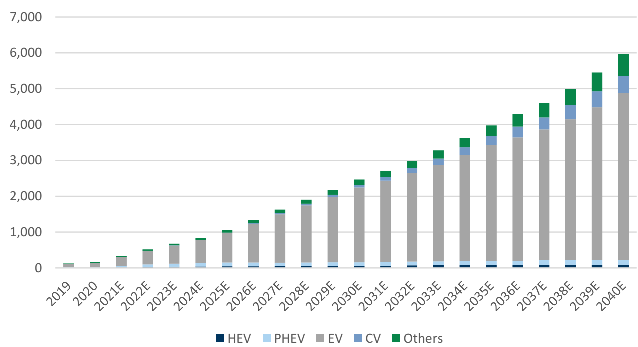
Source: IHS Global Insight, Goldman Sachs Global Investment Research

Greenflation demands battery innovation

Updated mobility-use battery demand outlook

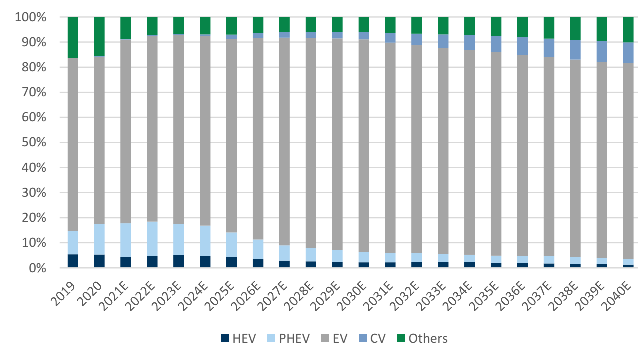
We view electrification as an irreversible trend, and we continue to base our medium-term mobility-use battery estimates on strong growth assumptions. Our new 2030 demand estimate is 2,464 GWh (previously, 2,292 GWh), which includes the addition of battery demand estimates for motorcycles and electric buses. We still assume passenger cars will be the largest EV battery application, but we now estimate steady growth in the penetration of electric motorcycles, too, particularly in India. We expect battery demand for mobility uses to increase to 2,464 GWh in 2030. We believe annual growth will average at 20% during 2020-2030. By 2040, we expect the market to have expanded to 5,963 GWh.

Exhibit 12: Forecasting average annual growth of 20%
Mobility-use battery demand estimates



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

Exhibit 13: EV use to make up the lion's share of demand
Battery demand by application



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

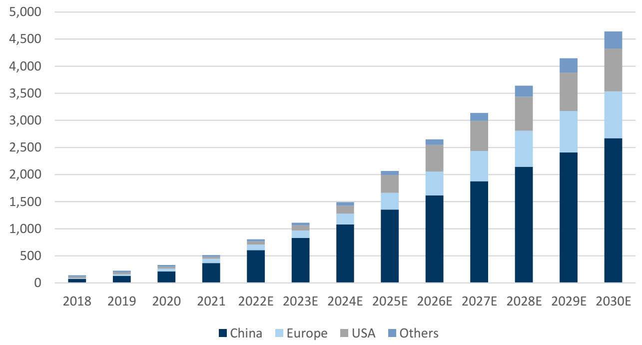
Plans to aggressively expand capacity...

Backed by strong battery demand for mobility use, battery suppliers and automakers have announced plans to actively expand their production capacities. Total production capacity looks set to grow to 7,376 GWh in 2030 from 524 GWh in 2020. This includes 10-20% capacity for consumer electronics/storage. By geography, production capacity in China is expected to grow markedly, taking the country's share of the total to 56% by 2030. Europe is set to be the next largest with 22%, followed by the US with 17%, and other regions with 6%.

...but actual battery output to differ

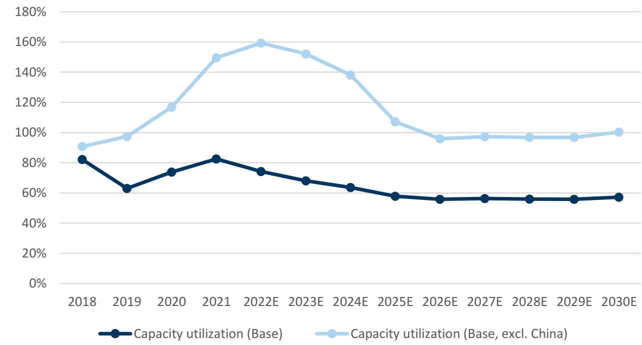
Although production capacity estimates suggest the risk of substantial oversupply in mobility-use batteries, we believe yields may deteriorate due to factors such as delays in the start-up of production by new battery maker entrants and the adoption of new technologies (use of high-nickel content, silicon additives). Allowing for these downside risks, we expect effective operating rates of 60-80% through to 2030. In addition, we think utilization could exceed 100% with the exclusion of production capacity in China. With local production for local consumption being a basic principle of the automotive battery business, we expect utilization rates to differ depending on the region and believe automakers will put much thought into developing regionally optimized strategies for battery procurement.

Exhibit 14: Aggressive production capacity expansion plans
Battery production capacity outlook by region (GWh)



Source: IHS Global Insight, company data, Goldman Sachs Global Investment Research

Exhibit 15: Effective utilization rates high
Estimated utilization rates adjusted for yield

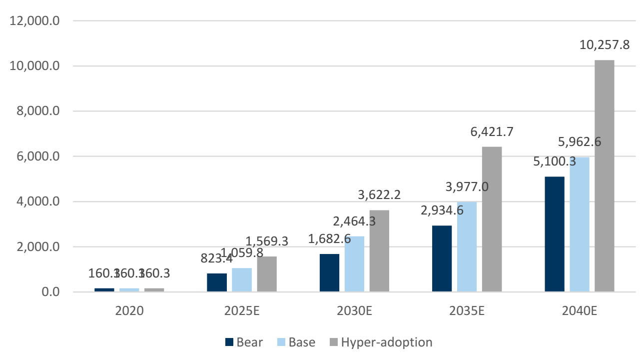


Source: IHS Global Insight, company data, Goldman Sachs Global Investment Research

Battery demand to vary considerably depending on EV sales

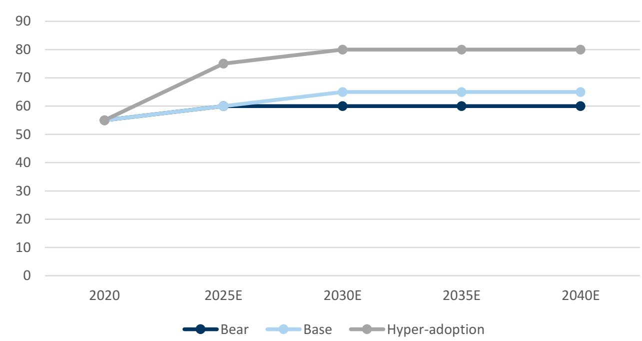
Demand for mobility-use batteries will naturally be greatly affected by the trend in EV sales. There is a large gap between our medium-term battery demand estimates depending on the bear and hyper-adoption scenarios we introduce in this report. In the bear scenario, as well a pessimistic outlook for EV sales volume, we assume relatively low battery capacity per vehicle on the basis that battery prices remain high. Meanwhile, in the hyper-adoption scenario, we assume larger battery capacities per vehicle as there is likely to be a greater emphasis on distance on a single charge. In 2020-2040, we expect different levels of average annual growth for each scenario, including 15% in the bear scenario, 23% for hyper-adoption and 20% in our baseline case.

Exhibit 16: Mobility-use batteries to be greatly affected by EV sales
Scenario analysis (GWh)



Source: IHS Global Insight, IEA, sne, Goldman Sachs Global Investment Research

Exhibit 17: Assuming differences in installed capacity per vehicle
Scenario analysis (kWh)



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

Green inflation may spur short-term shift to LFP

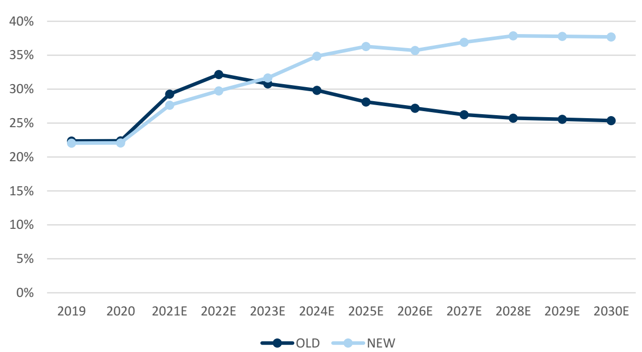
We think expanded use of LFP would be an effective short-term strategy for addressing higher costs. While LFP batteries have an energy density of 150-160Wh/kg, 30% below

NMC batteries, they are also safe and inexpensive, as they are less prone to degradation with an operating voltage of 3.4 V vs. 3.6-3.7 V for three-element NMC cathodes. LFP is becoming more widely used by Chinese automakers, as well as other major complete vehicle makers such as Tesla, Toyota, and VW. Hyundai Motor also stated at its March 2 CEO Day event that it would step up use of LFP batteries. LFP batteries accounted for 22% of global EV battery sales in 2020, and we estimate that the LFP-battery weighting will rise to 36% (we previously expected 28%) in 2025 and 38% (25%) in 2030.

Module-free structure is one advantage of LFP

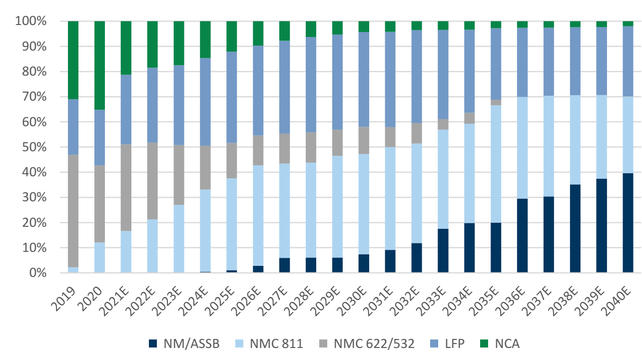
In addition to LFP batteries not using expensive elements such as cobalt and nickel, another cost-advantage they have versus NMC is their module-free structure, enabling lower costs for battery packs. Heat management takes less capacity in LFP batteries because of their lower voltage (vs. NMC). Yields are also stable, assuring durability even with a module-free structure. We expect NMC battery makers to aim for module-free structures in the future as well, but we think the technological hurdles are high given the very strong emphasis the auto industry needs to place on safety.

Exhibit 18: Raising our estimates for LFP cathode mix
Our outlook on the global sales weighting for LFP cathode EV batteries



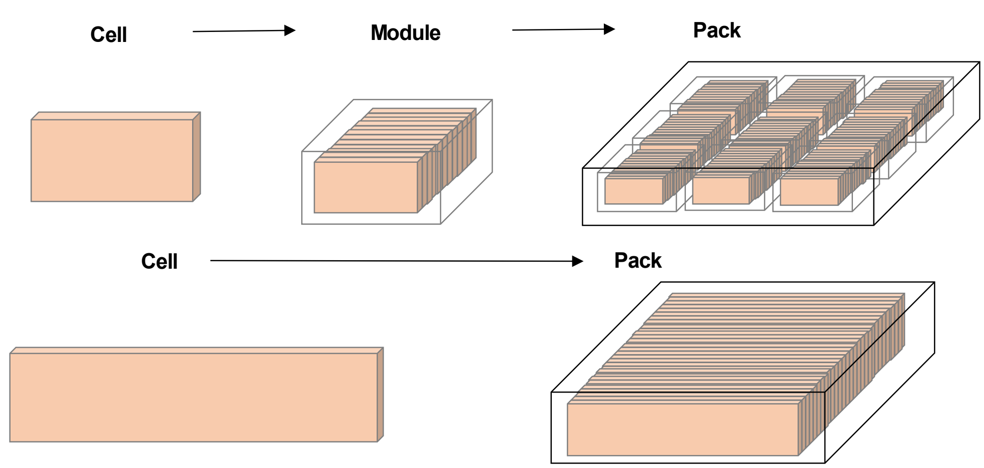
Source: SNE, Goldman Sachs Global Investment Research

Exhibit 19: Cathode materials evolving along with technologies
Global EV battery sales mix by cathode material



Source: SNE, Goldman Sachs Global Investment Research

Exhibit 20: Costs can be cut if modules can be eliminated
Module-free concept

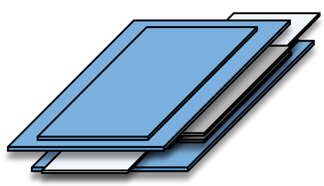
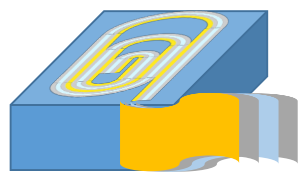
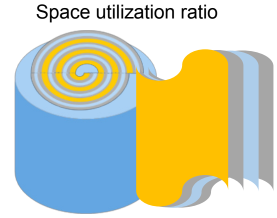


Source: Company data, Goldman sachs Global Investment research

Acceleration of growth in cell sizes

We also look for an acceleration in the growth of battery cell sizes. Panasonic's initiatives with its cylindrical batteries are of particular note. Panasonic announced after the February 28 close that it plans to establish two additional lines at the Wakayama plant to produce its new 4680 lithium-ion automotive battery, and to begin productivity verification and mass production in FY3/24. We assume the two new production lines at the Wakayama plant will initially be test lines, and that the company will enter volume production if the verification process proceeds smoothly. We envisage production capacity reaching around 4-5 GWh per line, with initial capacity of around 3-4 GWh. We think battery makers will also continue looking to streamline the production process by making larger pouch and prismatic cells as well. That said, larger cells also have demerits including the difficulty of making active materials of uniform thickness and temperature control within cells. Retaining their emphasis on safety, we think automakers will move to adopt larger cells little by little.

Exhibit 21: Cell sizes also to change
Conceptual cell structures

Cell Type	Pouch	Prismatic	Cylindrical
Inside of Cell	"Simple Electrode Stacking" Space utilization ratio 	"Jelly Roll" Space utilization ratio 	"Jelly Roll" Space utilization ratio 
Cell Layout in Module	"Cell layout = Stacking" Space utilization ratio	"Cell layout = Stacking" Space utilization ratio	"Cell layout = Side by side" Space utilization ratio
Wh/L	100%	93% (-7 pt.)	65% (-35 pt)
Wh/kg	100%	88% (-12 pt.)	93% (-7 pt)

Source: Company data, Goldman Sachs Global Investment Research

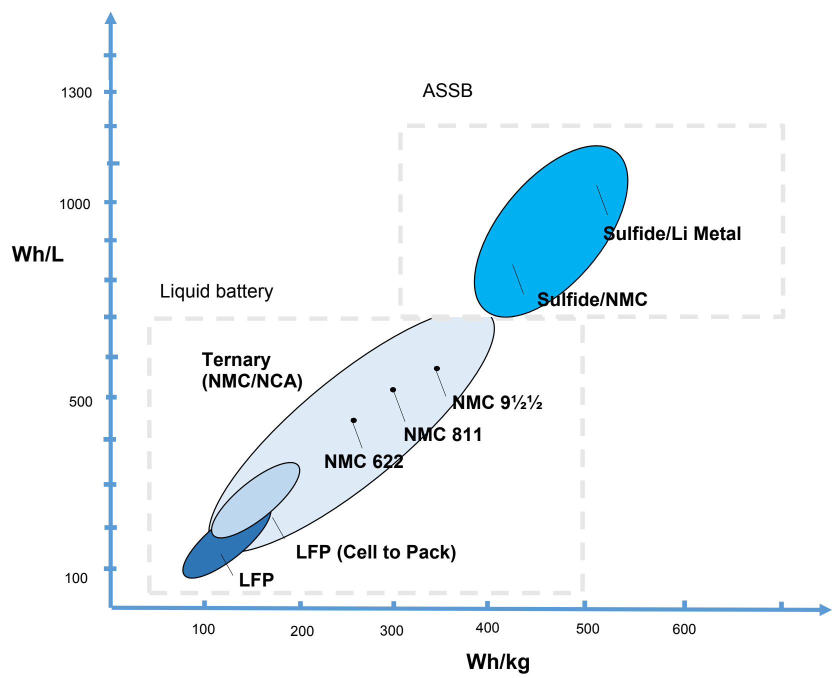
Increasing shift to high nickel cathodes over the medium term

The first commercial LiB was developed in 1991, and via the trial of various materials since, LiB energy density as of 2019 was 260Wh/kg and 620 Wh/l (NMC high-nickel batteries). Development looks to be on track to attain densities of 330 Wh/kg and 800 Wh/l by 2025, and technological innovations with both cathodes and anodes are likely to drive this forward. We see potential for changes in the cathode/anode material mix to elevate the value-add of other battery materials, such as binders and conductive materials. Raising energy density is the most critical factor in lowering battery costs.

Next-generation batteries also to come to the fore

As the theoretical limits of LiB are coming into view, we think evolution toward post-LiB will likely start in 2025-2030. We think all solid state batteries (ASSB) are likely to be adopted as automotive batteries, but development advances have repeatedly been followed by setbacks. The interface effect and dendrite formation have been the biggest bottlenecks for ASSBs, but options for cathode and anode materials that can be used are also growing. Meanwhile, the combination of materials used will also lead to great variance in battery properties and safety. Battery makers and major automakers alike appear confident that ASSBs will be ready for commercial production in the latter part of the 2020s.

Exhibit 22: Energy density to increase
Technology roadmap



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 23: ASSBs increasingly to be in the spotlight
Battery material overview

	←Low	Energy density		High→
Cathode	LFP	NMC622	NMC811	NMC9½½
Anode	Graphine	SiO <10%	SiO >10% Pure Si	Lithium metal
Eletcrolyte	Liquid	Gels	Solid Oxide	Solid Suflide
Separater	Yes			No

ASSB specific challenges (green dashed boxes: Lithium metal, Solid Oxide, Solid Suflide, No)

Source: Goldman Sachs Global Investment Research

EV strategies in the spotlight; we take a positive view of vertically integrated business models

Automakers announcing proactive EV strategies

A number of global automakers have announced aggressive EV sales strategies during the last six months. In the second half of 2021, Toyota raised its 2030 global sales volume target for BEVs, PHEVs and FCEVs combined to 3.5 mn units from 2.0 mn units, and increased its 2030 battery production capacity forecast to 280 GWh from its previous forecast of above 200 GWh. Nissan, meanwhile, said it aims to achieve an EV sales weighting of at least 50% by 2030, and plans to invest more than US$17 bn in electrification over the next five years. Nissan also announced on November 29, 2021 that it is targeting a commercial launch for all-solid-state batteries in 2028. In March 2022, Hyundai raised its global EV sales volume forecast to 1.87 mn units from 1.0 mn units and set its battery demand forecast at 170 GWh.

Exhibit 24: Global automakers' aggressive EV strategies
Major automakers' vehicle electrification plans (as of 2022)

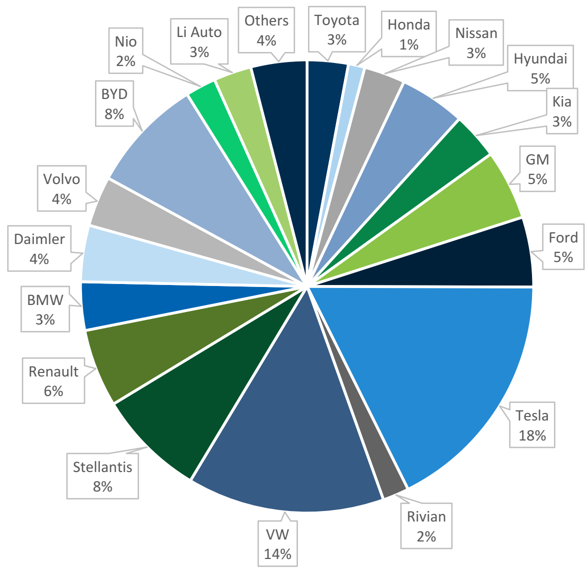
OEM	BEV volume target
Toyota	5.5mn electrified vehicle sales target by 2025, o/w 0.5mn to be pure EV. 3.5mn EV sales target by 2030 (o/w Lexus 1.0mn).
Honda	EV/FCV sales ratio of 40% in 2030 and 100% in 2040. By main region, Honda targets 40%/80%/100% (2030/2035/2040) EV ratio in North America and China and 20%/80%/100% in Japan.
Nissan	50% electrified vehicle sales by 2030
Mazda	25% EV sales target by 2030
General Motors	GM is targeting 1mn EVs by mid decade, and aspires to only sell zero emission vehicles by 2035.
Ford	Ford targets over 2 mn in annual EV production by 2026, representing about a third of its global production. By 2030, Ford targets 50% of its annual global production to be EV.
Volkswagen	20% of global sales to be BEV by 2025 and 50% by 2030/2031
BMW	2mn BEVs delivery by 2025, 50% of global sales to be BEV by 2030
Mercedes-Benz Group AG	25% of global sales to be BEV by 2025 and 50% of global sales to be zero-emission vehicles by 2030 Targets CO2 neutrality for new passenger car fleet by 2039
Stellantis	38% of EV/PHEV sales in EU in 2025 and 70% in 2030. In USA, 31% in 2025 and 35% in 2030
Renault	Renault branded passenger cars in Europe is expected to be BEV 90% in 2030.
Hyundai	Hyundai announced BEV sales target of 840k units by 2026 and 1.87mn units by 2030, with EV sales ratio of 17% by 2026 and 36% by 2030.
Kia	Kia announced updated BEV sales target of 807k units by 2026 and 1.2mn units by 2030, with EV sales ratio of 21% by 2026 and 30% by 2030.

Source: Company data, Goldman Sachs Global Investment Research

Expecting Tesla to dominate

Exhibit 25 shows our latest forecasts for EV market share in 2025. We expect Tesla, which specializes in the high-end market and was the first to achieve profitability in its EV business, to achieve a global market share of 18%. We think that Volkswagen, which has spearheaded vehicle electrification in Europe, will take the next largest share, at 14%, followed by Stellantis with 8%. Among Asian automakers, we think the largest market share (8%) will be taken by Hyundai Group, which has formed close relationships with Korean battery manufacturers. We expect market share to be relatively low among Japanese automakers, whose main strategies continue to call for acceleration in vehicle electrification from 2025, when they expect battery cost to fall below US$100/kWh.

Exhibit 25: We expect Tesla's dominance to continue
Our EV market share forecasts for 2025

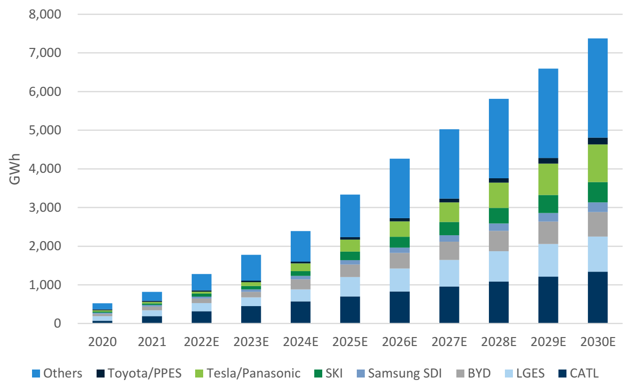


Source: IHS Global Insight, Goldman Sachs Global Investment Research

Putting in place vertically integrated business models

It goes without saying that sourcing sufficient batteries to match aggressive sales volume targets will be crucial. Among auto assemblers, we believe that Tesla, VW, BYD, and Toyota have committed to putting in place vertically integrated structures that include battery cell production. We estimate that CATL will have the largest battery production capacity in 2030, at 1,337 GWh, followed by Tesla at 970 GWh. We expect BYD, which specializes in LFP batteries, to have production capacity of 636 GWh. Toyota has said it plans to invest largely by itself in capacity of 280GWh.

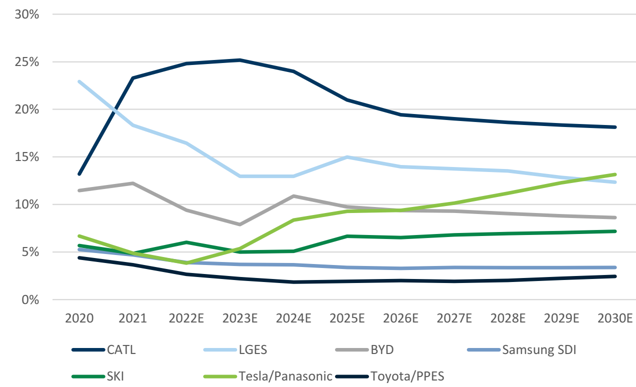
Exhibit 26: We focus on automakers that are putting in place vertically integrated production structures
Battery production capacity



Tesla/Panasonic includes in-house production by Tesla and procurement from Panasonic.

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

Exhibit 27: Battery makers vying with automakers
Share of battery production capacity



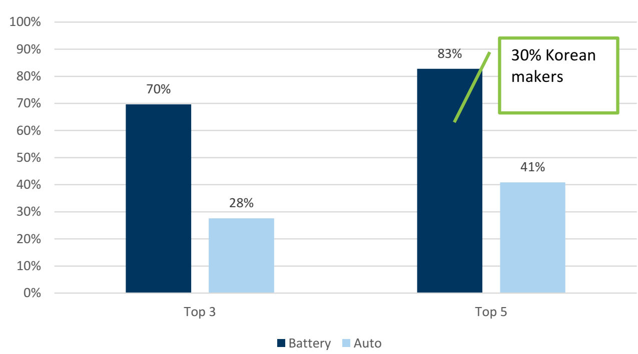
Tesla/Panasonic includes in-house production by Tesla and procurement from Panasonic.

Source: Company data, Goldman Sachs Global Investment Research

Focusing on the power balance between battery makers and automakers

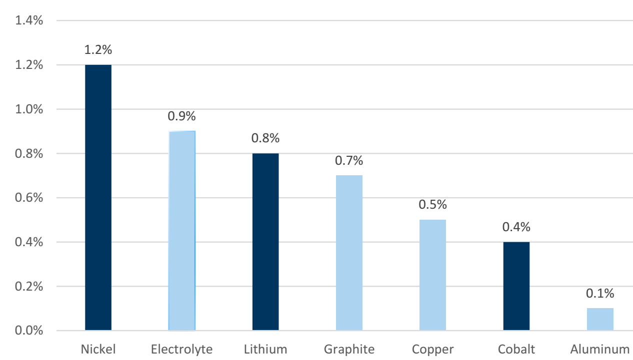
Market concentration is higher among battery makers than it is among finished vehicle makers. As of 2020, the top five global finished vehicle assemblers accounted for just 41% of total sales, whereas the top five battery makers accounted for 83% of sales. This naturally gives the battery makers an advantage when it comes to negotiating prices. Battery makers are adopting price adjustment systems for nickel, cobalt, and lithium to mitigate the impact of greenflation, but they are not using the system for electrolytes, anode materials, copper, and aluminum. We think it stands to reason that vehicle assemblers will try to redress the power balance with battery manufacturers by seeking to put in place vertically integrated business models.

Exhibit 28: Market concentration is high among battery makers
Market share comparison (as of 2020)



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

Exhibit 29: Selling prices do not automatically reflect price changes for all materials
Impact on battery cost of a 10% price increase for each material



Dark blue bars indicate materials covered by price adjustment systems

Source: SNE, Goldman Sachs Global Investment Research

Exhibit 30: Vertical integration of battery production still not the norm
Vehicle assemblers' battery procurement strategies (as of 2022)

OEM	Battery sourcing strategy
Toyota	Toyota owns 51% of PPES, a JV with Panasonic. Toyota has a strategic alliance with CATL and BYD on battery development and procurement. Battery capacity (including strategic partners) will increase to 280GWh by 2030, up from current 6GWh.
Honda	Denied the possibility of in-house production for current liquid lithium ion battery. JV with GS Yuasa, Blue Energy Honda has an alliance with CATL, holding stake of 1% in 2020. Honda is planning to use GM based EV platform in USA which is based on LGC battery, and also possible to use GM ultium battery in the future.
Nissan	Nissan announced 52GWh in 2025 and 130GWh in 2030
Mazda	No battery plan announced
General Motors	GM has a joint venture with LG Chem to mass-produce Ultium battery (NCMA) cells in Lordstown, Ohio at a US$2.3 bn facility. GM will power all future EVs on its scalable Ultium EV platform with five interchangeable drive units and three e-motors, known collectively as Ultium Drive.
Ford	60GWh US capacity plan together with SK Innovation.
Volkswagen	Plans to invest/partner in battery supply chain VW is planning to invest 240GWh battery capacity by 2030. VW is also considering China and USA Giga factories.
BMW	No battery plan announced
Mercedes-Benz Group AG	No battery plan announced
Stellantis	Two giga factories with 50GWh capacity (France end of 2023, Germany end of 2025) Global battery capacity target of 130GWh in 2025 and 250GWh in 2030.
Renault	Partnership with Envision AESC to set up 9GWh capacity by 2024 and 24GWh by 2030. Renault also aquired a 20% stake in Verkor aiming to add 20GWh capacity by 2030.
Hyundai	In order to achieve such scale, company will secure 170GWh batteries by 2030 by entering new partnerships, sourcing batteries from JVs, and diversifying sourcing into LFP batteries. Hyundai is sourcing batteries from LG Chem and SK Innovation.
Kia	Company plans on securing 119Wh battery supply until 2030 through JVs or local sourcing plans, targeting to increase energy density by 50% from 2022 level and reduce battery pack cost by 40%. Kia is sourcing batteries from SK Innovation as a main vendor.

Source: Company data, Goldman Sachs Global Investment Research

Further technological innovation needed

We believe that measures to counter green inflation must go beyond battery innovation to encompass everything from improving overall vehicle efficiency to creating an ecosystem, including battery recycling and reuse. We think the following initiatives could hold down battery costs:

(1) In addition to improving energy density through the shift to higher nickel content/silicon anodes, we think there is a need to reduce the use of natural resources (nickel and cobalt) by making effective use of lithium iron phosphate (LFP).

(2) We believe that further improvement in energy density will require the adoption of all solid state batteries (ASSBs). Toyota has been working on ASSB development for some time, and newly emerging ASSB companies such as QuantumScape have also been outlining their development roadmaps. It was recently reported that Nissan is to invest ¥140 bn with the aim of commercializing ASSBs by 2028.

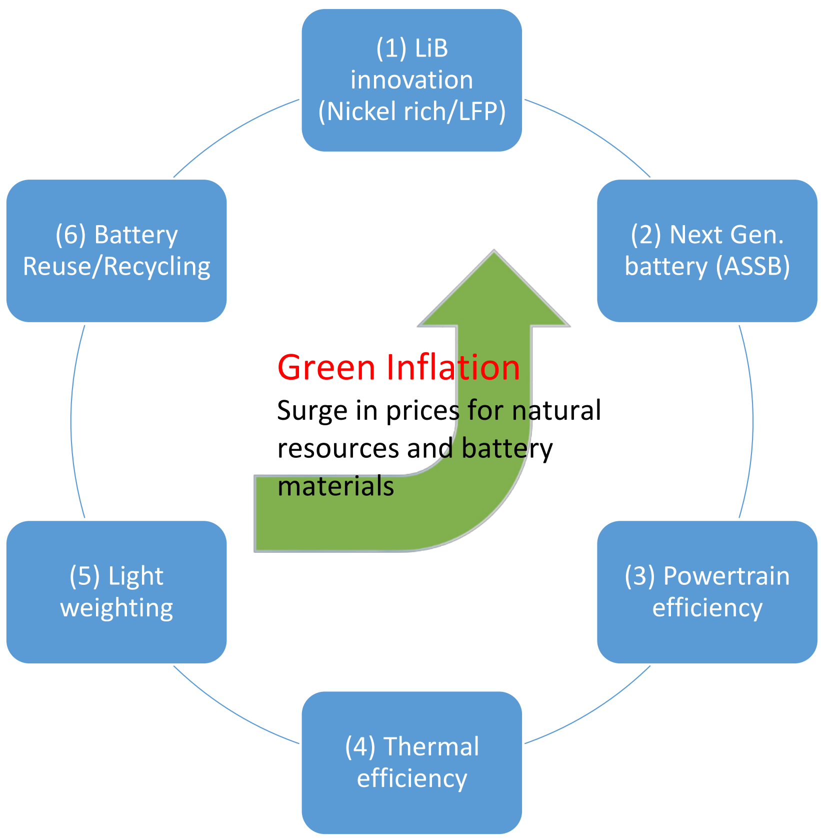
(3) We see considerable scope for increasing efficiency in powertrain units, which consume around 55% of battery output in EVs. We expect to see further adoption of silicon carbide power semiconductors, which contribute to reducing energy loss in inverters, and anticipate further innovation to improve the efficiency of motors.

(4) We think the use of heat pump technology could boost efficiency in air conditioners, which consume around 25% of EV battery output. We also expect overall thermal management capabilities to come into play, as the efficient heating/cooling of batteries and motors/inverters can improve a vehicle's electric power consumption.

(5) Lightweighting is another indispensable technology for increasing the range of EVs, which have to carry heavy batteries. In addition to the increasing adoption of high tensile steel, aluminum, and resin, we will also be keeping an eye out for measures to reduce the weight of tires.

(6) Many EV batteries will move on to their second life during the next 5-10 years. Recycling technologies will need to be established to efficiently recover natural resources such as nickel and cobalt, which could be in short supply in future. From a reuse perspective, we think expanding the second life market, in which EV batteries are repurposed as, for example, energy storage system batteries, will be beneficial.

Exhibit 31: Comprehensive improvement in energy consumption needed
Green inflation countermeasures



Source: Goldman Sachs Global Investment Research

Disclosure Appendix

Reg AC

We, Kota Yuzawa, Nikhil Bhandari, Mark Delaney, CFA, George Galliers, Fei Fang, Chandramouli Muthiah, Giuni Lee, Amber Cai, Joy Zhang, Kee Ryung Kim, Vinit Joshi, Ryo Harada, Hiroki Muramatsu, Shawn Shin, Songbo Liu, Bruno Dossena, Ryan Heeb, Eleanor Garland, Philipp Konig, Dora Zhou, Rupanshi Bajaj, Sian Keegan and Liliko Tanaka, 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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