ELECTRIC REVOLUTION 2021: FROM DREAM TO SCARE TO REALITY?

GLOBAL VIEW

AUGUST 2021

19 Bernstein teams with one question in mind: How will e-mobility impact the world's largest value chain?

We forecast 25 million new EV sales by 2030 and 40 million by 2035. By 2040, EV parc should grow to 600 million. It's crucial to be open minded toward e-powertrain diversity. Pure BEVs will likely not solve all environmental problems.

Global demand for large batteries is set to grow 18x to 3,043GWh by 2030. Supply constraints will limit more bullish EV adoption and battery costs.

Batteries do (and will) consume significant metals. The metals & mining industry will be crucial in providing raw materials needed for millions of EVs. We expect most leverage with copper, nickel, and lithium.

E-mobility only makes sense with renewable energy and in a circular economy. Full well-to-wheel CO2 and other emissions need to be considered and regulated if we truly want to lower mobility-related emissions.

PORTFOLIO MANAGER'S SUMMARY

The public, local and regional politicians, and scientists are pushing for increasingly stringent emission targets. Carmakers have accepted the transition and presented ambitious electric vehicle (EV) plans. Start-up companies have attracted more than US$1tn in combined new mobility valuations. As a result, e-mobility is no longer a battleground for Bernstein analysts. We're no longer debating whether batteries will take the lead or not. EVs are the future, and our teams merely discuss the steepness of regional adoption curves and supply demand issues in the value chain.

Yet, if society is serious about removing emissions from transportation, we need to consider all parts of the value chain. This transformation of the >US$2tn automotive value chain will create many winners and losers, and comes with several environmental and social issues that need to be addressed. To be clear, EVs make little sense without renewable energy and a circular economy. These are crucial reasons why we continue on the journey of cross-sector collaboration. Without a deep understanding of interdependencies across the value chain, investors will struggle to make the right decisions.

The financial market has concluded that startups, battery makers, metals & mining players, chemicals companies, etc. will be the winners, while autos companies will lose out. We understand this narrative but find it overly consensual. What if carmakers restructure faster, roll out attractive EVs, and sustain their brand equity into the world of EVs?

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SIGNIFICANT RESEARCH CONCLUSIONS

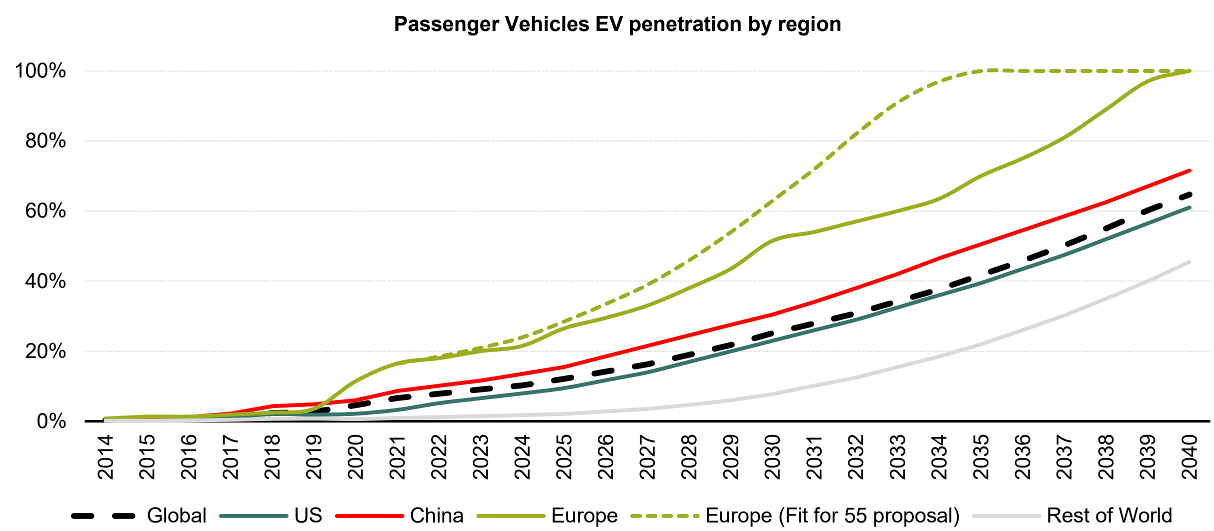
WHEN AND WHERE WILL ELECTRIC VEHICLES DOMINATE?

The move toward zero-emission personal mobility triggers a radical transformation of the largest automotive value chain and has major implications for consumers, companies, and investors. Our global EV sales model offers a realistic assessment of EV adoption by region. Our bottom-up analysis is based on a simple question: "What does the auto industry need to deliver in order to ensure compliance with fuel economy and CO2 emissions standards?"

Significant electrification is needed from basic 48V systems through to full battery electric vehicles (BEVs). Whichever way we look at this, powertrain electrification is the only viable, globally available, and industrialized technological solution in the long term to comply with regulations and emission standards. EV penetration will widely depend on regulation differences and consumer acceptance across regions.

Globally, we expect EVs to account for ~65% of new passenger vehicle (PV) sales by 2040, the vast majority of which will be BEVs. Europe will likely lead the way, with EV penetration set to reach 100% by 2035 (assuming the proposed Fit for 55 package is approved) or 2040 at the latest (if the auto industry's expected pushback to the plan bears fruit). China should follow with >70% EV penetration by 2040, while the US at ~60% is expected to be just below the global average (under current policy, but likely higher if Biden's 40-50% EV target by 2030 is achieved). Wider EV adoption in the Rest of the World (roughly a third of global vehicle sales) will likely take years to materialize, pulling the global average down (see Exhibit 1).

EXHIBIT 1: **We forecast global EV penetration of ~65% by 2040**

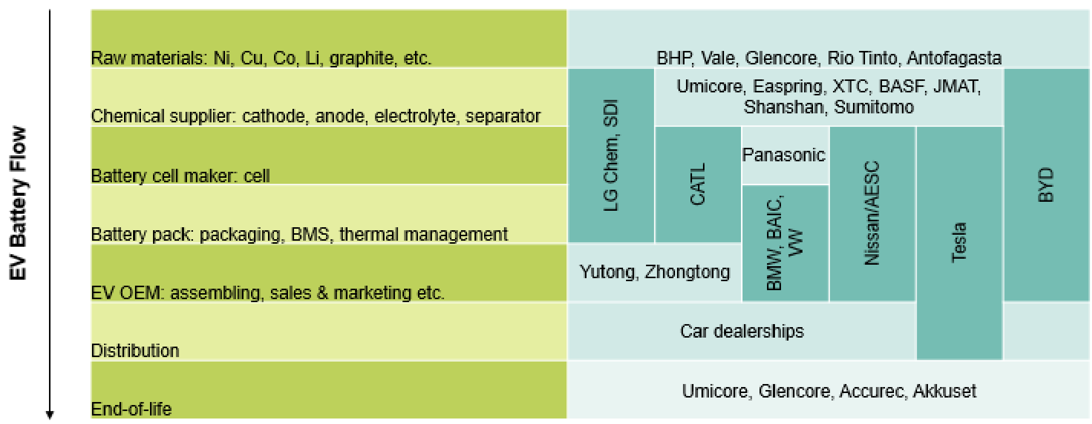


Source: IHS Markit, and Bernstein estimates (2021+) and analysis

PRODUCT LIFE CYCLE ASSESSMENT OF EV BATTERIES

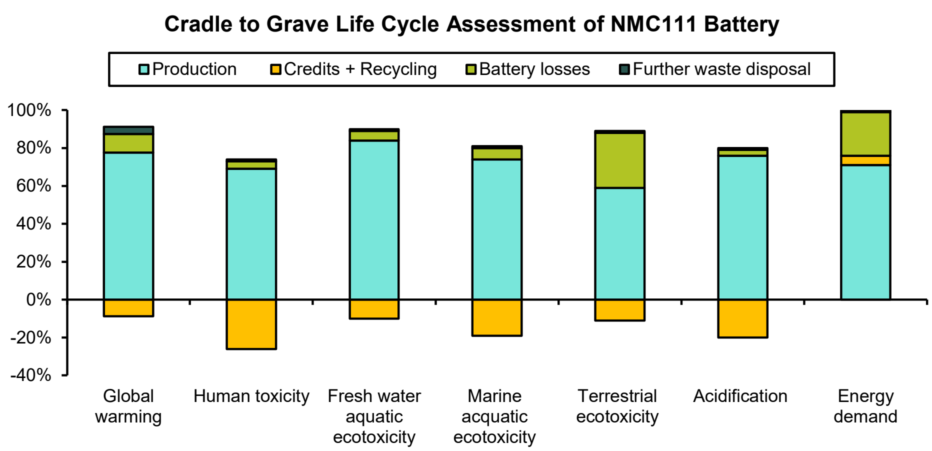
While EVs are a key driver of the low-carbon transition, most consumers focus largely on the emission-reduction potential of EVs in use, without paying much attention to the environmental impact during the production or end-of-life-cycle recycling phases. Given the rise of regulatory requirements, most notably in the EU, calling for greater transparency around a product's net environmental impact, our life cycle analysis on EV batteries finds the greatest impact during the upstream production stage. The increased focus on EVs' environmental impact could create investment opportunities in second-life applications, circular product design, and supply chain traceability. Although the market for a "second life" for EV batteries has not yet reached scale, the 10 million EVs on the road today will reach their end of life and enter the reuse/recycling market by 2040, creating greater economies of scale for these applications.

EXHIBIT 2: **Key players in the EV battery supply chain, as well as emerging players in the end-of-life phase**



Source: World Economic Forum, Kelleher Research Study on Reuse and Recycling of Batteries, and Bernstein analysis

EXHIBIT 3: **The production and battery manufacturing stage of EV components has the greatest impact on the environment during the life cycle**



Note: Further waste disposal refers to the landfilling and incineration of materials; battery loss refers to the amount of electricity lost during the recharging phase over the lifespan of the battery; net recycling impact refers to the impact of the recycling process minus credits obtained by replacing virgin materials with recovered materials.

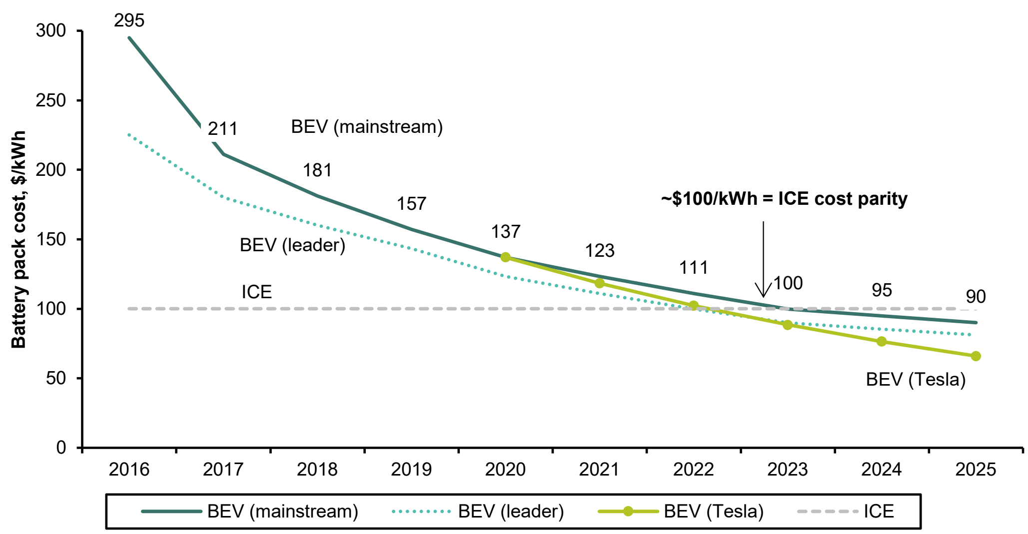
Source: *Journal of Applied Sciences* and Bernstein analysis

REACHING THE HOLY GRAIL OF BATTERY COST PARITY

Lithium-ion battery (LiB) costs have fallen a staggering 96% since 1991, which is a 10% CAGR reduction over 30 years. Large battery cells, which were only introduced to the market in volumes in the last 10 years, have seen an even more dramatic cost decline, with prices falling at a 19% CAGR over the last 10 years as the less mature large-cell battery costs catch up with small cells, which are close to parity on a pack basis today.

Despite risks from material cost inflation, we expect battery pack prices to reach $100/kWh by 2023, the point at which the average EV reaches cost price parity with the average ICEV. This implies automakers can produce an EV at the same upfront price as an ICEV, without any subsidies. By 2025, the average battery price will likely fall to $90/kWh, with market leaders at ~$80/kWh (see Exhibit 4). Tesla is targeting a 56% reduction in battery prices over 2020-25, and could see its battery prices fall to $65/kWh if it can implement new manufacturing processes and better battery-vehicle integration as well as improvements in energy density. We think this will be challenging, given the cost inflation of raw materials.

EXHIBIT 4: **We expect battery prices to fall from US$137/kWh in 2020 to US$100/kWh by 2023 and US$90/kWh by 2025, which is a 35% decline**



Source: Bloomberg, company data, and Bernstein estimates (2021 onward) and analysis

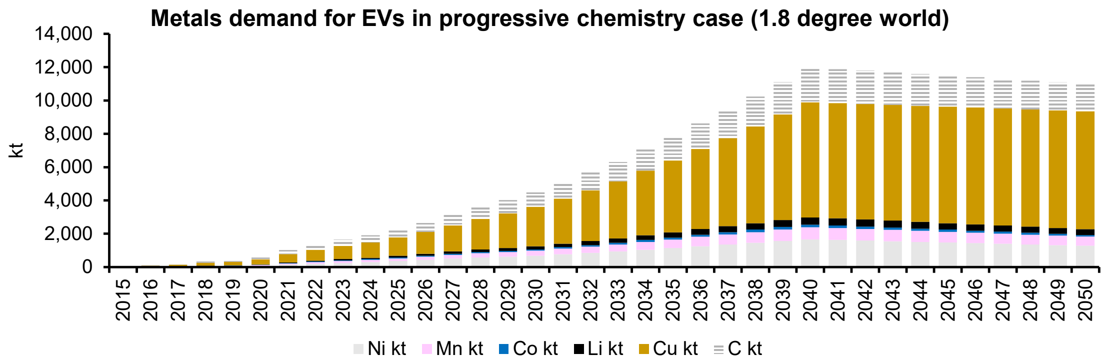
LASHING OUT THE ACTION, RETURNING THE REACTION, BATTERIES ARE HERE TO STAY AND METAL IS THE MASTER

The metals & mining sector will likely play an important role in providing raw materials (metals) that will underpin the Electric Revolution that will displace the ICE. Addressing the climate challenge will likely create a trillion-dollar metals opportunity.

First, batteries do (and will) consume significant metals. The average metal in a battery today is ~50-200kg versus the 200kg of copper in a typical home. Multiply this by one billion vehicles and you can see the potential for tremendous demand (see Exhibit 5).

Combine that with the typical cost of these metals of ~US$756-US$2,818 per vehicle (as of August 19, 2021 spot prices), and one sees a trillion-dollar addressable market. We also note that typical EV prices are in the US$40,000 range. Thus, the EV purchase price has the ability to absorb significant metals price inflation in its cost (~4% or US$1,600 per vehicle), i.e., the battery metal.

EXHIBIT 5: **Annual metal demand for EVs...a plateau and gradual fall as chemistry innovation wins**

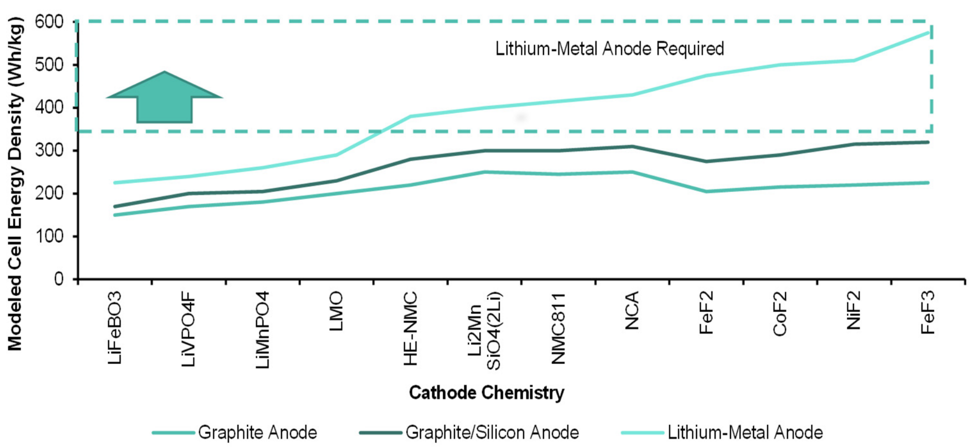


Source: SNL, Bloomberg, and Bernstein estimates (2021+) and analysis

ANODES – TAKING EV BATTERIES TO ANOTHER ENERGY LEVEL

The anode is the bottleneck to advancing battery energy density. The cost of LiBs has decreased by ~31x over the past two decades. However, cost reductions are slowing as cell energy density reaches a peak of ~250Wh/kg. As cathode energy density increases, so must the size of the anode, thereby outweighing any benefits. Adding silicon to the anode or using Li-metal anodes in solid-state batteries (SSBs) can achieve higher energy densities of >250Wh/kg and as high as ~500-600Wh/kg (see Exhibit 6).

EXHIBIT 6: **Innovations in anode technology are required to take cell energy density to a higher level**

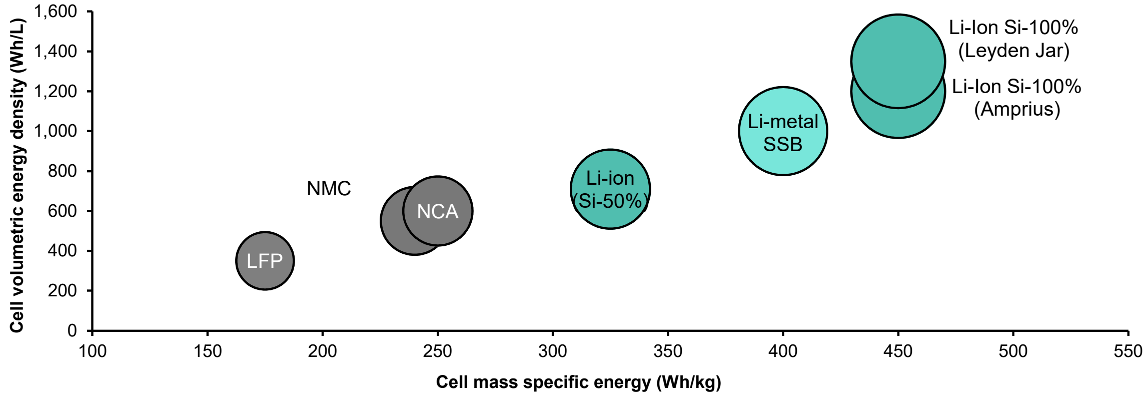


Source: QuantumScape from BMW Group and Bernstein analysis

Solid-state Li-metal batteries have a safety and cost advantage over high-silicon. SSBs use an ultra-thin lithium metal that further increases energy density to 400-500kWh/kg. They have the added benefit of lower cost of manufacturing and improved safety. At scale, the cost benefit is estimated to be ~14% versus LiBs using graphite anodes.

Innovations in high-content silicon anodes are also very promising. Companies such as Nexeon and Sila Nanotechnologies are using high-content silicon anodes that increase energy density by >30%. Amprius and Leyden Jar have developed 100% silicon anodes that they claim can deliver up to 2x the energy density of typical LiBs with graphite anodes (~450kWh/kg), greater than that of SSBs (see Exhibit 7).

EXHIBIT 7: **Innovative silicone anode companies can achieve higher energy density than SSBs using Li-metal anodes**



Note: Cathode used in Leyden Jar is NMC622, others are not specified.

Source: QuantumScape, Faraday Institute, SES, company websites, and Bernstein analysis

High-silicon anode adoption will likely happen more quickly than SSBs. SSBs are only at testing or pilot stages and the technology, which has been in development for ~40 years, has suffered myriad technical challenges. Despite ambitious scaling plans by leading SSB developers, we don't see it taking a meaningful share of anode chemistry until after 2030.

EV CHARGING...ANOTHER STRING TO OIL MAJORS RENEWABLES BOW

Serving the growing EV fleet offers another attractive growth market for the European Integrated Energy companies with current global fleet of just 0.5% penetration set to grow to 36% by 2040. To support this, Europe's current fleet of 286,000 public chargers should grow to 4.5 million by 2030 or as much as 7.346 million in some scenarios.

Government policy clearly supports this Electric Revolution, such as the Green Deal's Alternative Fuel Infrastructure Directive (AFID) target ratio of 0.1 public charger per EV, or announcements in the recent Fit for 55 package. Atypically for the Oil Majors, EV charger infrastructure rollout also has public backing, ranking among the most important factors for EV adoption across consumer surveys carried out by a variety of industries.

Oil Majors will likely be a big part of the power supply needed for public charging in Europe, growing from 3.7GWh in 2020 to 257.5GWh in 2040, i.e., from US$0.9bn of revenue today to US$62.4bn in 2040 with gross margin potential of US$58.3bn. EBITDA from public charging should grow from -US$14mn today, reaching breakeven in 2026, and US$46bn by 2040.

Such a revenue model will benefit from other opportunities including from network membership fees, lower costs from station batteries, and home and fleet charging, not to mention EV lubricant sales and cross-selling high-margin convenience to this new forecourt footfall. Finally, it can also capture the climate-conscious customer with certified renewable EV power offers, complementing current carbon-neutral fuel sales.

INDIA ELECTRIC VEHICLES: POWERING THE ELECTRIC REVOLUTION THROUGH POLICY PUSH

The Indian government is pushing for the start of an EV revolution. To promote manufacturing, a Production-Linked Incentive (PLI) scheme was announced by the government, covering various sectors. For advanced cell chemistry (ACC), US$2.4bn of incentives have been allocated for five years. The scheme targets setting up local battery manufacturing capacity of 50GWh per year, with 25% and 60% domestic value addition by years two and five, respectively.

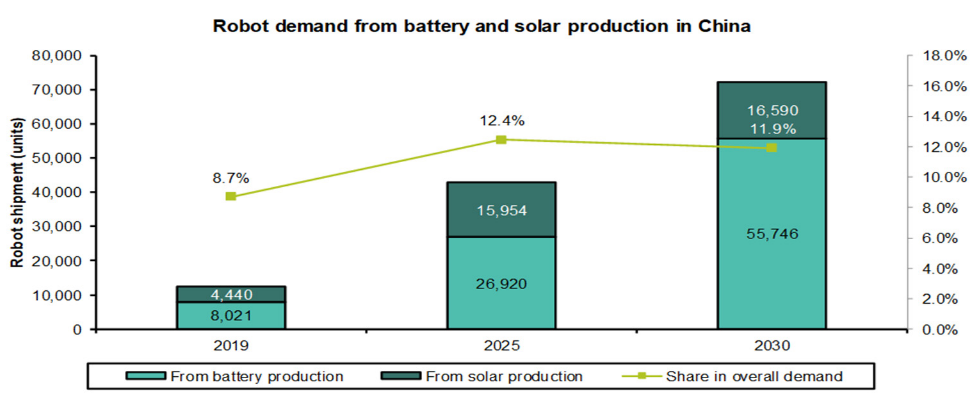
We expect domestic ACC battery production to start in CY2024 and get fully commissioned by CY2027. We estimate for manufacturers, the scheme would imply a benefit of ~18% on revenues on a base case. The primary ACC batteries applications is EVs. At 3kWh battery capacity per electric two-wheeler (2W) (or 30kWh for cars), the target battery manufacturing capacity is sufficient to power 16.7 million 2Ws or 1.7 million cars per year, broadly in line with current annual domestic demand for these end markets.

While battery manufacturers may be concerned about the demand scale-up to fully utilize the incentives, we see that as less of a challenge. Our base case EV adoption scenario assumes a gradual increase in EV sales mix across auto end markets over the next decade, with 60% and 25% of domestic 2W and PV sales, respectively, by 2030. Accordingly, we estimate annual EV sales to be 20 million by 2030, with EV stock of 70 million across all auto end markets. The implied battery demand to service this market would be 64GWh per year by 2027 and 144GWh by 2030, suggesting offtake may be less of a challenge for PLI-backed battery manufacturing capacity.

AUTOMATION AND ESG: CHINA'S CARBON NEUTRALITY ON ROBOTICS, SERVO MOTION, LASER, AND VISION

Climate change will have a material and positive impact on automation demand in the coming decade. In 2020, China promised to hit a CO_2 emission peak by 2030 and achieve carbon neutrality by 2060. Almost immediately, the power and transportation industries sharply increased investment in renewables and EVs. We analyzed the detailed production processes and automation needs for EV batteries and solar panels and, based on that, quantified the impact on key automation technologies — robotics, laser, vision, and servo motion — and automation players in China.

EXHIBIT 8: **Robot demand from battery and solar panel production in China will likely increase in absolute levels as well as in relative importance**



Note: Product share is defined as the ratio of robot demand in battery and solar industry, and total robot demand.

Source: MIR Databank, Statista, China Photovoltaic Industry Association (CPIA), and Bernstein estimates (2025+) and analysis

SIC: SIZING THE MARKET

By now, no one will question the merits of silicon carbide (SiC) for power semiconductors and EVs. As an emerging semiconductor material, SiC delivers better efficiency for high-power applications. Particularly for EVs, SiC promises to extend mileage by 5-10%, or even 15% according to Cree and reduce charging time from two hours to seven minutes. In this *Blackbook*, we try to address one of the major controversies — the size of the SiC market.

Starting with disclosures from Tesla and STM, we estimate the SiC content per car costs US$425 for chips and US$600 for modules now. Then we calculate the SiC content per horsepower (hp), as mainstream EVs will likely start to adopt SiC and their lower hp ratings will require lower power semiconductor content. By 2025, we estimate SiC chip costs to fall by 37%.

With these assumptions, we estimate the SiC market will be US$2.4bn in 2025, below the guidance of Cree and STM, but above third-party forecasts, if: (1) 5 million EVs have SiC, (2) each EV has the average hp of current cars to contribute US$1.4bn in 2025, and (3) non-EVs contribute US$1bn additionally. One extra car and one extra hp to the adoption base will add US$280 and US$6.7 to the SiC market, respectively (see Exhibit 9). (See our sizing model at SiC Market Size Model.)

Cost reduction, adoption in EV and non-EV, and hp rating are key swing factors. Substrate accounts for the bulk of SiC device cost and, therefore, is key to cost reduction and deserves more research. Overall, we find SiC in the non-EV segment can't be ignored and Infineon is well positioned there. For EV, silicon will likely remain meaningful and Infineon is the clear leader.

EXHIBIT 9: **We estimate the power SiC market to be US$2.4bn in 2025**

Power SiC Market Size Estimate

Forecast Assumptions		Remarks
Horsepower Assumption		
Target Horsepower per Vehicle (hp)	212	The avg of US cars per EPA; 247 hp if other vehicle types are included
kW per Horsepower	0.75	
Target Power Output per Vehicle (kW)	158	
Penetration Assumption		
BEV Shipment (M Unit)	6.8	Forecast of Bernstein European Auto team
SiC Penetration in BEV	65%	Assumption
PHEV Shipment (M Unit)	3.2	Forecast of Bernstein European Auto team
SiC Penetration in PHEV	20%	Assumption
BEV/PHEV with SiC (M Unit)	**5.1**	
Format of SiC Adoption		
% of Chip	30%	Assumption but calibrated with inputs from IHS and Yole
% of Module	70%	
SiC Content per Vehicle Estimate		
Value of SiC Diode & SiC Used in OBC, etc. vs. Inverter	30%	Assumption but calibrated with inputs from IHS and Yole
SiC Chip Value per Vehicle (US$)	188	
SiC Module Value per Vehicle (US$)	317	
Blended Average Value per Vehicle (US$)	**279**	
SiC Content per Vehicle Estimate		
SiC Chip Market Size from EV (US$M)	**1,415**	
Non-EV SiC Market Size in 2025 (US$M)	1,009	Forecast of Yole
Total SiC Market Size in 2025 (US$M)	**2,424**	

Source: Yole, IHS, US EPA, and Bernstein estimates (all data) and analysis

ROBOTAXI IN CHINA – THE FUTURE OF ROAD TRAVEL?

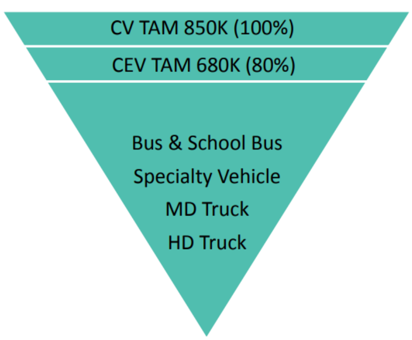
Driverless taxis, known as robotaxis, can be used commercially in China. Robotaxis were launched in May 2021 by Baidu with a fixed fare of RMB30 per ride. Current usage is limited to a small area in the Shou-Gang Industrial Park in western Beijing at a range of ~3km (a round trip of the area). In the next three years, Baidu plans to expand robotaxis to 3,000 vehicles in 30 cities. Unlike the West, China is likely to take the vehicle to everything (V2X) approach, which leverages roadside infrastructure to provide additional support for the autonomous driving (AD) algorithm, reducing hardware costs compared to the standalone strategy more commonly used in the US and Europe.

Safety is still the foremost concern, but Chinese passengers show high acceptance of AD and robotaxis. Though we do not think wide adoption will happen soon, robotaxis should ultimately replace traditional cars in the private mobility service sector (taxis, ride hailing, car rentals) — an RMB900bn market as of 2021 likely growing to RMB1,200bn in 10 years. Robotaxis will likely disrupt ride hailing. Leading player Didi is getting ready for the change and is in a privileged position, with the opportunity to enhance its driverless technology through the tremendous data contribution by the drivers on its network.

THE COMMERCIAL EV COMPETITIVE LANDSCAPE

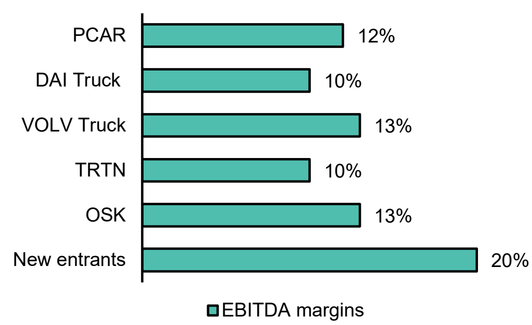
The transition from ICE to BEV in commercial vehicles (CVs) is near an inflection point. There is growing consensus among commercial truck OEMs that by 2025 total cost of ownership (TCO) curves of BEVs and ICEs will converge for a broader range of vehicles. **80% of 850,000 CVs sold in North America will likely transition to a BEV powertrain.** The vehicles most suitable for early BEV adoption operate under 200 miles per day and/or return to base at the end of the day. Buses (5% of the addressable market) were first movers, but the upcoming wave will likely be much larger, representing 70% of TAM. As a result, we estimate the TAM of medium- and heavy-duty BEV trucks is 580,000 units per year in the US or 680,000 units in North America.

EXHIBIT 10: **80% of the North American CV market is suitable for EV**



Source: Bernstein analysis

EXHIBIT 11: **Truck OEM EBITDA margin comparisons (note: Volvo Truck excludes buses)**



Source: Company reports and Bernstein analysis

EV margins could be 700bps higher than the 10-13% ICE incumbents currently generate. These margins are more achievable for high-volume manufacturers than specialty incumbents. The hurdle rate for breakeven profitability for new entrants into the specialty segments is 1,000 units p.a. in some cases, which risks fragmentation and low-price discipline; for high-volume manufacturers, scale and distribution serve as a powerful competitive advantage. **There is a strong bias toward vertical integration across incumbents and new entrants.** This approach captures a greater share of vehicle profits, enables better optimization of the powertrain, and is more capital intensive, so incumbents will be most likely to take it.

APPLE CAR...YES/NO? HOW GOOD? HOW BIG? WHO GETS HURT?

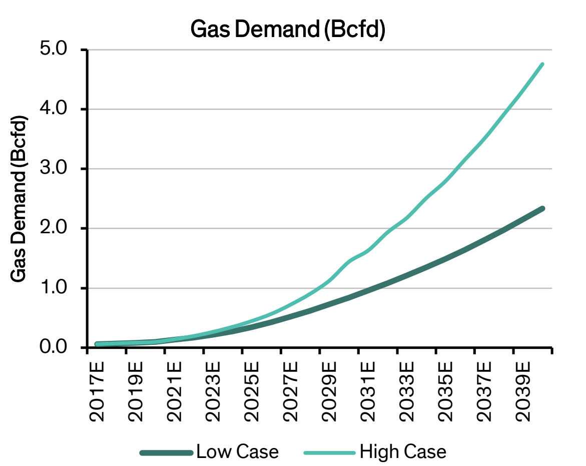
Six years into "Project Titan," Apple is still not expected to launch a car before 2024-25. While Apple likely finds the US$2tn+ automobile market attractive — due to its large addressable market, history of capturing disproportionate profits in lower-margin industries, and ability to subcontract manufacturing — its historical selectivity in bringing new products to market makes the launch of an Apple car, which we suspect will be all electric and have high-level autonomy, still uncertain.

Assuming Apple is ultimately able to launch a car in 2025, we believe that very optimistically, Apple could sell 1.5 million cars by 2030 — adding ~US$75bn in revenues, or about 15% of Apple's total revenues, effectively doubling Apple's revenue growth during the period (from ~3% to ~6%). We maintain Apple's entry into the auto market would be felt more by traditional (premium) auto OEMs rather than newer entrants like Tesla, akin to the entrance of the iPhone into the smartphone market.

EV GROWTH COULD DRIVE US GAS PRICES

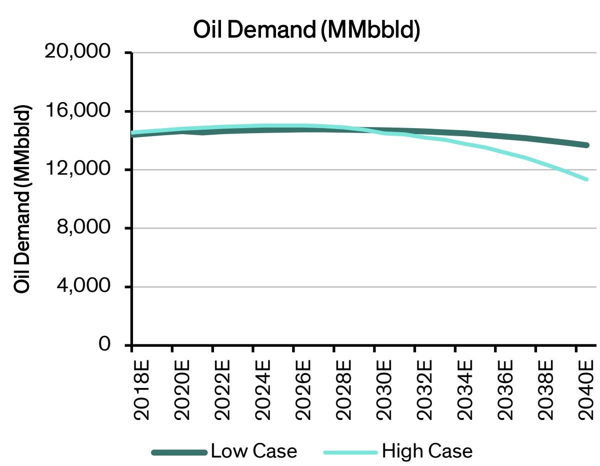
We are frequently asked by investors whether EVs could be good for US natural gas (albeit bad for oil demand). We find high penetration of EVs would indeed be good for US gas price, but perhaps not for the reason that most might think. The new demand for gas, even in a relatively bullish case, is actually quite small, owing to the high fuel efficiency of EVs (4-5x more fuel efficient than gasoline cars). Moreover, gas only makes up two-fifths of electricity generation, leading to only ~5bcfd of incremental gas demand by 2040 (6% of today's gas demand), even with high EV penetration.

EXHIBIT 12: **Increase in gas demand from EVs would require ~2.5-5bcfd more gas (~4-6% of current total domestic consumption, or 3-5% inclusive of exports)**



Source: Bernstein estimates and analysis

EXHIBIT 13: **Oil demand in the US would fall from 15mbd to 11.5mbd and 13.5mbd in the high and low case, respectively, if run pro rata across oil**



Source: Bernstein estimates and analysis

However, the larger and perhaps underappreciated impact on the gas market would be the decline in oil demand and, therefore, oil and associated gas supply, which should move gas price up. Further, if associated gas supply falls but demand remains constant, meeting gas demand would require bringing the higher-cost dry gas basins back into the equation faster. Thus, a view of high EV penetration might be most beneficial in the oil and gas sector to Fayetteville and Barnett players.

GREEN IS GOOD; SMART GREEN EVEN BETTER

Infrastructure enablers — public charging and grid backbone: The two main infrastructure investments to enable EV rollout are a public charging network and upgrades to the electricity distribution grid to cope with the rise in peak charging demand.

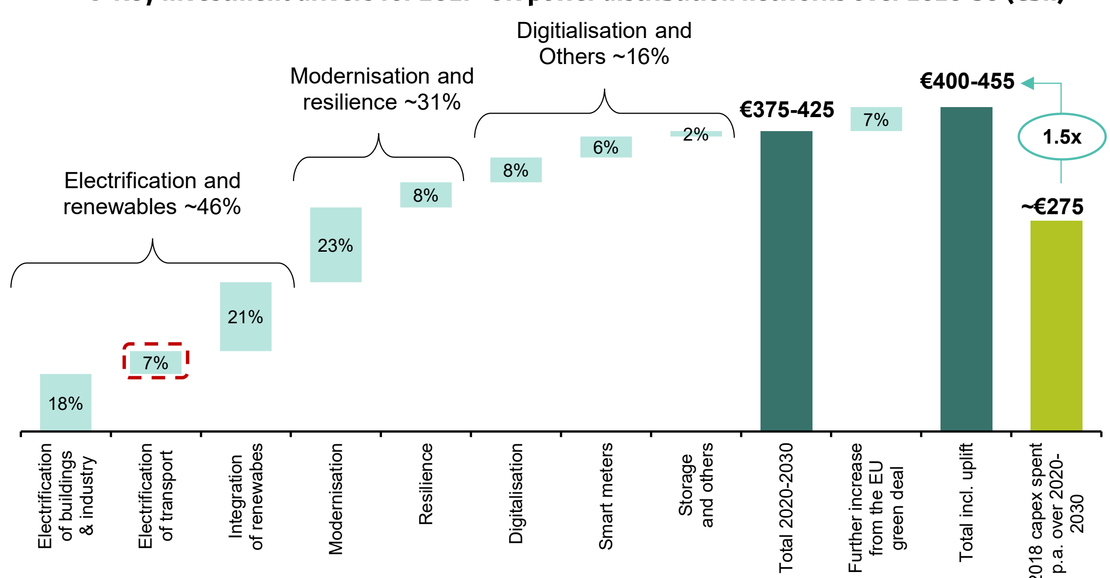
Public charging network, including fast chargers has been growing: Although slow chargers still represent 88% of all public charging points in Europe, fast charging has grown much faster at a 137% CAGR since 2011. We forecast investment in public charging infrastructure of ~€90bn by 2050 to support mass EV rollout in Europe.

EXHIBIT 14: **Public charging infrastructure required to support 100% EV penetration in Europe**

	2017A	2020A	2025E	2030E	2035E	2040E	2045E	2050E
EVs as % of new car sales	1.9%	10.7%	21.8%	51.6%	100.0%	100.0%	100.0%	100.0%
EVs as % of stock	0.3%	1.1%	6.7%	22.3%	54.0%	80.2%	92.7%	100.0%
Total # of EVs	121,661	213,367	347,631	847,047	1,608,916	2,057,111	2,276,620	2,412,734
# of super-fast charging points	2,454	3,569	16,410	61,162	156,396	240,560	284,658	312,550
# of fast charging points	8,858	17,815	75,434	268,510	670,910	1,017,696	1,193,107	1,301,330
# of slow charging points	110,349	191,983	255,787	517,375	781,610	798,855	798,855	798,855
investment required (EURm)		**129**	**1,498**	**3,961**	**6,789**	**3,702**	**1,791**	**1,542**
Cumulative investment (EURm)		**687**	**4,179**	**18,483**	**47,207**	**71,246**	**83,607**	**91,343**
% of fast/super-fast charging points		10%	26%	39%	51%	61%	65%	67%

Source: ACEA, International Energy Agency (IEA), and Bernstein estimates and analysis

EXHIBIT 15: **Key investment drivers for EU27+UK power distribution networks over 2020-30 (€bn)**



Source: Eurelectric/E.DSO, Monitor Deloitte data and estimates, and Bernstein analysis

Grid impact and investments: We expect electricity demand to increase by 25% when the entire car fleet is electric in Europe by 2050 and a further 5% by 2030. This impact is manageable but will require grid upgrades to overcome thermal and voltage limitations in local grids. Fast and ultrafast charging networks will also need some dedicated infrastructure. By 2030, distribution grids in EU27+UK will likely require €25-€35bn (7-8% of overall spend) for integrating EVs. By 2050, we estimate distribution grid investments for EV integration to be €100-€185bn in Europe.

EVs also presents an opportunity for the grid, and upgrades requirements can be minimized through smart charging and vehicle to grid (V2G): Smart charging systems (V1G) connect to the grid, and control charging rates and schedules to benefit the grid (and the user) by moving demand to off-peak/high renewables output hours. Furthermore, bi-directional V2G charging can enhance these advantages by using the vehicle battery to supply power back to the grid.

Electrification is key to decarbonize transport, industry, and buildings. To decarbonize electricity (and produce green hydrogen), global renewables capacity should grow from 1TW today to more than 30TW by 2050. Flexibility in power to complement wind and solar generation will grow in importance, and demand-side flexibility will play an important role. Uncontrolled EV charging could result in significant challenges for peak demand, whereas bi-directional flows from EVs to the grid (V2G) would be a source of valuable flexibility. Regulators will push for this flexibility: "It is paramount to immediately begin the deployment of smart charging and, whenever viable, of V2G solutions." Grid investments will increase to replace assets, to integrate renewables, EVs, and heat-pumps, as well as to digitize the grid. The impact of EVs on grid investments will depend heavily on the degree to which flexible demand (via smart V1G or V2G charging) is utilized and the state of the existing grid. Utilities view EV charging as an opportunity complementary to their existing business models and are deploying charging infrastructure, with notable examples being Engie's EVBox, Enel's dominance in Italy, and E.ON's pan-European presence.

EXHIBIT 16: **Opportunities and risks of electrification across the value chain**

	Generation			Networks		Retail	
Climate change trends	Wind/Solar	Flexibility Hydro/ batteries/ demand	Back-up/transition Gas/Nuke/ Coal/H2/CCS	Electricity	Gas	Services	Supply
Renewables	✓✓	✓	✗ ✗	✓			
Electrification (EVs, HPs, Industry)	✓✓	✓		✓✓	✗✗	✓	
Efficiency/ demand shift	✗			✗		✓	
Green gas / hydrogen	✓				✓		
Carbon capture							
Trends	✓✓✓✓	✓	✗ ✗	✓✓	✗	✓	
Description	+ Growth & cost exceed expectation + Adequate margins + 70-80% of mix by 2050, plus green hydrogen	+ Flexibility & storage valuable long-term + In Europe price-taker	+ Coal "closed" + Nuclear a political debate/expensive + Gas for transition + Hydrogen/nuke/ gas+CCS for last 10-20% back up. Remuneration?	+ Investments needed in to integrate renewables & growing demand, replace aging assets and to digitize	+ Natural Gas falls 80% by 2050 partially replaced by hydrogen/ green gas + Transition risks	+ EV charging + Energy efficiency services	+ Growth in de-mand + Margin pressure might offset growth

Source: Bernstein analysis

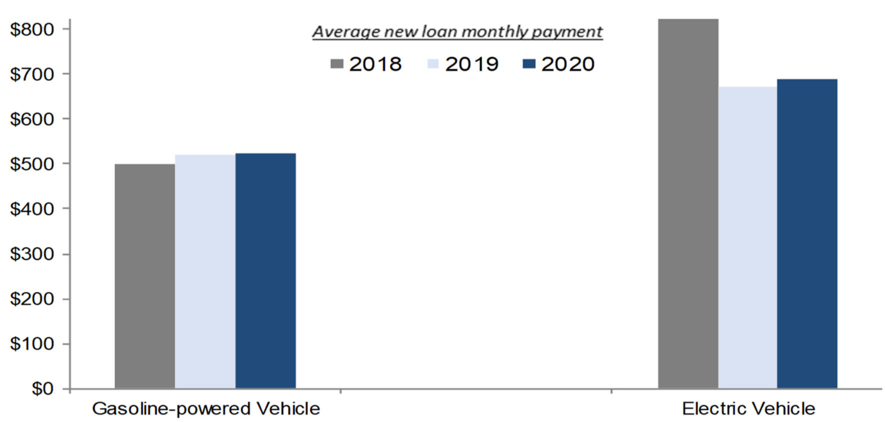
RISE OF EVS AND ROLE OF AUTO LENDERS

In the US auto finance market, captives (e.g., Ford Motor Credit) now represent the largest market share at 34% of total financing in 2020 — a position historically held by banks. We believe the value of captives further increases in an EV world as OEMs will have greater incentive to "own the consumer" to sell software updates, battery performance upgrades, autonomous driving features, connectivity, etc.

New vehicles in the US tend to be purchased most commonly with loans (56%); the next most common auto financing method is leasing (26%) and the rest are purchased outright in cash (18%). EVs tend to have considerably higher lease rates and we believe as the whole concept of "mobility as a service" becomes more attractive, people will turn more toward leasing vehicles. One of the limiting factors in faster adoption of EVs is cost. EVs tend to be meaningfully more expensive up-front compared to the average ICE vehicle. That said, battery technology improvements and greater manufacturing scale point to EVs becoming more competitive on price over time (see Exhibit 17).

Residual values: EVs do not have the greatest reputation of holding their value off-lease, as rapidly improving battery technology makes models just a few years old feel quite outdated. There is also a risk the residuals of EVs drop as pricing is inflationary on the back of massive government incentives. For now, of course, the used EV market is tiny. Longer term, carmakers should be in a much better position to manage residual values with all the vehicle data and more sophisticated software. Better, less volatile residuals, we believe also lend themselves to the leasing model becoming more attractive.

EXHIBIT 17: **EV costs have limited widespread adoption, but they are becoming more affordable**



Source: Experian and Autonomous analysis

VALUATION METHODOLOGY

See Disclosures Appendix of this *Blackbook* for details on the valuation methodology.

RISKS

See Disclosures Appendix of this *Blackbook* for details on the risks.

INVESTMENT IMPLICATIONS

See individual chapters of this *Blackbook* for investment implications.

GLOBAL AUTOS: WHEN AND WHERE WILL ELECTRIC VEHICLES DOMINATE?

OVERVIEW

The move toward zero-emission personal mobility triggers a radical transformation of the largest automotive value chain and has major implications for consumers, companies, and investors. Electric vehicle (EV) policies can even determine the outcome of elections. In this chapter, we offer our realistic assessment of global EV adoption by region. To some EV bulls, our penetration forecasts might look conservative.

- Globally, we expect EVs to account for 65% of new PV sales by 2040, the vast majority of which will be full battery EVs (BEVs). Europe will likely lead the way, with EV penetration set to reach 100% by 2035 (assuming the proposed EU's new Fit for 55 package is approved) or 2040 at the latest (if the auto industry's expected pushback to the plan bears fruit). China should follow with >70% EV penetration by 2040, while the US at just over 60% is expected to be below the global average (under current US policy, but likely higher if Biden's 40-50% EV target by 2030 is achieved). Wider EV adoption in the Rest of the World (roughly a third of global PV sales) will take years to materialize, pulling the global average down.

- Leaving aside industry lobbying, what stands in the way of much faster and broader BEV adoption? The biggest and more powerful pushback might come from consumers. If regulation forces consumers/voters to drive BEVs, compromising their lives (entailing hassles of charging, more expensive vehicles, major city restrictions, etc.), people might start voting with their feet. This can create a political dimension that will adjust the EV adoption curve to a socially bearable slope.

- We are convinced carmakers will play a meaningful role in the future of electric and connected mobility. It is naive to assume future EV TAM will be exclusive to new entrants. However, this is what current new versus traditional valuations suggest. We are also convinced that industry self-help — especially more dynamic wind-down of ICE operations and improved pricing — is a key ingredient for improved valuation of OEMs.

EV IS NOT A NEW CONCEPT

In recent years, the auto industry has spent a lot of time discussing new automotive technologies, the need to improve fuel efficiency and reduce carbon emissions, as well as the resulting emergence of EVs. But EV is not a new concept — in fact, it is a very old one. In the early 1900s, the electric motor was one of the three main types of engines for an automobile (the others being steam power and gasoline). For a brief time, EVs were more popular than gasoline cars. Now, some 120 years later, EVs appear ready to take the center stage once more — and this time, likely for longer. Many auto industry followers will be familiar with the GM EV1 — the carmaker's failed attempt to build the first mass-produced EV of the modern era in the late 1990s. A decade ago, in September 2011, as the industry was starting to embark on investments in new auto technology that would meet upcoming fuel efficiency legislations, Bernstein published a series of notes titled "The Future of Powertrain," exploring the potential and costs associated with the move. An even older Bernstein report, dating back to 2007, began with the following statement: *"We believe an increasing focus on carbon emissions combined with improving battery technology is bringing electric vehicles closer to mass production."*

It may have taken nearly 15 years, but that moment is finally here. Almost the entire auto industry is increasing its efforts to develop and roll out alternative-fuel cars, and EVs are starting to gain popularity with consumers across the globe. In 2021, full BEVs will likely account for over 5% of global light vehicle production — no longer a "niche" technology. With intensifying emissions regulations and dramatic clean air initiatives in several cities and regions, the only way for automakers to meet their targets is by selling more EVs. We can all agree that EV demand will only increase in the coming years. At some point in the future, EVs will inevitably become more than popular than gasoline-powered cars again — the question is not if, but rather when and where.

THE BERNSTEIN GLOBAL EV SALES MODEL

In this chapter, we introduce our new global EV sales model and take a closer look at EV demand by region out to 2040. Our bottom-up regional analysis is based on a simple question: "What does the auto industry need to deliver in order to ensure compliance with fuel economy and CO2 emissions standards?" Our penetration forecasts cover BEVs, plug-in hybrid electric vehicles (PHEVs), hybrid electric vehicles (HEVs), and ICE powertrains in all major regions globally.

This may seem like an overly simplistic approach — we acknowledge that a number of other factors also come into play, including changing consumer preferences and sentiment toward EVs, cost, government subsidies and incentives, product availability, battery range, and charging infrastructure. However, we believe regulation underpins the shift to EVs and will continue to do so in the future.

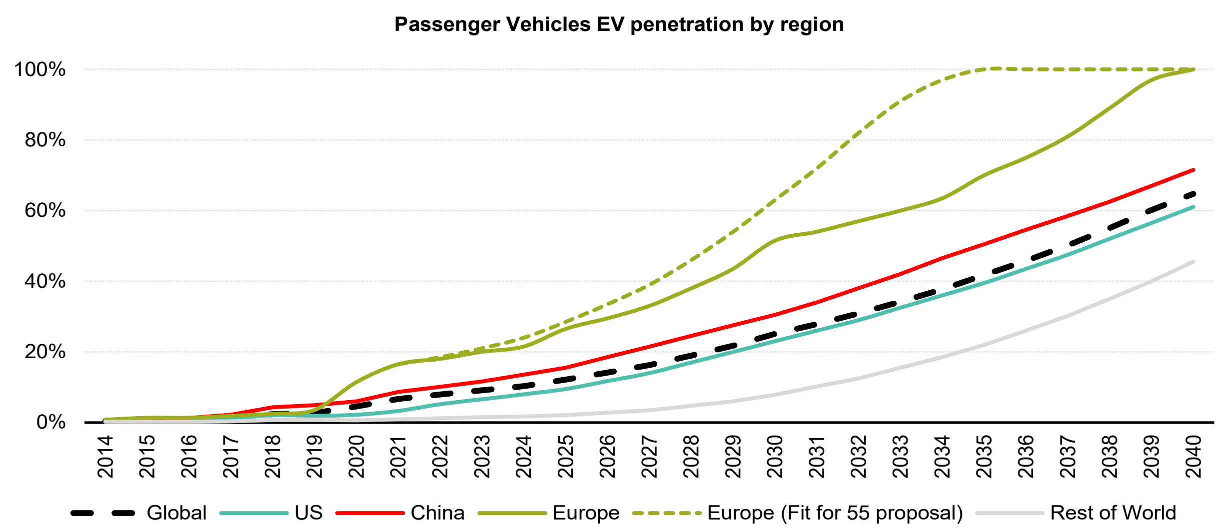
Unless automakers severely restrict their vehicle mix or take temporary measures (such as pooling), the only way to comply will be to rush new fuel-saving technologies to the market. Non-compliance with emission regulations can lead to major problems. In the past few years, auto companies have paid major fines, settled with courts and consumers, recalled fleets of vehicles, and exposed their customers to a lot of inconvenience. Needless to say, this is a key reason for the very depressing valuation of OEM stocks.

Significant electrification will be necessary from basic 48V systems through to full BEVs. Whichever way we look at this, powertrain electrification is the only viable, globally available, and industrialized technological solution in the long term in order to comply with regulations and emission standards. Obviously, there are different degrees of electrification required depending on a vehicle's use case and selling price. EV penetration will widely depend on regulation differences and consumer acceptance across regions.

Globally, we expect EVs to account for ~65% of new PV sales by 2040 (see Exhibit 18), the vast majority of which will be full BEVs (see Exhibit 19). Europe will likely lead the way, with EV penetration set to reach 100% by 2035 (assuming the EU's new Fit for 55 proposed package is approved) or 2040 at the latest (if the auto industry's expected pushback to the plan bears fruit). China should follow with >70% EV penetration by 2040, while the US at just over 60% is expected to be below the global average (under current US policy, but likely higher if Biden's 40-50% EV target by 2030 is achieved). Wider EV adoption in the Rest of the World (roughly a third of global PV sales) will likely take years to materialize, pulling the global average down.

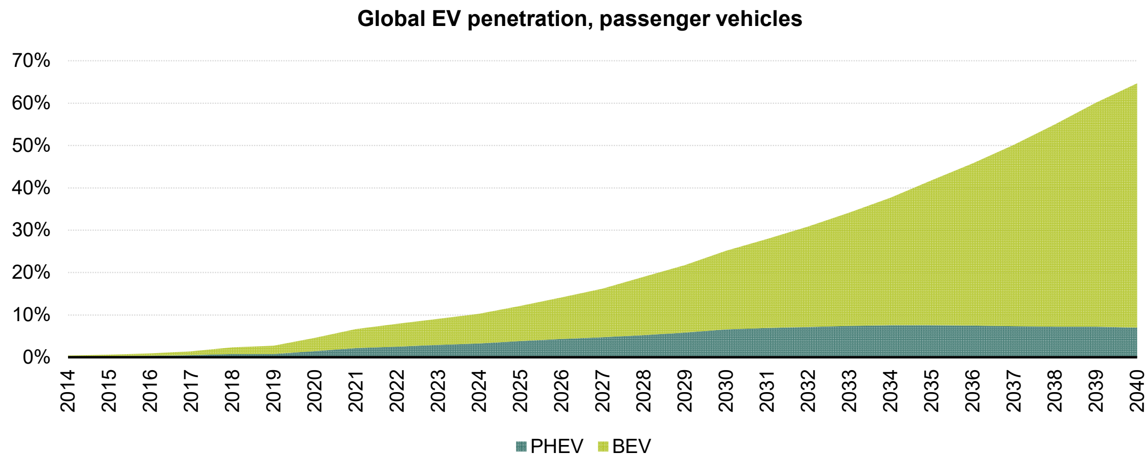
A number of governments worldwide have established or proposed fuel economy or greenhouse gas (GHG) emission standards for PVs and light-duty CVs/light trucks. Regulations in these markets cover more than 80% of global PV sales. They influence long-term strategic planning of all major auto manufacturers around the world and are among the most effective climate-change mitigation measures implemented over the past decade. Even though governments have taken differing approaches to shaping their regulations, using different drive cycles and vehicle certification test procedures, the outcome is the same: vehicular CO_2 and other emissions need to be dramatically lowered (see Exhibit 20).

EXHIBIT 18: **We forecast global EV penetration of ~65% by 2040**



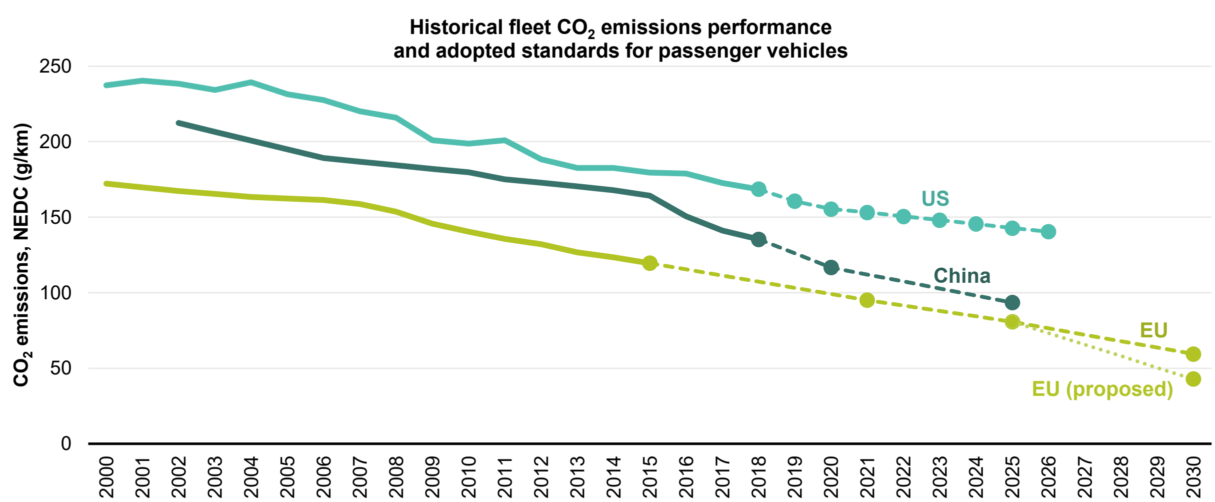
Source: IHS Markit, and Bernstein estimates (2021+) and analysis

EXHIBIT 19: **BEVs will likely account for the majority of EVs**



Source: IHS Markit, and Bernstein estimates (2021+) and analysis

EXHIBIT 20: **CO2 emission targets for new vehicle sales are getting tougher: EU is leading, other regions following**



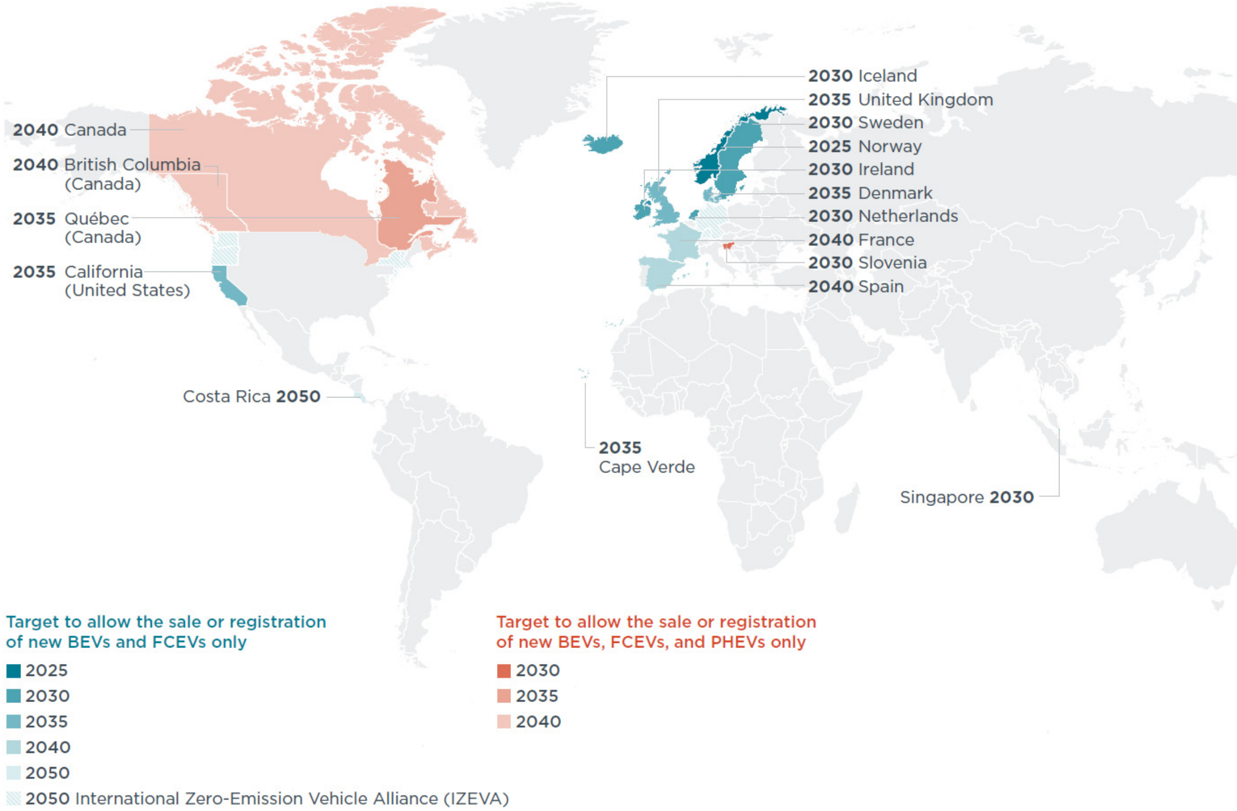
Note: gCO_2/km normalized to NEDC; US includes Passenger Cars and Light Trucks

Source: International Council on Clean Transportation (ICCT) and Bernstein analysis

ICE bans will further influence consumer demand

Emissions standards are not the only challenge the auto industry needs to navigate through in the coming years. The shift to EVs and changing consumer perception is also influenced by a forced end to sales of diesel and gasoline cars through governments bans, at both the national and regional level. These bans have been the most prolific across Europe and predominantly affect passenger cars. The earliest ban will be in Norway in 2025; however, volumes there are small. The UK's ban on ICEs by 2030 will have the largest impact in Europe on the number of ICE vehicles sold (though sale of hybrid cars will be allowed until 2035). Outside Europe, a date for ICE bans has been put in place in California, Canada, and Singapore, to name but a few (see Exhibit 21).

EXHIBIT 21: **Governments targeting 100% phaseout of new ICE car sales**



Source: ICCT and Bernstein analysis

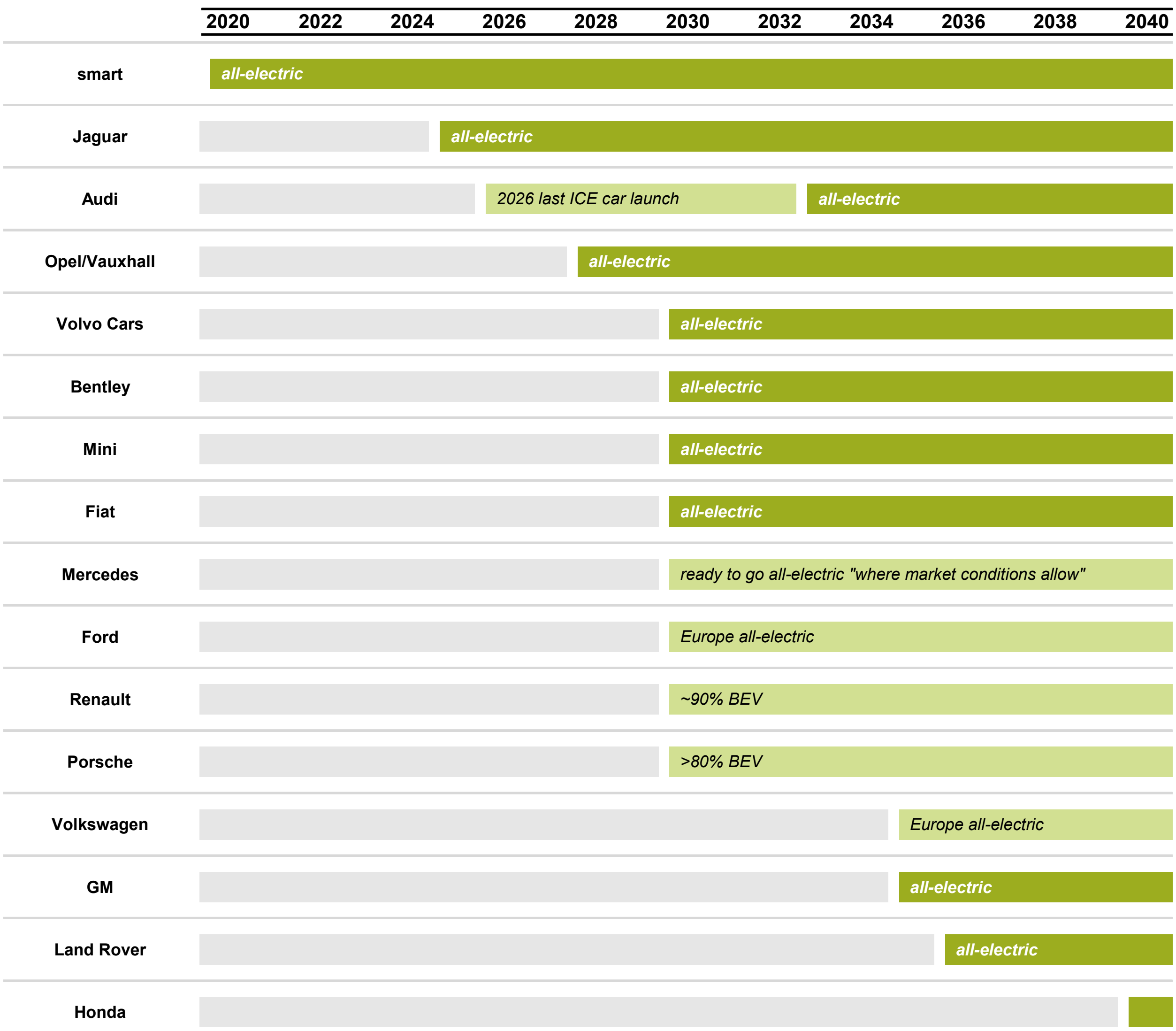
The race to all-electric

The European Union (EU) has long had the toughest CO2 emissions regime as it combines demanding targets with severe non-compliance fines. This is why Europe has become the most prominent region globally with respect to powertrain electrification and is now acting as a battleground for the race to all-electric. These days, it seems every other week, a new automotive brand is pledging to "phase out ICE sales from 2025" and become "all-electric by 2030," with some putting their focus on Europe, in particular. For most brands, this will be an important milestone as they have been using the ICE for over a century and it's been a core pillar of their brand DNA.

In a highly competitive market, with automakers long battling to differentiate themselves from the crowd, it is certainly interesting to remember that BMWi and Smart were early adopters among traditional OEMs. BMW unveiled its fully electric i3 and i8 models at the 2009 Frankfurt Motor Show, and series production of the i3 was launched in the autumn of 2013. Peak BMWi sales were at 60,000 in 2019. At the 2019 Frankfurt Motor Show, Daimler's Smart brand unveiled its new EQ Fortwo and EQ Forfour models, which were designed from scratch as fully electric cars. With annual global sales of around 100,000 units, Smart is a marque that is largely irrelevant outside Europe. However, this marked a historic turning point for the broader auto sector, as Smart became the first brand from a "traditional" automaker to switch its entire product portfolio from gas engines to an electric-only roster from the beginning of 2020.

Many more automaker brands have followed suit since, including GM, Audi, Volvo Cars, JLR, Fiat, Opel/Vauxhall, Mini, VW (Europe only), Ford (Europe only) and, more recently, Mercedes as the automaker is "getting ready to go all-electric where market conditions allow" — a clever but also realistic piece of communication (see Exhibit 22). Interestingly, when Ursula von der Leyen, President of the European Commission, appeared before the press on July 14, 2021 to announce the EU's Fit for 55 proposal, she hinted to the fact that the voluntary ICE phase-out announcements by the manufacturers themselves have assisted with the decision to propose a 100% reduction in CO2 for new vehicle sales by 2035: *"Over the last few weeks and months, to some extent the car builders have come up with the answer themselves. In the last few weeks, about a dozen of the large global automakers have announced that they will switch their fleet to emission-free vehicles between 2028 and 2035."*

EXHIBIT 22: **Global OEMs ICE phase-out plans**



Note: JLR (Jaguar, Land Rover), Stellantis (Opel/Vauxhall, Fiat), Ford, GM, and Honda are not covered by Bernstein.

Source: Company reports and Bernstein analysis

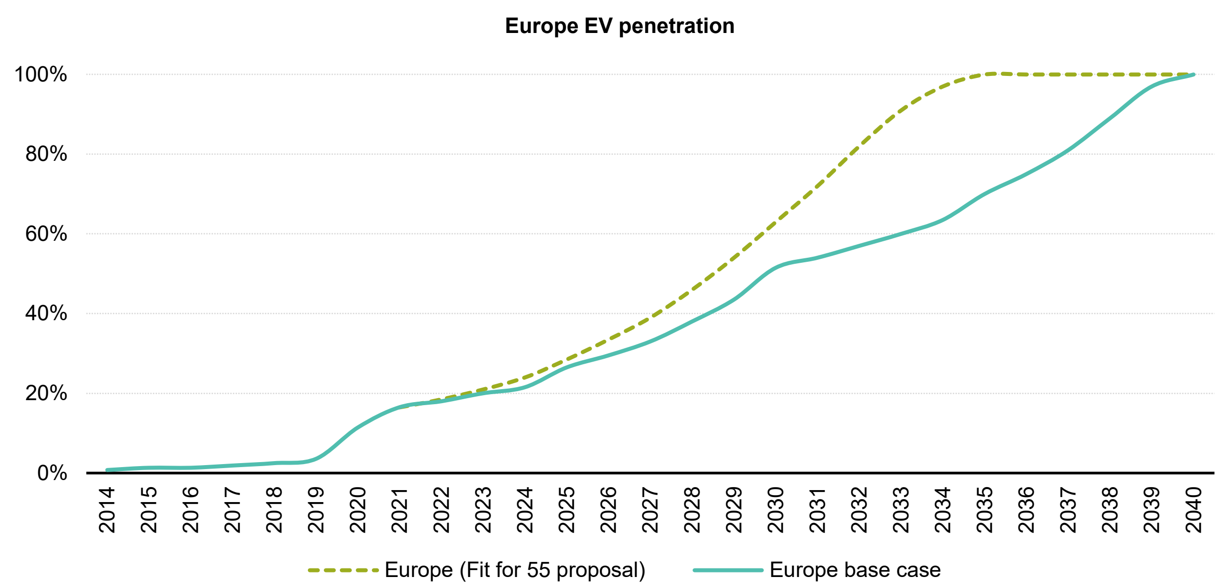
EUROPE — LIFE ALREADY LOOKED TOUGH...IT'S ABOUT TO GET EVEN TOUGHER

Europe is the toughest market globally for CO2 emissions legislation. For several years now, the European auto industry has been under massive pressure to deliver a big near-term cut in CO2 emissions, facing almost a 25% reduction by 2021 compared to 2019 levels. A cut of this magnitude has never been achieved or attempted before. Thereafter, the current adopted standards dictate a further 15% reduction by 2025 and a total 37.5% CO2 cut by 2030.

This was already an immense task and it's about to get much tougher. The industry was already struggling to see how it could hope to meet these targets, but the European Commission is determined to tighten them further. The latest Fit for 55 proposal is certainly ambitious and will require an even faster shift to EVs.

The policy proposal sets a CO2 target value of -55% for passenger cars by 2030 (versus 2019 levels) and a 100% reduction in CO2 for new vehicles by 2035. Under our base case scenario (i.e., pre-proposal), we forecast a 52% EV penetration in 2030, rising to 70% by 2035 and 100% in 2040. While the Fit for 55 climate plan will not require a significant change in the EV outlook in order to meet the 2030 target (the currently adopted targets were widely expected to be revised anyway), it is likely to result in an EV sales boom and a rapid acceleration in EV adoption, with consumer interest picking up before the 2035 deadline (with the *de facto* ban on new diesel and petrol cars). Under this scenario, our 2030 EV estimates rise to 63% (see Exhibit 23).

EXHIBIT 23: **Assuming the EU's Fit for 55 proposal is adopted, we expect a 70% EV penetration by 2030-31**



Source: European Automobile Manufacturers' Association (ACEA), and Bernstein estimates (2021+) and analysis

The empire strikes back?

Before the roadmap becomes a law, the auto industry is expected to put into use its notorious lobbying power and push back on the plan. Achieving sales of zero emission-only vehicles by 2035 will be particularly challenging for certain countries. In 2020, BEVs made up 5.4% of all new car sales across the EU. Of the 27 member states, 19 had a battery electric car market share of less than 5%, and 10 had a BEV market share less than 2%. In addition to the availability of affordable BEVs, a major question is whether consumers are ready to move to full BEVs as this will impact their ability to use their cars on their own terms, especially if they don't have access to home/overnight charging.

Undoubtedly, a tough battle lies ahead for the European Commission as it negotiates with member states. The measures may prove too controversial for some: before the announcement, the French government was among those lobbying for a later ICE phase-out (by 2040 instead of 2035). Several auto companies and trade bodies are already pressurizing governments to reject the proposal. The German Association of the Automotive Industry, the VDA, said the measures were "anti-innovation," calling them "almost impossible to achieve" for companies, including suppliers. Spain's motor industry, the EU's second largest after Germany, said the sector had been singled out for unfavorable treatment even though other industries between them produced more than two-thirds of the EU's GHG emissions and urged the Spanish government "to consider its position." Ultimately, we would not be surprised if some concessions are made, e.g., by allowing sales of hybrid cars to 2040.

The biggest and most powerful pushback might come from consumers. If regulation forces consumers/voters to drive BEVs, compromising their lives (with the hassle of charging, more expensive vehicles, major city restrictions, etc.), people might start voting with their feet. This can create a political dimension that will adjust the EV adoption curve to a socially bearable slope.

The auto sector is unlikely to get off easy

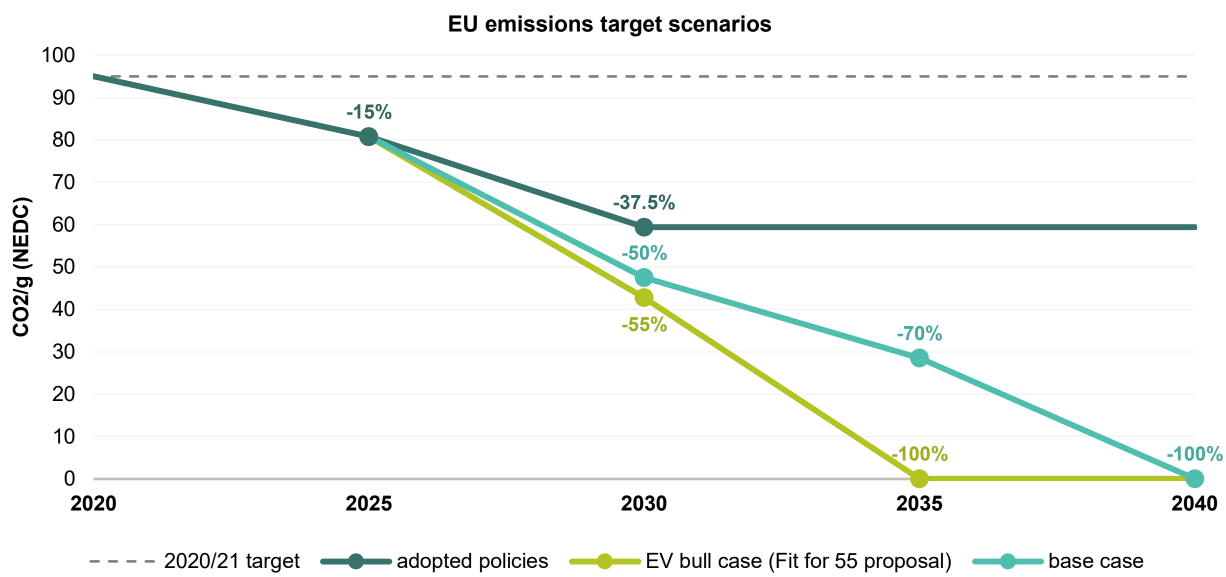
The Fit for 55 proposal forms the cornerstone of the European Green Deal, which was unveiled in late 2019. The overarching objective of the European Green Deal is to reach net-zero GHG emissions by 2050, a goal that will be enshrined in a "Climate Law." With road transport accounting for about 20% of GHG emissions in the EU, and average fleet emissions increasing rather than decreasing in past years, the automotive sector is once again one of the key areas of focus.

While the current adopted objective to deliver a 37.5% cut in emissions by 2030 was always likely to be revised, the proposed measures are set to be dramatic. The magnitude of the task now faced by the industry is ever more daunting and the economics look fearsome. The new rules set up a complicated transition period that may create uncertainty and will require a fundamental change in auto industry technology, industrial footprint, employment, and corporate structure, as automakers are struggling to come up with new strategies.

Far before 2030, even the 2021 and 2025 targets will likely be challenging

The looming new 2030 and 2035 CO2 rules look set to ratchet up the pain on the European industry (see Exhibit 24). But even before that, OEMs need to find a way to clear the near-term problem: the European Commission's 2021 CO2 rules. After the 2015 target of 130g/km was set in 2009, the European Commission issued a regulatory proposal specifying a 95g/km target by the end of 2021 (see Exhibit 25). This 27% reduction in CO2 over six years already represented an enormous challenge for the automakers, who have failed to make progress in recent years and are all now engaged in a rapid scramble to meet the 2021 guidelines. Time is running out — for the European fleet to hit 95g/km by the end of 2021, average CO2 emissions need to fall over 10% annually. The Commission will levy huge fines for non-compliance. These fines are deliberately large and onerous because they are designed to steer automakers toward delivering lower carbon technologies rather than being incentivized to "pay to pollute."

EXHIBIT 24: **Revision of the 2030 targets was expected, but the route to zero emissions by 2035 looks challenging**



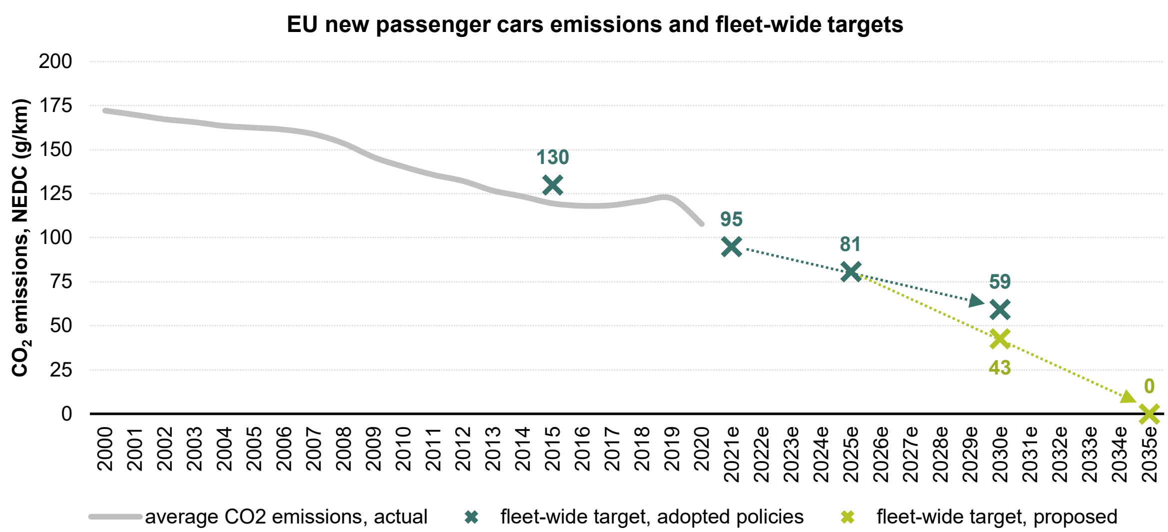
Source: European Commission, and Bernstein estimates and analysis

Instead of paying fines, most OEMs are rushing new technologies to market that they hope will allow them to meet, or at least get close to, their targets. This will take the form of a suite of technologies, from "basic" 48-volt electrical systems via mild PHEVs and full BEVs. This will be costly, but not as financially painful as paying the fines. It is important to note that the cost of CO2 reduction is not linear. The first gram of improvement is obviously cheaper than the last (e.g., going from 120 to 119 is a lot cheaper than going from 96 to 95). OEMs can make easy wins at a reasonable cost to improve their CO2 output from current levels. The final few grams will be the most expensive, and some OEMs may fall short and choose to pay a modest amount in 2021 or pool emissions with other manufacturers, rather than crowd the market with BEVs to the detriment of pricing.

The industry made virtually zero progress on CO2 emissions between 2014 and 2019

From 2007 to 2015, OEMs drastically improved their fuel economy through a combination of light-weighting, ICE efficiency improvements, and hybridization. Many OEMs beat the 2015 target of 130g/km early. In 2015, the European fleet average stood at 120g/km, 8% below the required level and a decrease by nearly one-third since 2007. However, progress has stalled in recent years. In 2016, fleetwide emissions improved modestly to 118g/km before rising in 2017 and rising further still in 2018 and 2019 to more than 122g/km. Diesel's collapse, the SUV boom, and more stringent test parameters made it much harder for OEMs to reduce their emissions. The European auto industry is required to deliver a ~25% reduction in CO2 emissions on a fleet basis in 2021 versus 2019 levels. The industry has been slow to accept the magnitude of the challenge. It has also been rather vague (and arguably even evasive) about the profit impacts when talking to investors. This complacency — both internal and external — is partly due to the industry's long history of successfully renegotiating or delaying regulations: for a while, the industry held out hope that the rules might be revised. But regulators in Europe have become less conciliatory and national political support — including in Germany and France — seems to have waned.

EXHIBIT 25: **European CO2 emissions standards: OEMs are required to reach an average of 95g/km by end-2021**



Source: European Environment Agency (EEA) data and estimates, and Bernstein analysis

CHINA: MID-TEENS EV PERCENTAGE BY 2025

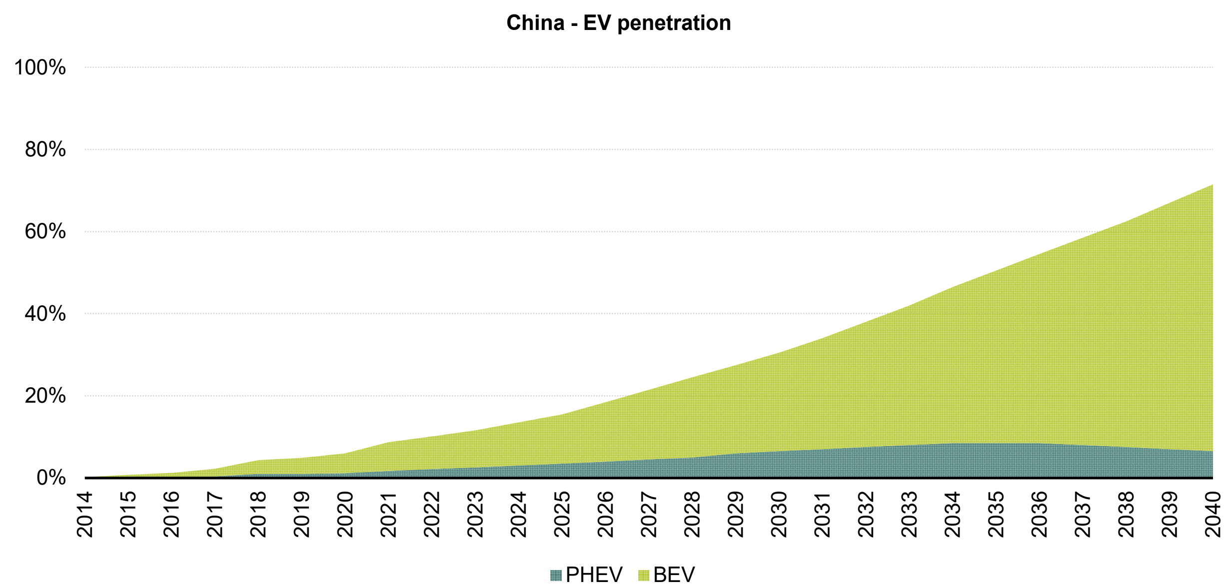
We expect EV adoption in China will continue to be driven by policies in the medium term. Chinese policymakers have been most effective with pushing EV adoption within corporate and leasing fleets and in Tier 1 cities. For example, a number of cities have published rules mandating that all new ride-hailing cars must be EVs.

While the Chinese government aims to have new energy vehicles (NEVs; defined as BEVs and PHEVs) make up ~20% of all vehicle sales by 2025, we consider that unlikely. In the absence of major technological breakthroughs, we forecast EV penetration will only reach a mid-teens percentage over the medium term in our base case scenario, falling short of the government's goal. By 2025, we project China auto sales to reach 25-26 million units and NEV sales of ~4 million units, implying a 15% EV penetration rate.

Longer term, EV adoption among individual buyers in other cities will be key to lifting overall EV penetration rate. Individual buyers in other cities make up ~80% of PV sales in China, but only ~40% of China's NEV sales. We forecast overall penetration could reach 31% by 2030 if 20% of the individual buyers in other cities go electric, coupled with 50% penetration among individuals in the top 6 cities and 80% penetration among corporate and leasing buyers. Based on our China PV sales volume projection of 30 million units in 2030, NEV sales will reach approximately 9 million units. By 2040, we expect EV penetration to reach ~70% (see Exhibit 26).

To boost EV sales, the government could continue to impose stricter policy measures and expand them to cities that currently don't have license plate restrictions. Or more organically, we observe that successful model rollouts, especially in the premium brand segment, can meaningfully drive EV adoption.

EXHIBIT 26: **China: we forecast overall EV penetration to reach 31% by 2030 and ~70% by 2040**



Source: China Association of Automobile Manufacturers (CAAM), and Bernstein estimates (2021+) and analysis

We expect 2021 to be an aggressive EV year for OEMs, as many seek to not only keep up with ever-climbing compliance hurdles but also make up for lost ground in 2020. That said, the lack of underlying consumer demand for EVs due to an insufficient EV charging infrastructure, lack of residential parking, and affordability constraints will, in our view, remain a significant challenge for OEMs as they seek to achieve Corporate Average Fuel Consumption (CAFC)/EV credit compliance in 2021 and beyond. Pockets of EV demand have appeared in the premium segment, mainly in the top cities. However, we suspect some mass market players may be forced to pursue low-priced EV fleet sales for the sake of

CAFC/EV credit compliance, as in the case of SGM Wuling's Hongguang Mini BEV. We worry this could lead to persistent margin pressure in the coming years.

Rollback of 2021-23 credit targets sends a message

In mid-2020, China's MIIT published the final rules for China's 2021-23 CAFC/EV credit targets, ending a year of debate and speculation on how Chinese policymakers would shape the industry's medium-term EV adoption targets in the face of growing evidence that consumer EV adoption was not progressing as desired, as well as mounting EV losses at the OEMs. In the end, while the headline targets for 14%, 16%, and 18% EV credit quotas were retained, we think the final rules represented a partial softening of China's EV credit quota policy and confirmed a shift toward greater emphasis on gasoline fuel economy improvement and hybrids. The inclusion of a rising "fuel-saving vehicles" multiplier means the real hurdle for compliance will be more lenient. Under the final rules, hybrid sales volumes will account for 0.5x, 0.3x, and 0.2x in 2021-23 in the calculation of annual EV credit targets. This means hybrid sales will become more effective at lowering the overall hurdle for EV credit compliance.

Taking a step back, we think the final 2021-23 CAFC/EV rules are important for a couple of reasons. First, for their own sake, and second because they represent the first time Chinese policymakers had made a major concession to the auto industry on the subject of EV production targets. Ultimately, we think the final rules represent a compromise on the part of Chinese policymakers. One could reasonably argue the rollbacks contained in the 2021-23 final rules were partly in response to the Covid-19 outbreak. But major headwinds (affordability, lack of charging infrastructure, etc.) continue to work against consumer EV adoption in China. We wonder if the Chinese proverb that "the law cannot be enforced when everyone is an offender" will continue to apply in future years if consumer EV demand remains lackluster, and stand in the way of auto industry CAFC/EV credit compliance.

CAFC credit compliance remains a high hurdle for many other OEMs

We don't doubt that China still wants to push for higher EV adoption over time. But for OEMs without access to hybrid technology, CAFC credit compliance will continue to imply EV production volume hurdles that exceed those implied by EV credit compliance alone.

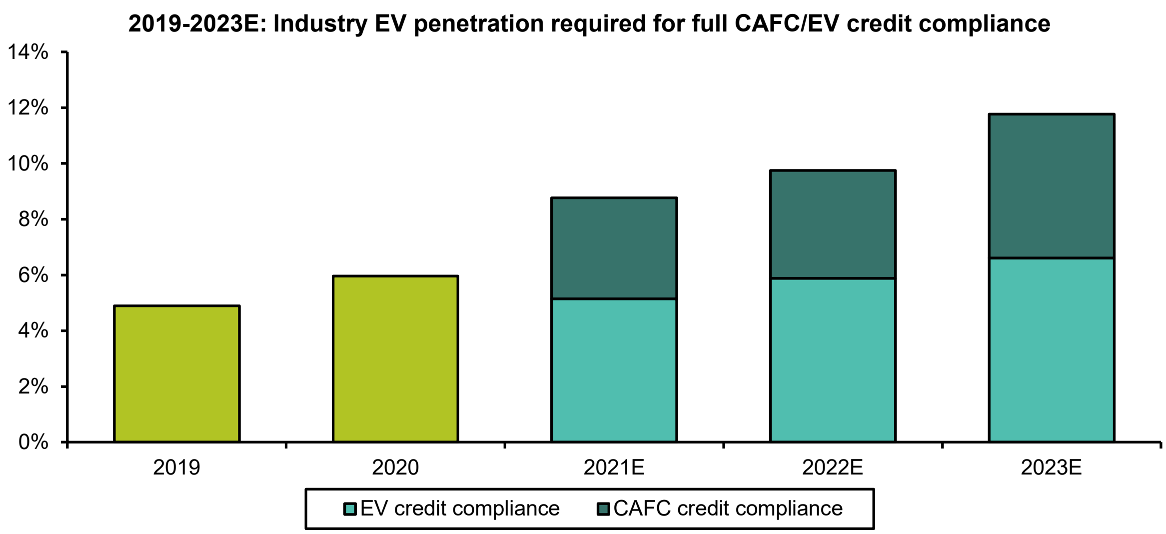
Within BEV/PHEV volumes, we assume BEV will remain a more popular powertrain versus PHEV, at an 80:20 mix, in line with the last couple of years in China. We estimate the Chinese auto industry will need to achieve ~5.1% EV penetration in 2021, rising to ~6.6% in 2023, if it is to achieve full EV credit compliance (see Exhibit 27). Incorporating the demands of CAFC credit compliance, we think full compliance across the industry will require ~9% EV penetration in 2021, rising to ~12% in 2023 (see Exhibit 28). In practice, we think the combination of lackluster consumer EV demand and the struggles of China's minor OEMs means actual industry volumes are at significant risk of falling short of these numbers. It will be interesting to see if Chinese policymakers will be accommodative again if and when this happens, or if they come down harder on offenders.

EXHIBIT 27: **We think full EV credit compliance across the industry will require over 6% BEV/PHEV sales penetration by 2022-23 — levels already reached today...**

		2019	2020	2021E	2022E	2023E
BEV mix		79%	80%	80%	80%	80%
PHEV mix		21%	20%	20%	20%	20%
Credits per BEV	*a*	5.8	5.2	3.0	3.0	3.0
BEV share of overall sales	*b*	3.9%	4.8%	4.1%	4.7%	5.3%
BEV credits	***c = a x b***	**22.4%**	**24.6%**	**12.4%**	**14.1%**	**15.9%**
Credits per PHEV	*d*	2.0	2.0	1.6	1.6	1.6
PHEV share of overall sales	*e*	1.0%	1.2%	1.0%	1.2%	1.3%
PHEV credits	***f = d x e***	**2.1%**	**2.4%**	**1.6%**	**1.9%**	**2.1%**
BEV+PHEV penetration	***g = b + e***	**4.9%**	**6.0%**	**5.1%**	**5.9%**	**6.6%**
Credit target	***h = c + f***			**14.0%**	**16.0%**	**18.0%**

Source: MIIT, and Bernstein estimates and analysis

EXHIBIT 28: **...but shortfalls in CAFC credit compliance will imply a higher level of EV sales penetration is needed; we estimate full CAFC/EV credit compliance will require 9%, 10%, and 12% EV penetration for 2021, 2022, and 2023, respectively**



Source: MIIT, company reports, and Bernstein estimates and analysis

2020 CAFC/EV credit compliance scores fell short of target

In 2020, the industry failed to achieve CAFC credit compliance in China, and several OEMs ran into a net CAFC/EV credit deficit in 2020. These OEMs will have to make up for the deficit either by drawing on credits carried forward from past years or by purchasing credits from players with surplus (e.g., EV pure-plays like Tesla or other EV startups) in order to achieve compliance.

On a volume-weighted basis, the industry achieved CAFC of 5.75L/100km in 2020, compared with a target of 5.37L/100km. Excluding imported vehicles, which generally have higher fuel consumption, domestically built cars reached aggregate CAFC of 5.69L/100km versus a target of 5.33L/100km.

Compared with an industry production volume of 19.9 million units in 2020, the Chinese government's CAFC/EV credit compliance rules implied that OEMs needed to generate 2.4 million EV credits (i.e., ~12% of production). In practice, the MIIT's 2020 data showed a total of 3.27 million EV credits generated over the course of the year. Under the dual CAFC/EV credit system, however, after netting 3.27 million units of EV credits against -7.45 million units of CAFC credits, the industry is left with a shortfall of -4.18 million units.

EV credits were priced around ~RMB 2,000-3,000/credit in 2020. With the industry-wide net credit shortfall in 2020 and, hence, a depleting carry-forward credit balance, credit pricing is expected to go up this year. Media recently reported that FAW VW will buy credits from Tesla at RMB 3,000/credit. Looking at 2020 on a standalone basis (i.e. assuming there is no carry-forward credit or pooling of credits with related entities), -4.18 million EV credits in shortfall represents an RMB12.5bn (~US$2bn) trade opportunity for the industry.

Various modifications to the 2020 CAFC/EV credit calculation (announced in February 2021) did not help much either. This included lowering CAFC requirements for vehicles equipped with technologies that improve fuel efficiency (e.g., start-stop systems, braking energy recovery systems, and gear shift reminder systems), and allowing NEV credit deficits incurred in 2020 to be made up for with surplus generated in 2021. Despite the modifications, even some of the larger carmakers struggled with compliance.

US: UNPREDICTABLE POLICY MAY HINDER FASTER ADOPTION

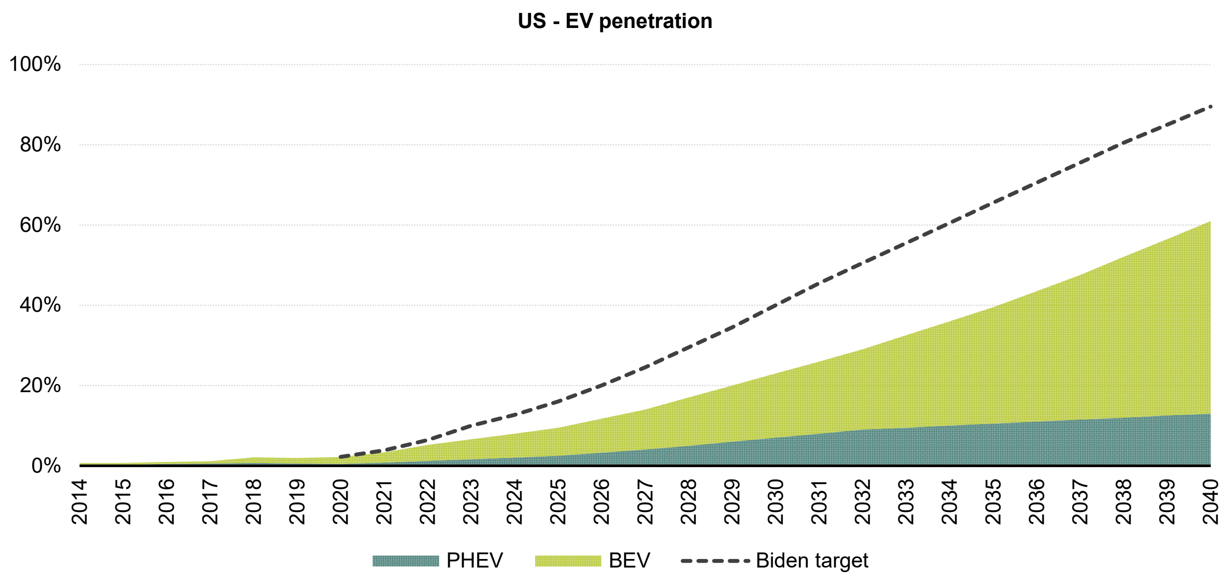
The US has been a laggard in terms of EV adoption compared to Europe and China. While fuel economy standards have been in existence for many years, targets to date have been manageable and mostly met through improvements to existing ICE technology.

Importantly, standards are constantly revised and have been made either easier or harder to meet, depending on whether a right- or left-wing government was in office. More recently, under former President Trump, the National Highway Traffic Safety Administration (NHTSA) sought to indefinitely delay and then reverse Obama-era penalties. As a result, in 2020, a new final rule was issued that relaxed the GHG and Corporate Average Fuel Economy (CAFE) standards for model year (MY) 2021-26 vehicles.

In addition, manufacturers have the option to pay fines in lieu of meeting the standards. During the Trump administration, the NHTSA did not increase penalties for non-compliance, meaning many automakers preferred to pay fines (even amounting to billions of dollars) than build more efficient fleets. Simply put, the fines appear to be too low to motivate compliance.

Since Biden took office, it has long been assumed that the CAFE standards would once again be revised. The recently proposed rule is set to cover MY 2023-26 vehicles and implies EV adoption rates similar to those under the Obama administration (the 2012 rule). The Biden administration is also negotiating with automakers to 'pledge' for a 40-50% EV target by the end of the decade. Increasing EV adoption from 2% in 2020 to >40% in 2030 will be a daunting task, while the voluntary nature of the commitment makes the proposal unenforceable. This target will almost certainly require a suite of policies such as enhanced purchase incentives and huge investments in charging infrastructure, which will need approval by Congress, thereby creating further uncertainty. We expect EV penetration of around 60% by 2040, with further upside potential should policy become more aggressive toward EV (see Exhibit 29).

EXHIBIT 29: **Long-term EV adoption may remain uncertain, given the rollback of standards in 2020**



Source: SNE Research, Bureau of Economic Analysis (BEA), and Bernstein estimates (2021+) and analysis

REGULATORY BACKGROUND

The US has two sets of parallel standards:

- CAFE standards adopted by the NHTSA, an agency within the Department of Transportation (DoT), and
- GHG emission standards adopted by the US Environmental Protection Agency (EPA).

The first CAFE standards were adopted in the 1970s, in response to a spike in gas prices prompted by the Arab oil embargo. The fuel economy standard stayed essentially constant over the ensuing decades. Then in 2008-09, a dramatic spike in oil prices due to a variety of factors, an administration supportive of tackling climate change, and a domestic auto industry facing bankruptcy provided momentum for significantly upping the standards.

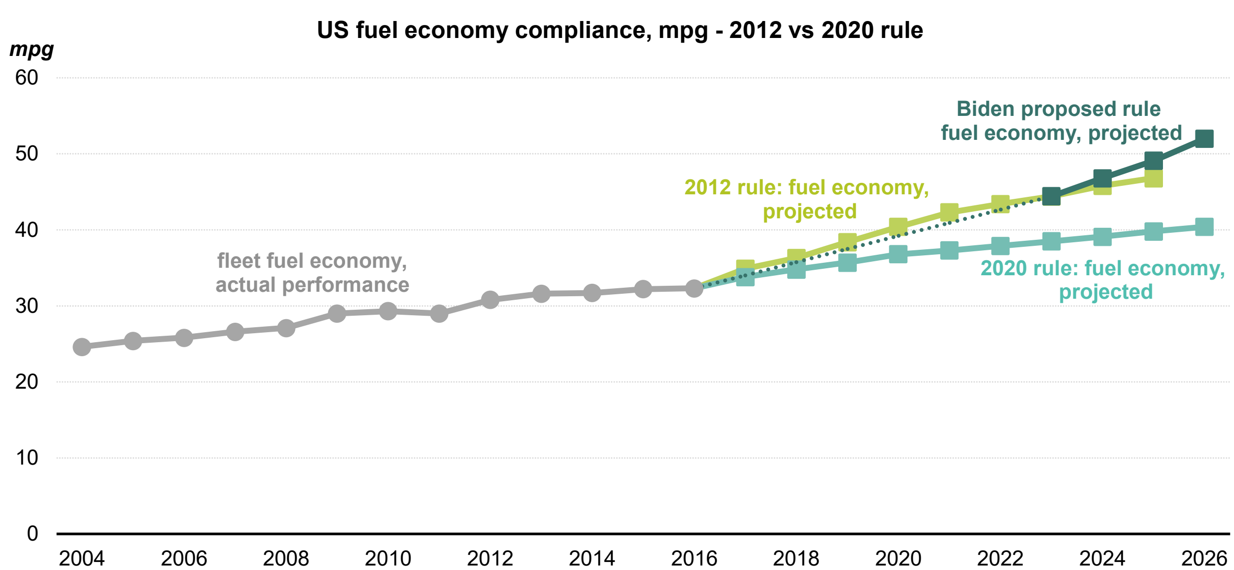
Following an announcement by President Obama in 2009, the US adopted an aggressive approach to reduce GHG emissions. For the first time, regulation jointly set up GHG emissions (adopted by the EPA) and CAFE standards (adopted by the NHTSA) applicable to PVs and light trucks covering MY 2012-16, with the inaugural GHG emission standards becoming effective in MY 2012. At the time, the estimated improvement in fuel economy by MY 2016 was 29%, from an average 2009 level of 26.4mpg to 34.1mpg in 2016.

Following the successful adoption of the program, former President Obama requested the agencies to continue their efforts to develop a second phase of the National Program, with the standards extended to MY 2017-25 light-duty vehicles. In 2012, EPA and NHTSA jointly issued GHG emissions and fuel economy standards to cover MY 2017-25. At the time, the combined fuel economy for passenger cars, light-duty trucks, and SUVs was estimated to increase from an average MY 2016 level of 34.1mpg to 49.6mpg in 2025, an increase of 45% (before flexibilities, credits, and penalty payments are taken into account).

The regulation included an obligation to complete a mid-term review of the MY 2022-25 standards by April 2018 and determine whether it was feasible to meet the 2025 standards with existing technology. The EPA completed such mid-term evaluation in January 2017, in the final days of the Obama administration, and concluded that the 2025 GHG and fuel economy standards should be kept unchanged.

However, the EPA under the Trump administration — prompted by a petition from US automakers — reopened the mid-term evaluation process shortly thereafter, with an eye to making the requirement less stringent. In early August 2018, the EPA and NHTSA determined that the 2025 standards were too stringent and should be revised, and issued a proposed ruling that, if enacted, would abandon the goals set previously by President Obama. As a result, in March 2020, a new final rule was published that relaxed the GHG and CAFE standards for MY 2021-26 vehicles. Under the new relaxed requirements, the industry needs to achieve a fleet-wide average of roughly 40.4mpg by MY 2026, compared to the 46.7mpg projected requirement by MY 2025 in the 2012 rule. The new CAFE targets came into effect in June 2020 (see Exhibit 30).

EXHIBIT 30: **Current fuel economy standards (2020 rule) are expected to be moved again during the Biden administration**



** all figures are based on older CAFE calculations and not current "real world" EPA estimates on new car window stickers*

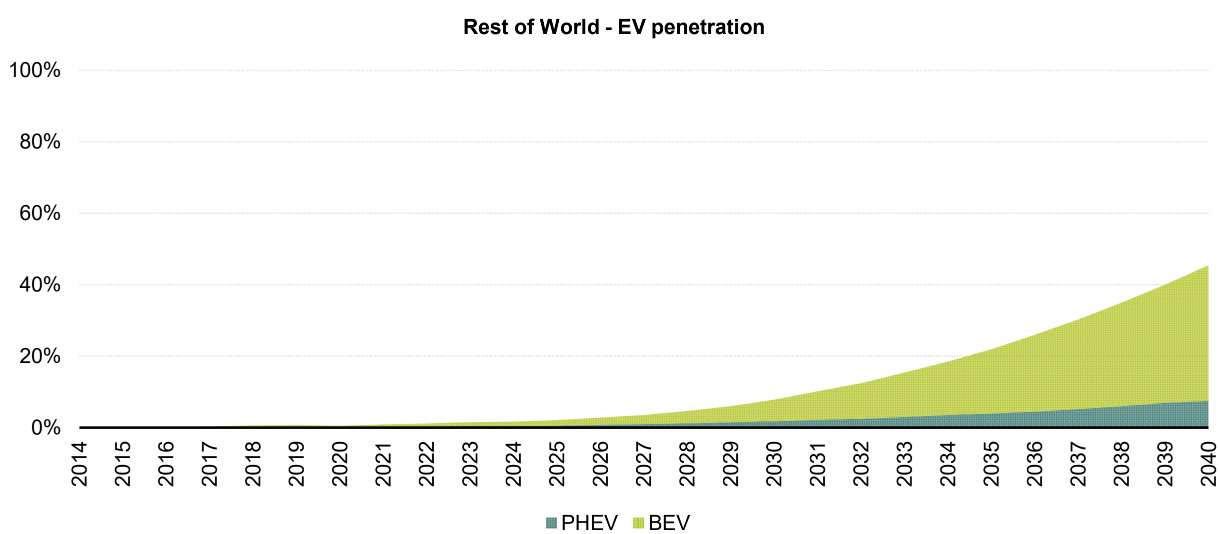
Source: NHTSA data and estimates (2018+) and Bernstein analysis

REST OF THE WORLD

So far, we focused our analysis on emissions and EV policy in the three main regions — Europe, China, and the US. While regulation is also expected to drive sales of low-emission vehicles in other large-volume markets, we forecast EV penetration rates to remain well below the global average. Countries including Japan, Brazil, India, and Canada have already either adopted or proposed fuel economy or GHG emission standards for PVs. However, these appear to be less stringent compared to those in Europe or China, and therefore will require a lower EV mix to achieve. In addition, other important countries — particularly those in emerging markets — have yet to embrace electrification, partly because of low affordability and lack of choice.

The reality is it will take years for EVs to become prevalent in parts of Eastern Europe, Latin America, South Asia, and Africa. In these places, the future of mobility will likely continue to be dominated by the ICE. We expect the EV penetration rate for PVs in the Rest of the World to rise from less than 1% today to ~10% by the early 2030s, increasing to nearly 50% by 2040 (see Exhibit 31).

EXHIBIT 31: **EV penetration in the Rest of the World**



Source: SNE Research, IHS Markit, and Bernstein estimates (2021+) and analysis

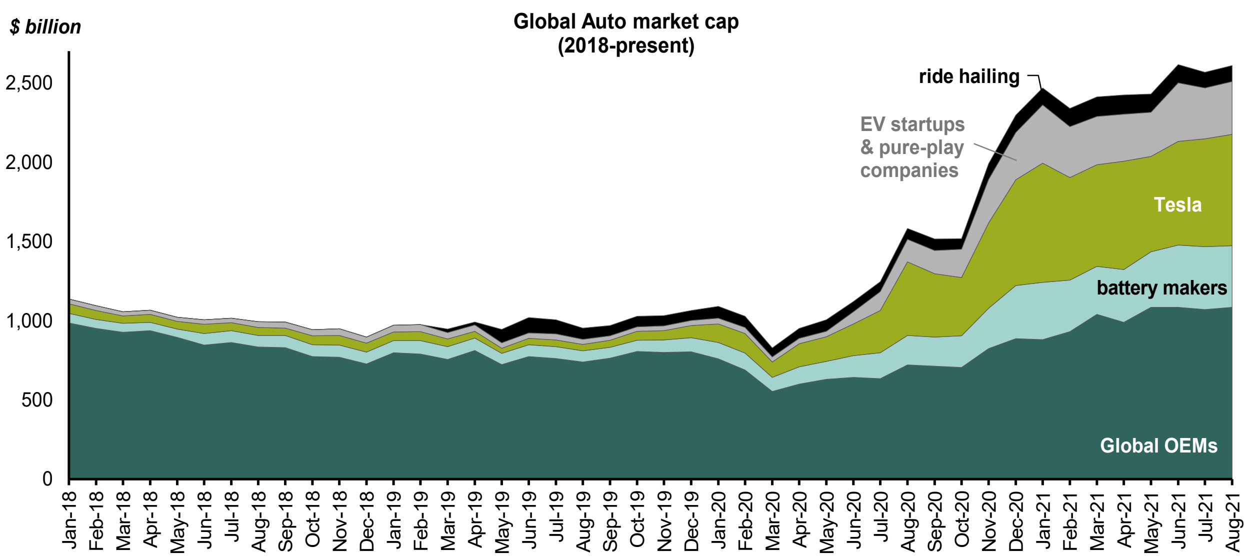
INVESTMENT IMPLICATIONS

We have a positive stance on the autos sector with a preference for global premium brands. Volume and mix trends will likely remain supportive despite some short-term pressures from semiconductor supply bottlenecks. Car/vehicle ownership continues to be supported by consumers' changing mobility preferences. In addition, we remain convinced investors need to pay more attention to the industry's current self-help momentum. Efficiency gains from winding down ICE operations faster will have a very material, positive impact on earnings and cash flows. Finally, we are confident that carmakers will play a meaningful role in the future of electric and connected mobility. Combining these two arguments, we are convinced that earnings momentum remains supportive (versus consensus) and valuation has substantial upside.

The financial market's excitement concerning new mobility remains enormous. The combined US$1tn market cap of traditional global OEMs has obviously seen a cyclical recovery during the past 12 months. Yet, new automakers and EV-related players have doubled the market value of the "new auto" value chain. Individual mobility is one of the hottest topics, attracting massive speculation and ultra-high valuations — just not for traditional OEMs, yet. Their valuation has even declined in 2021 YTD, as investors don't believe in the sustainability of fundamentals.

Do (some) OEMs deserve a share of this "new auto" excitement? In our view, valuations of and sentiment toward traditional OEMs continue to be far too pessimistic. We remain convinced that established companies with global reach, brand equity, and strong balance sheets will play a dominant role in the future of mobility. We are convinced the substantial and excessive derating of auto OEMs is overdone (see Exhibit 32).

EXHIBIT 32: **The exciting world of new mobility**



Source: Bloomberg and Bernstein analysis

PRODUCT LIFE CYCLE ASSESSMENT OF EV BATTERIES

OVERVIEW

- EVs are a key driver (pun intended) of the low-carbon transition. Most consumers, however, have largely focused on the emission-reduction potential of EVs in use, without paying much attention to the environmental impact during the production or end-of-life cycle recycling phases. The rise of regulatory requirements, most notably in the EU, calls for greater transparency around a product's net environmental impact across its life cycle. We conduct a life cycle analysis on EV batteries to better understand the environmental impact and risks/opportunities along the value chain.

- We find the greatest environmental impact of EV batteries during the upstream production stage. In addition to environmental impacts such as energy use and GHG emissions, EV batteries could also have biodiversity impact, as hazardous waste could increase marine and freshwater ecotoxicity.

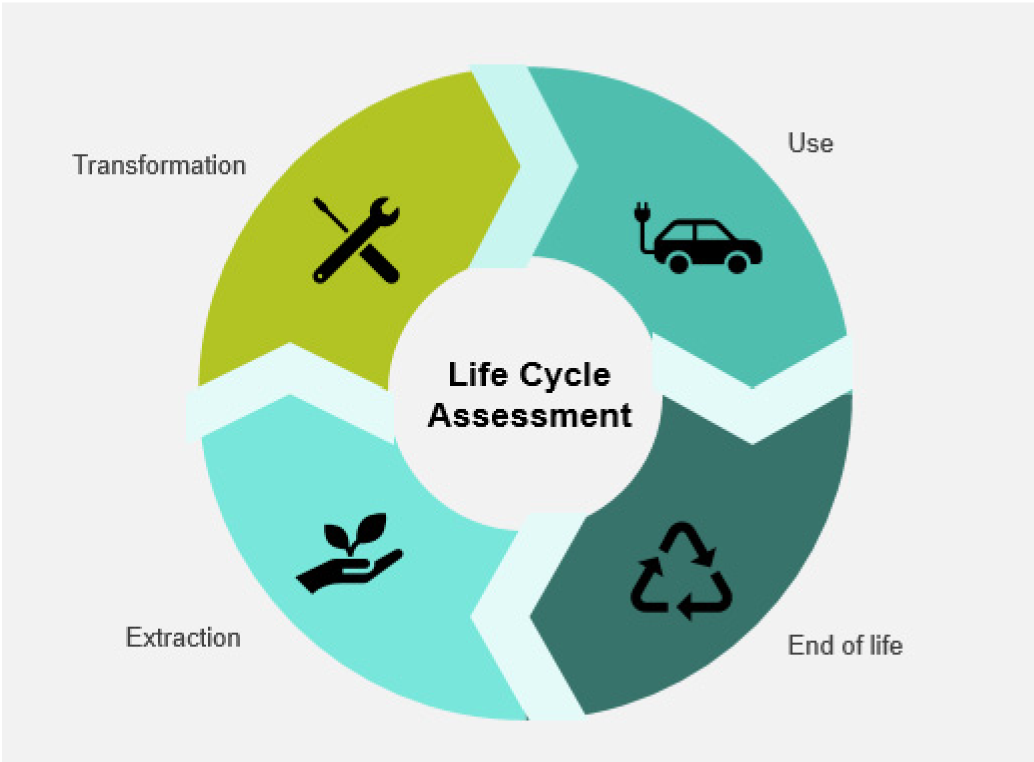
- This increased focus on EVs' environmental impact could create investment opportunities, from second-life applications to circular product design to supply chain traceability. In particular, we expect there could be significant demand for reusing EV batteries in second-life applications (e.g., in a different vehicle or in a stationary application such as a wind turbine) by refurbishing and repurposing these batteries. Although the market for a "second life" for EV batteries has not yet reached scale, the 10 million EVs on the road today will reach their end of life and enter the reuse/recycling market by 2040, creating greater economies of scale for second-life applications.

SUPPLY CHAIN TRACEABILITY AND PRODUCT LIFE CYCLE MANAGEMENT

What is a life cycle analysis? A life cycle approach considers the spectrum of resource flows and environmental interventions associated with a product or organization from a supply chain perspective. It includes all stages from raw material acquisition through processing, distribution, use, and end-of-life, and assesses all relevant environmental impacts, health effects, resource-related threats, and burdens to society (see Exhibit 33).[1]

[1] https://ec.europa.eu/environment/eussd/pdf/footprint/PEF%20methodology%20final%20draft.pdf

EXHIBIT 33: **A life cycle approach considers the spectrum of resource flows and environmental interventions associated with a product or organization from a supply chain perspective**



Source: Carbon Footprint and Bernstein analysis

REGULATORY FRAMEWORK

Regulatory requirements are calling for greater supply chain management and traceability of products. While the EU has addressed the issue from an environmental and social angle with the introduction of the EU Taxonomy, the US Department of Energy (DOE) approaches supply chain management from a security and risk perspective.[2] Regardless of which way you spin it, both governments seem to have a particular focus on raw metals and materials extraction in the upstream supply chain phase, calling for greater circularity of products to better manage potential future political and supply risks. We review some of the major regulatory developments next.

EU Taxonomy

The EU Taxonomy is a major piece of regulation that establishes a framework to classify business activities or products based on their contribution to specified environmental objectives. In particular, an economic activity can only be classified as environmentally sustainable if it makes a substantive contribution to at least one of the EU Taxonomy's six environmental objectives and does no significant harm (DNSH) to the other five (see Exhibit 34).[3]

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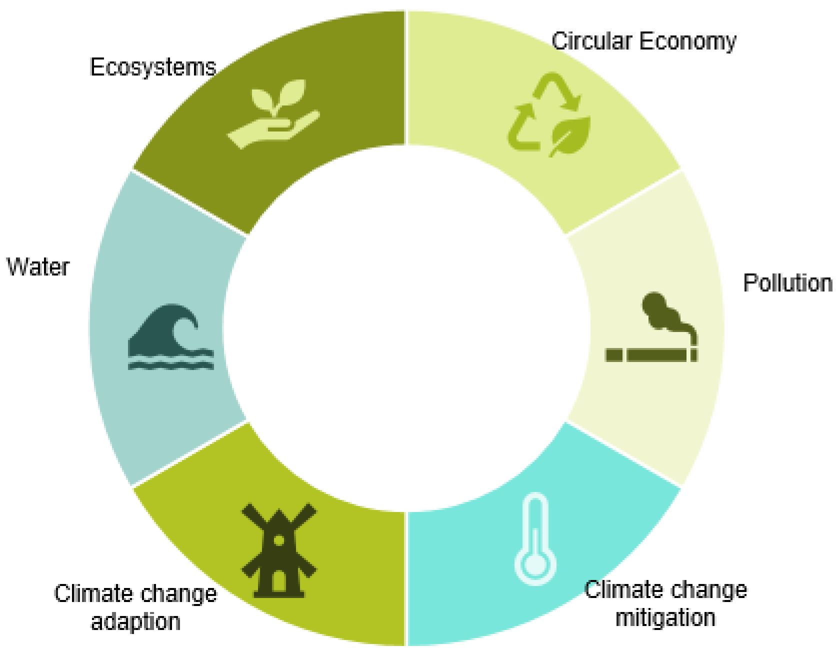
[2] U.S. Department of Energy's Strategy to Support Domestic Critical Mineral and Material Supply Chains

[3] https://ec.europa.eu/info/sites/default/files/business_economy_euro/banking_and_finance/documents/200309-sustainable-finance-teg-final-report-taxonomy_en.pdf

Among the six objectives, climate change mitigation and adaptation objectives start to apply on January 1, 2022. To comply with the first two objectives, investors will need to understand GHG emissions across the entire value chain of a product (see Exhibit 35).

The other environmental objectives in the EU Taxonomy will come into effect on January 1, 2023, which will consist of pollution, biodiversity, water, and circular economy.[4] The next wave of environmental metrics will go beyond emissions to measure the sustainability of an economic activity more comprehensively. Although not yet required, a life cycle analysis can help investors evaluate a product's environmental impacts holistically beyond GHG emissions.

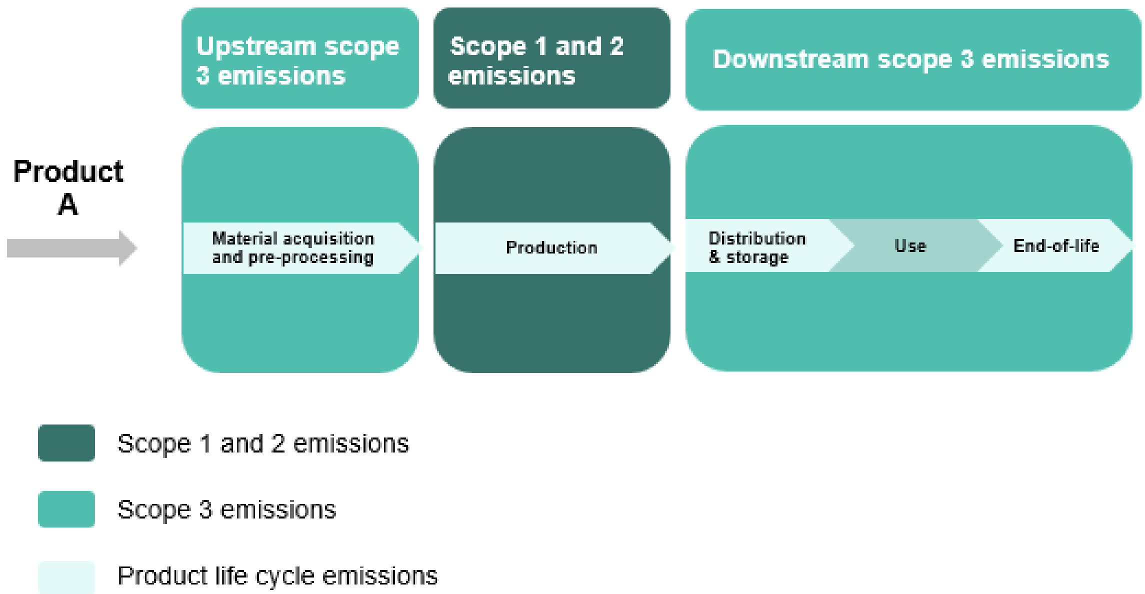
EXHIBIT 34: **An activity can only be considered sustainable if it makes a significant contribution to one of the six environmental objectives under the EU Taxonomy without doing significant harm to the other five**



Source: European Commission and Bernstein analysis

[4] The ABCs of ESG: Key Frameworks, Regulations and Disclosures

EXHIBIT 35: **Measuring GHG emissions across the life cycle of a product can help investors better understand an economic activity's contribution to the climate change mitigation objective of the EU Taxonomy**



Source: GHG Protocol and Bernstein analysis

Climate change mitigation and adaption of an EV

To help investors better understand the first two environmental objectives in the context of EVs, we lay out the metrics from the EU Taxonomy here. Passenger light vehicles are identified in the EU Taxonomy as a potential climate change mitigation activity (i.e., due to lower emissions across the lifetime of the vehicle) or a climate change adaption activity (e.g., traditional ICE vehicles that switch to using electric power rather than using conventional fossil fuels).

Current regulations only evaluate EV emissions during the "tank to wheel" phase, or during energy conversion in the vehicle. However, the Clean Vehicles Directive acknowledges that life cycle and well-to-wheel emissions are to be addressed down the road, which would evaluate EV GHG emissions more holistically.

Climate change mitigation: Under the EU Taxonomy, zero tailpipe emission vehicles (including EVs) automatically qualify for making a substantive contribution to the climate change mitigation objective (see Exhibit 36). Vehicles with tailpipe emission intensity of maximum 50g CO2/km also qualify until 2025 as an interim target. From 2026, only vehicles with zero-emission intensity will qualify.

EXHIBIT 36: **Criteria for passenger cars to qualify for making a substantive contribution to the climate change mitigation objective under the EU Taxonomy**

Mitigation criteria:	CO2 emissions per vehicle kilometre (gCO2/km).
Passenger cars and light commercial vehicles:	1) Zero tailpipe emission vehicles (incl. hydrogen, fuel cell, electric). These are automatically eligible. 2) Vehicles with tailpipe emission intensity of max 50 g CO2/km (WLTP) are eligible until 2025. 3) From 2026 onwards only vehicles with emission intensity of 0g CO2/km (WLTP) are eligible.

Source: European Commission and Bernstein analysis

Climate change adaption: Unlike the climate change mitigation objective that sets specific quantitative metrics, given its focus on emissions levels, the climate change adaption objective is context and location specific.[5] Traditional passenger light vehicles making the transition from ICEs to electric- or hydrogen-powered engines can be considered as adapted activities under current "tank-to-wheel" guidelines. Although the EU Taxonomy has not yet released specific metrics for contributing to the other environmental objectives, it is possible that EVs could be considered as activities *enabling* the adaption, especially those that re-integrate precious metals from batteries toward second-life applications. We will dive deeper into this analysis later in the chapter.

Climate change adaption activities stress the need for life cycle analysis and the creation of sustainable value chains at the point of design.[6] The EU Sustainable Finance Technical Expert Group indicates that for new economic activities, the "do no significant harm" criteria must be met *at the point of design and construction*. For existing activities and assets, all material physical climate risks must be assessed and adapted within a time horizon of no longer than five years.

Sustainable battery development

For batteries specifically, the EU released a Strategic Action Plan on Batteries[7] aimed at making Europe a global leader in sustainable battery production and use, as part of the broader Green Deal Circular Economy Action Plan.[8] The Green Deal also contains a new Eco-Design[9] directive aimed at improving the energy efficiency and sustainability of products in various phases of their life cycle.[10] In the context of batteries, the directive contains sustainability requirements in terms of sustainable sourcing (e.g., supply chain due diligence), internal storage, energy efficiency, as well as other requirements (see Exhibit 37).

[5] EU Taxonomy Technical Annex
[6] EU Taxonomy Technical Annex (pg. 29-33)
[7] https://ec.europa.eu/commission/presscorner/detail/en/ip_20_2312
[8] https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en
[9] https://ec.europa.eu/growth/industry/sustainability/product-policy-and-ecodesign_en
[10] https://ec.europa.eu/growth/industry/sustainability/product-policy-and-ecodesign_en

EXHIBIT 37: **The EU has proposed ways to make batteries more sustainable, including higher resource efficiency and energy density, implementing supply chain due diligence, and allowing greater recyclability and reusability**

Source: European Commission and Bernstein analysis

US Executive Order 13817 — a federal strategy to ensure secure and reliable supplies of critical minerals

While the EU sets the global high watermark in terms of sustainability and environmental regulation, the United States' Executive Order 13817 — A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals was passed in 2017 and addresses the issue from a national security angle. The US DOE sets strategic goals in the context of critical mineral and material supply chains, including developing technology to ensure greater supply chain resiliency, supporting private sector adoption and capacity for sustainable domestic supply chains, fostering new capabilities to mitigate future supply chain challenges, and coordinating efforts with international partners.[11]

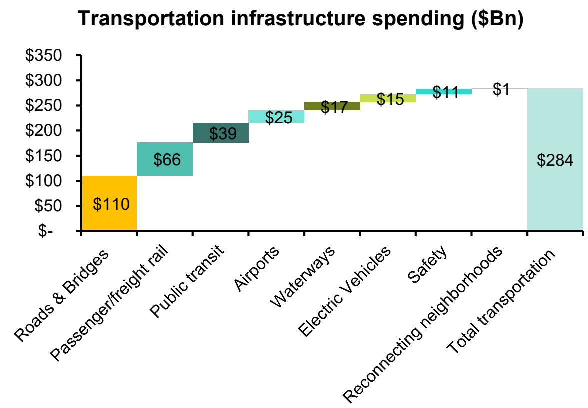
Although the US strategy lacks the same level of outward environmental objectives as the EU, the DOE proposal discusses the development of circular battery value chains to retain critical minerals and metals. The strategy states that the DOE is well positioned to

[11] U.S. Department of Energy's Strategy to Support Domestic Critical Mineral and Material Supply Chains

transform linear supply chains to fully realize opportunities for circularity and efficiency. Focus will be placed on connecting supply chains and fostering collaboration with industry and municipal waste to integrate recycling and reuse strategies into supply chains.[12] The US DOE ReCell center established a US$5.5mn Battery Recycling Prize in 2019, the same time the center was established, to incentivize the development of innovative ideas that will enable collection of 90% for all end-of-life lithium ion batteries in the US for recycling.[13]

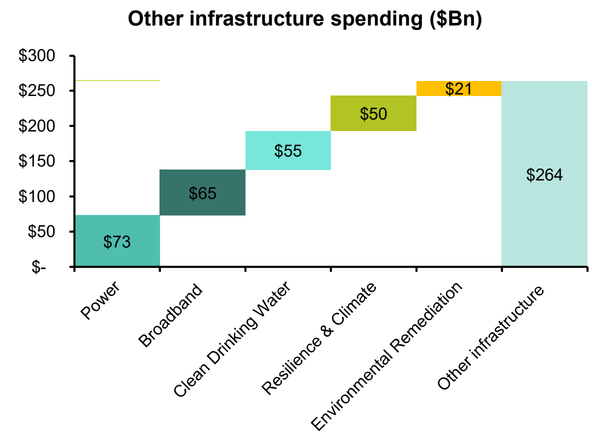
Last, in addition to the executive order on critical materials, the US government's more recent infrastructure bill proposed in 2021 also has a particular focus on the transportation sector, including a US$15bn investment in EVs, as well as scaling up the power and clean energy infrastructure (see Exhibit 38 and Exhibit 39).[14]

EXHIBIT 38: **As part of the transportation infrastructure category, the bill proposes a US$15bn investment in EVs...**



Source: NPR and Bernstein analysis

EXHIBIT 39: **...as well as investments focused on power, clean energy, and electricity, all of which will require critical materials for electrification**



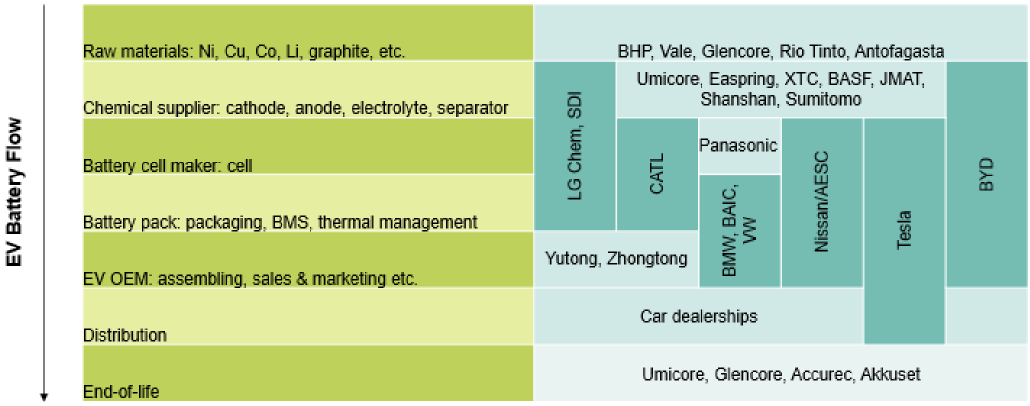
Source: NPR and Bernstein analysis

LIFE CYCLE ANALYSIS OF EV BATTERIES

The key players in the EV supply chain consist of raw materials and mining companies, battery assembly and manufacturing, OEMs, and recycling companies at end-of-life[15] (see Exhibit 40).

[12] U.S. Department of Energy's Strategy to Support Domestic Critical Mineral and Material Supply Chains (pg. 21)
[13] Gaines et al. 2021. Direct Recycling R&D at the ReCell Center, *Recycling*. MDPI.
[14] Net Zero 101: Climate summit, Biden infrastructure bill, investor sentiment poll... all you need to know in one place
[15] Electric Revolution 2020: Supercharging the Next Decade (Part 9). Catalysts - How viable will EV battery recycling become?

EXHIBIT 40: **Key players in the EV battery supply chain, as well as emerging players in the end-of-life phase**

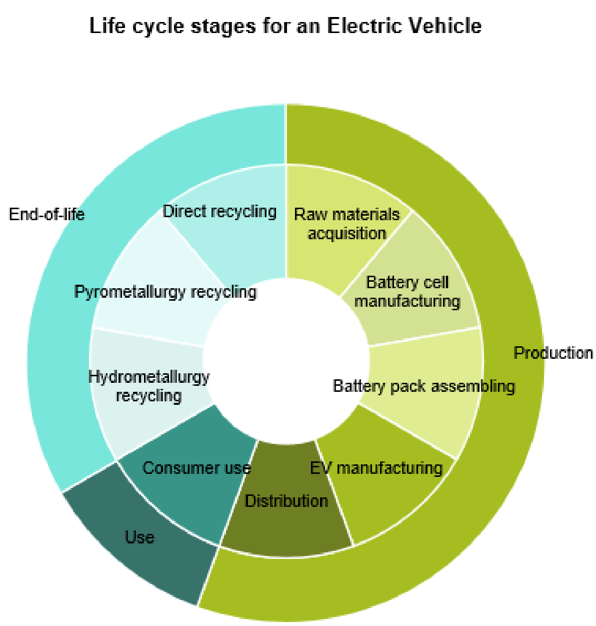


Note: BHP, Vale, Glencore, Rio Tinto, Antofagasta, Umicore, BASF, and JMAT are covered by Bernstein.

Source: World Economic Forum, Kelleher Research Study on Reuse and Recycling of Batteries, and Bernstein analysis

A life cycle analysis of an EV measures its environmental impact throughout the value chain. Although a life cycle analysis of an EV is not yet required from a regulatory perspective, we expect more regulatory focus on this issue and believe that companies and investors should be prepared for more disclosure requirements down the road. We've included a step-by-step diagram of each piece in the life cycle (see Exhibit 41). While many studies have assessed the impacts of the production stage of EV batteries, there is a lack of research focusing on the other stages such as the end-of-life phase.

EXHIBIT 41: **Relevant life cycle stages for EV batteries**



Source: European Commission: Follow-up feasibility study on sustainable batteries and Bernstein analysis

Raw materials acquisition

The first phase of a life cycle assessment analyzes the upstream production stage. A lot of focus in the EV market has shifted toward LiBs, in particular NMC (nickel, manganese, cobalt) batteries because they feature a higher energy density than batteries previously used in EV production.[16] NMC111 is the most common NMC battery, whereas NMC622 and NMC811 are nickel-rich batteries under development for higher energy and lower cost in the future.[17]

During the upstream raw material sourcing stage, the transportation of batteries also has environmental impacts, given the areas that they are typically sourced from, such as the Democratic Republic of Congo (DRC), and the areas they are typically manufactured in, such as China. In addition, the current modes of transport (truck, tanker, and rail) are typically powered by oil or diesel, causing GHG emissions during the upstream transportation stage.

Exhibit 42 color codes the metals roughly by their native state and shows requirements by chemistry. Note that copper is present in all batteries (and in the stator, inverter, and charger as well). Other metals trade off in terms of dominance by chemistry type.

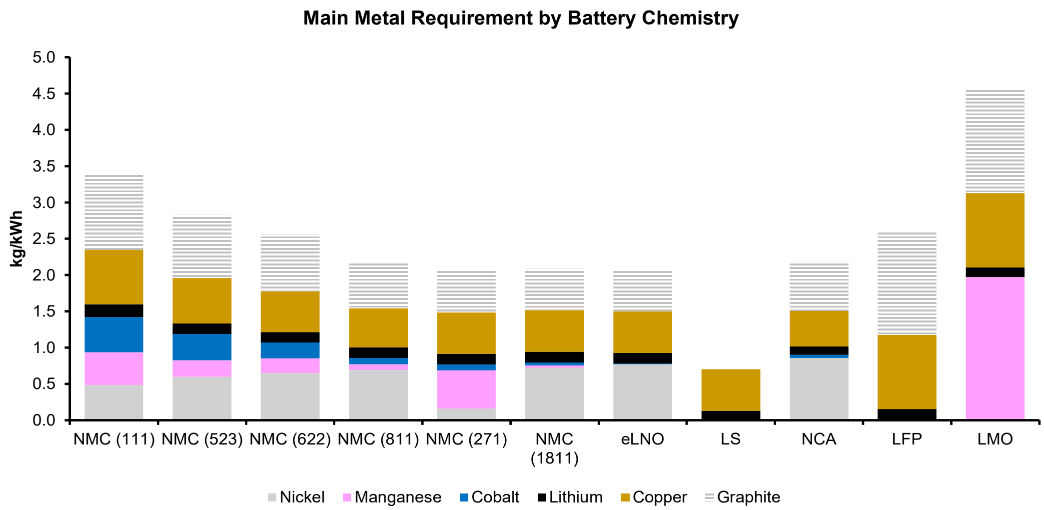
Said another way, battery chemistries can be found without cobalt, or without manganese, or without nickel, or with variable amounts of lithium and copper (but will always need some). Not all batteries are created equal in terms of commerciality, performance, safety, etc. But to the extent that batteries are substitutable, the cost of raw materials will influence decisions.

Exhibit 43 shows the complete chemistry, which allows the reader to guess the mnemonics of the battery chemistry — N = nickel, M = manganese, C = cobalt, A = aluminum, S = sulfur, F = (f)errous iron, and P = phosphorus. Numbers of course correspond to ratios (NMC523 is 5 parts nickel, 2 parts manganese, and 3 parts cobalt).

[16] Antonella Accardo, Giovanni Dotelli, Marco Luigi Musa and Ezio Spessa. 2021. "Life Cycle Assessment of an NMC Battery for Application to Electric Light-Duty Commercial Vehicles and Comparison with a Sodium-Nickel-Chloride Battery," *Applied Sciences.*

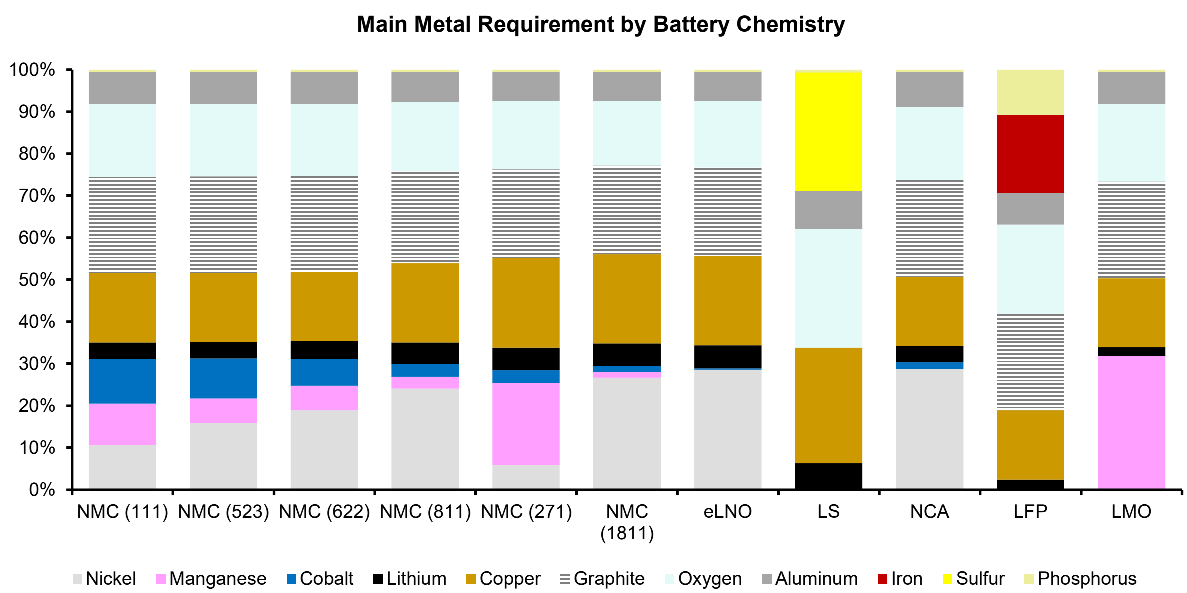
[17] Dr. Y. L. Ding, Z. P. Cano, Prof. A. P. Yu, Prof. Z. W. Chen. University of Waterloo. Automotive Li-Ion Batteries: Current Status and Future Perspectives

EXHIBIT 42: **In terms of "metal/graphite" mass requirements, we see variation in mass needed and in composition depending on which chemistry technology wins; a 50kWh battery for a single EV requires from <50kg to >200kg of these materials...**



Source: Bernstein estimates (all data) and analysis

EXHIBIT 43: **...shown as 100% of mass (including low-cost components)**

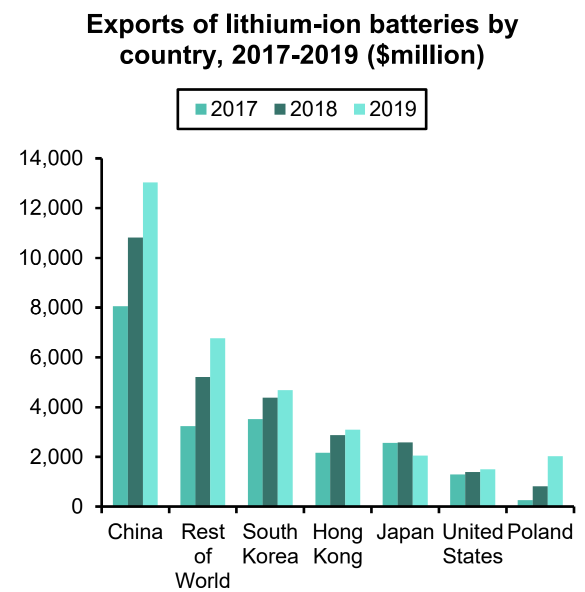


Source: Bernstein estimates (all data) and analysis

Distribution

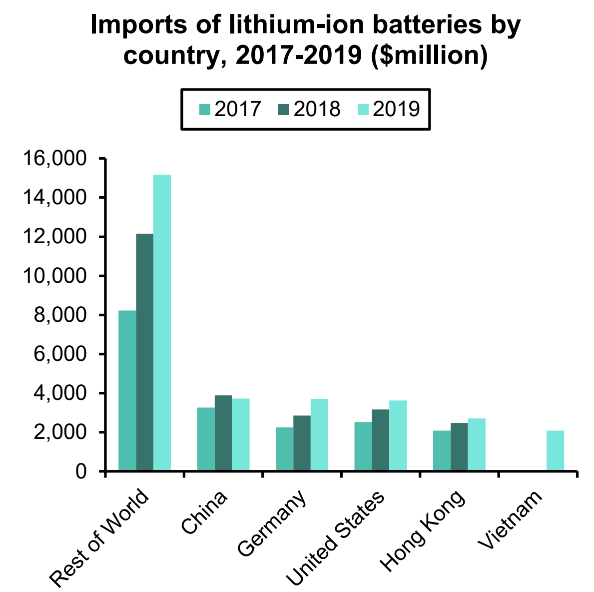
In addition to the emissions and environmental impact at the raw materials sourcing stage, the life cycle analysis also includes emissions during the distribution stage (from the battery manufacturer to the OEM). As shown in Exhibit 44, the main battery manufacturing and assembly companies are largely based in China — LG Chem, Panasonic, and SDL. China (excluding Hong Kong) continues to lead the way in LiB exports, while major importers of LiBs are more fragmented (see Exhibit 44 and Exhibit 45). It's worth noting, however, that China is not able to export cathode material to Europe due to Free Trade Agreements requiring that 55-60% of the value of an EV be produced locally. The cathode, which is likely to come from China, is the most valuable part of the battery. This has been a key issue for the cathode market in China causing a supply glut in the market during the peak of Covid-19.

EXHIBIT 44: **China (excluding Hong Kong) continues to lead the way in LiB exports...**



Source: United States International Trade Commission and Bernstein analysis

EXHIBIT 45: **...while major importers of Li-ion batteries are more fragmented**

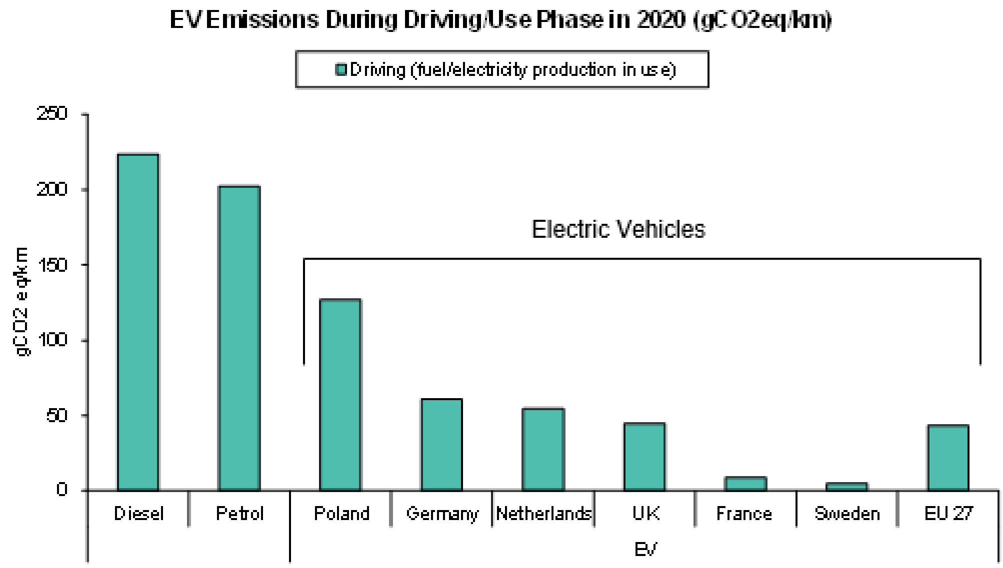


Source: United States International Trade Commission and Bernstein analysis

Use phase

The use stage is when the vehicle leaves the manufacturer and is transferred to the hands of the consumer. Although EVs do have an environmental footprint during the beginning-of-life and end-of-life stages, their emissions during the use phase are lower than those of vehicles with petrol- and diesel-based engines (see Exhibit 46). That said, depending on the power mix in the local electricity grid, EVs in Poland for example, where coal is a higher proportion of the power mix, generate more emissions than EVs in Sweden.

EXHIBIT 46: **EVs have a lower environmental impact during the "tank to wheel" phase compared to vehicles with petrol- and diesel-based engines**



Note: Emissions based on EU electricity grid mix

Source: Transport & Environment and Bernstein analysis

End-of-life

The end-of-life stage begins when the product is discarded by the user and ends when the product is returned to nature as a waste product or enters another product's life cycle (as a recycled input).[18] The typical recycling process consists of the smelting of batteries in a furnace, where the high temperature process recovers an alloy of copper, cobalt, nickel, and iron, but cannot recover graphite, electrolyte, or plastic materials (because they are burned)[19] (see Exhibit 47).

EXHIBIT 47: **Recycling process for electric batteries**

Materials	Fate
Active Cathode Materials	Recycled
Graphite	Burned
Copper	Recycled
Aluminum	Landfill
Plastics	Burned
Lithium	Landfill
Carbon black	Burned
PVDF	Burned

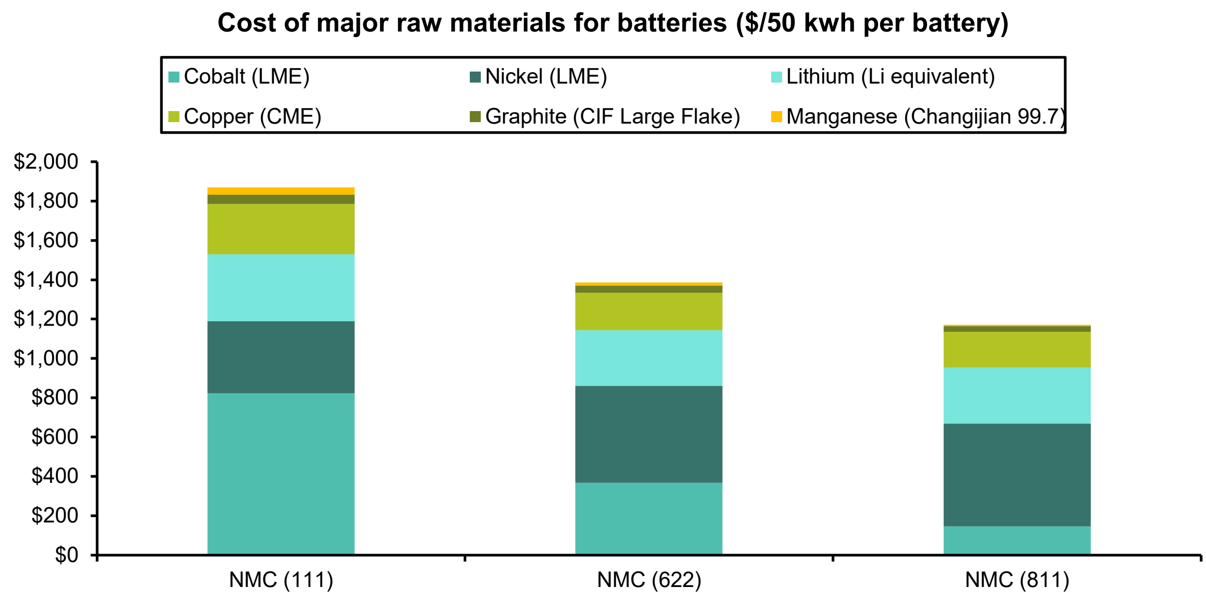
Source: Life Cycle Assessment of an NMC Battery for Application to Electric Light-Duty Commercial Vehicles and Comparison with a Sodium-Nickel-Chloride Battery, *Journal of Applied Sciences*, and Bernstein analysis

[18] https://ec.europa.eu/environment/eussd/pdf/footprint/PEF%20methodology%20final%20draft.pdf

[19] Accardo, Dotelli, Musa, Spessa. 2021. Life Cycle Assessment of an NMC Battery for Application to Electric Light-Duty Commercial Vehicles and Comparison with a Sodium-Nickel-Chloride Battery. *Applied Sciences.*

As mandatory recycling regulations have come into effect in the EU, interest has grown in the recovery of materials. Materials make up over half the initial cell cost, and cathode materials are the largest contributor to the overall material cost, so there is a financial incentive to recover cathode materials.[20] Cathode materials typically consist of cobalt (Co) as well as lithium (Li), nickel (Ni,) and manganese (Mn). Our Global Metals & Mining team provides an analysis of the cost of raw materials in batteries,[21] showing the largest financial incentive is in recovering the cobalt, nickel, and lithium that make up the cathode. The cathode metals range from US$1,567 in NMC111 batteries, US$1,160 in NMC622 batteries, and US$959 in NMC811 batteries. Outside of the cathode, copper is also typically recycled and makes up a solid portion of the cell cost — ranging over US$255 in NMC111, US$191 in NMC622, and US$183 in NMC8111 batteries (see Exhibit 48).

EXHIBIT 48: **Given the high cost of raw materials for batteries, once recycling reaches scale the market could make economic sense for OEMs**



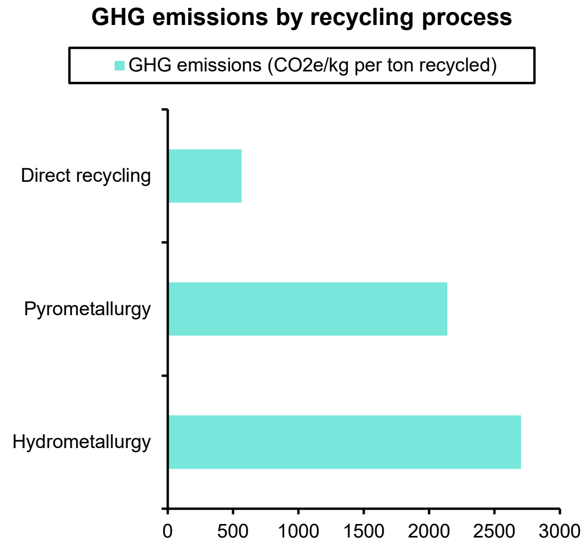
Source: Bernstein estimates (all data) and analysis

Direct recycling of Li-ion batteries has lower environmental impacts compared to traditional recycling methods and is a promising method from a sustainability standpoint (see Exhibit 49 and Exhibit 50). Direct recycling is the recovery, regeneration, and reuse of battery components directly without breaking down the chemical structure. By maintaining the chemical structure of the original battery components, a lower-cost re-constructed material can be sold to battery manufacturers. This will in turn help reduce the cost of EV batteries and drive up the value in recycling EV batteries.[22] In addition, various studies have discussed the ways in which direct recycling is more effective than traditional methods

[20] Gaines, Linda (2018). "Lithium-Ion Battery Recycling Processes: Research Towards a Sustainable Course." *Sustainable Materials and Technologies*.
[21] Climate Change Scenarios: What does battery metal demand look like in 1.8 degree world?
[22] https://recellcenter.org/

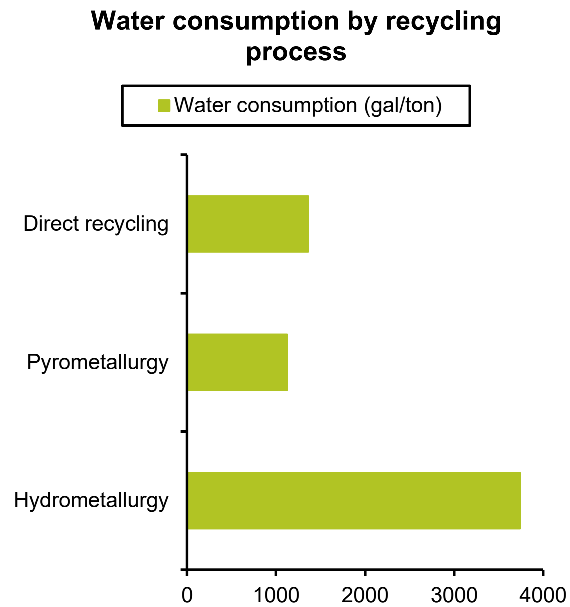
because it recovers the cathode particle without decomposing it into substituent elements (see Exhibit 51).[23]

EXHIBIT 49: **Direct recycling produces lower GHG emissions compared to other forms of recycling**



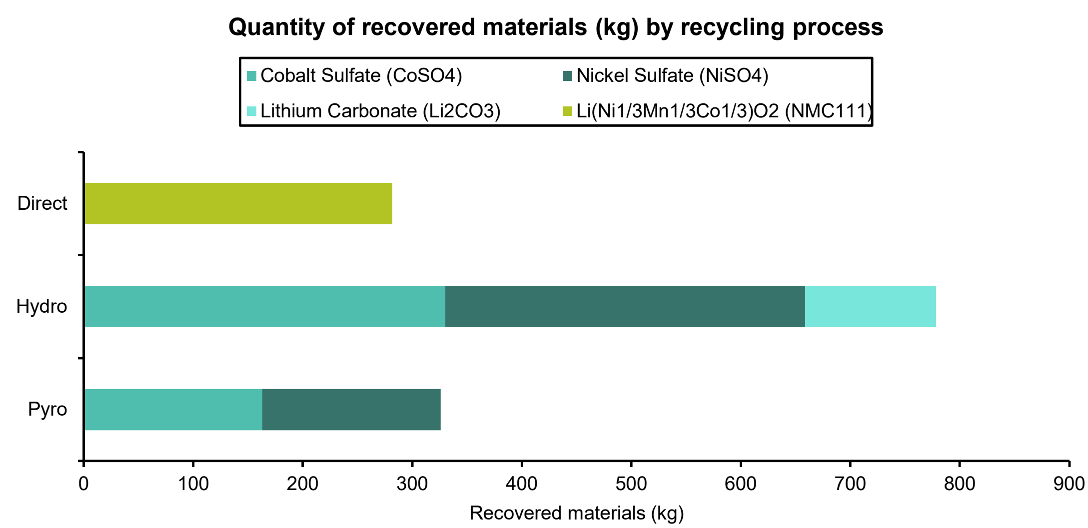
Source: Argonne National Laboratory and Bernstein analysis

EXHIBIT 50: **However, all three forms of recycling use a meaningful amount of water**



Source: Argonne National Laboratory and Bernstein analysis

EXHIBIT 51: **Direct recycling recovers less materials than hydrometallurgy, but recovers more components of the NMC111 battery used in EVs**



Source: Argonne National Laboratory and Bernstein analysis

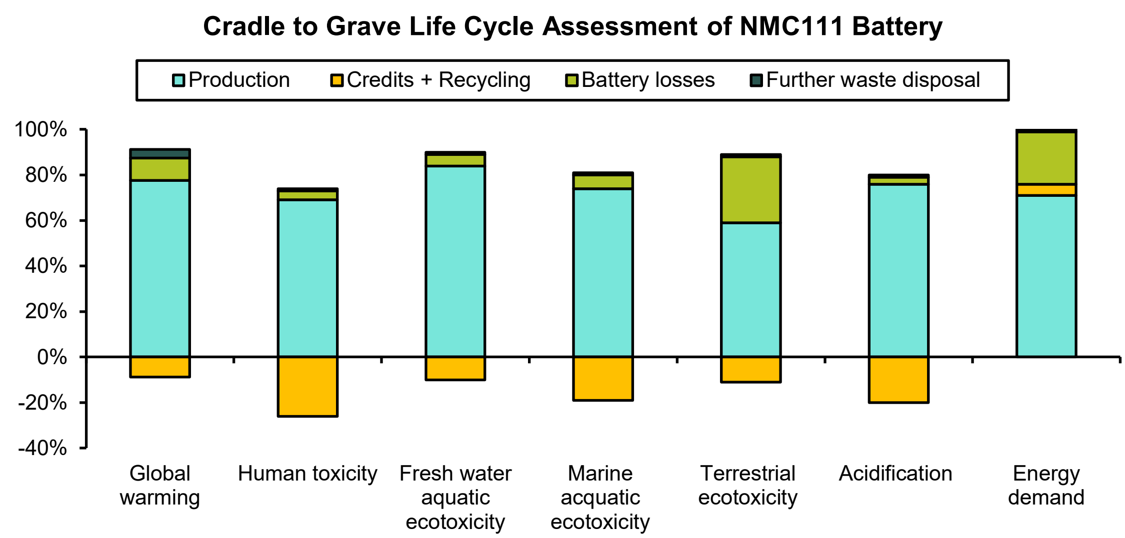
[23] https://www.sciencedirect.com/science/article/pii/S2214993718300599

NET ENVIRONMENTAL AND BIODIVERSITY IMPACTS

We find the production and battery manufacturing stage of EV components has the greatest impact during its life cycle. Most previous studies focus on batteries' energy use and emissions when using life cycle analysis. We add to the discussion by looking at other implications, such as biodiversity impacts of the EV battery chain using a reference study from the *Journal of Applied Sciences*.[24]

For example, the analysis finds that recycling of batteries (e.g., avoidance of virgin materials) helps lower marine and freshwater ecotoxicity, which are damaging to organisms and human health, given the concentration of metals as hazardous waste in coastal areas.[25] Recycling also lowers the impact of acidification of oceans, where rising acidity causes the bleaching of coral reefs, destroying the natural ecosystems for many marine organisms[26] (see Exhibit 52).

EXHIBIT 52: **The production and battery manufacturing stage of EV components has the greatest impact on the environment during the life cycle**



Note: Further disposal refers to the landfilling and incineration of materials; battery loss refers to the amount of electricity lost during the recharging phase over the lifespan of the battery; net recycling impact refers to the impact of the recycling process minus credits obtained by replacing virgin materials with recovered materials.

Source: *Journal of Applied Sciences* and Bernstein analysis

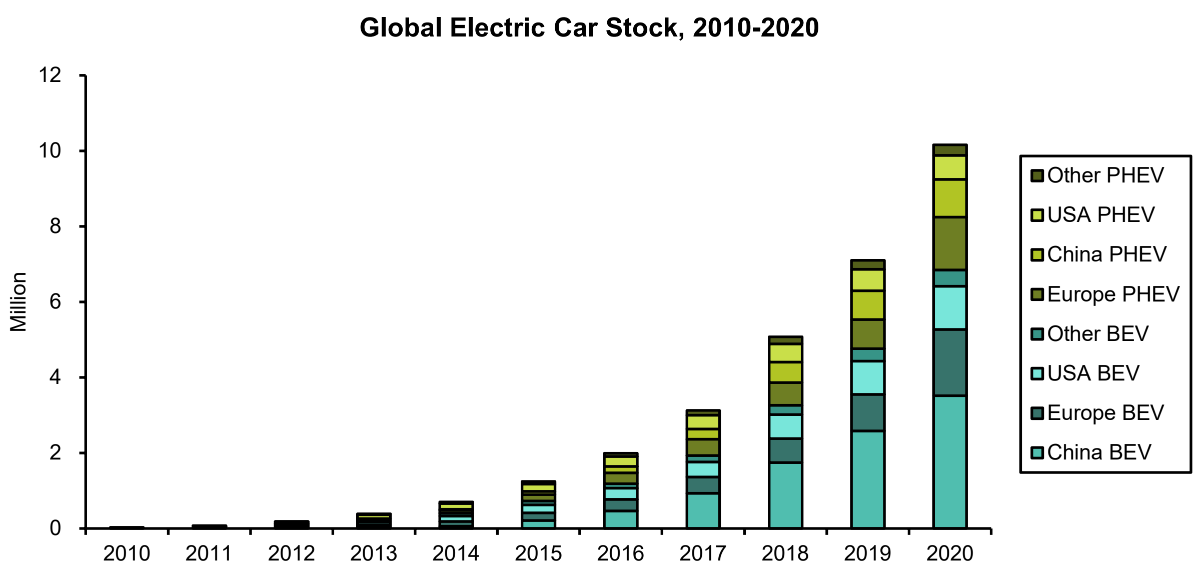
[24] Accardo et al. 2021. Life Cycle Assessment of an NMC Battery for Application to Electric Light-Duty Commercial Vehicles and Comparison with a Sodium-Nickel-Chloride Battery. *Journal of Applied Sciences*.
[25] https://scialert.net/fulltext/?doi=jas.2004.1.20
[26] https://www.whoi.edu/press-room/news-release/scientists-identify-how-ocean-acidification-weakens-coral-skeletons/#:~:text=The%20rising%20acidity%20of%20the,corals%20to%20build%20their%20skeletons.&text=Corals%20grow%20their%20skeletons%20upward,thicken%20them%20to%20reinforce%20them.

"SECOND LIFE": CLOSING THE LOOP ON EV BATTERIES

Battery production has not yet reached the scale required for recycling to become economical.[27] The amount of recycling happening today is mostly due to regulatory requirements in the EU. In addition, there is only a small number of EVs reaching the end-of-life phase today, limiting the number of batteries available for recycling and re-manufacturing.

The average life of an EV is estimated to be ~13 to 20 years. Considering there were ~1.2 million EVs on the road in 2015, by 2035 those EVs will reach the end-of-life stage. By 2040, the 10 million EVs on the road today will reach their end of life (see Exhibit 53). Although battery recycling hasn't reached the scale needed to be economical today, it could become a meaningful market down the road. The average life for an EV battery is around eight to 10 years,[28] so demand for replacement batteries means recycling could reach scale sooner than recycling of all components of an EV.

EXHIBIT 53: **More than 1 million EVs were on the road in 2015, and more than 10 million were on the road in 2020 with BEVs driving the expansion**



Source: IEA Energy Outlook 2021 and Bernstein analysis

THE CIRCULAR EV BATTERY VALUE CHAIN

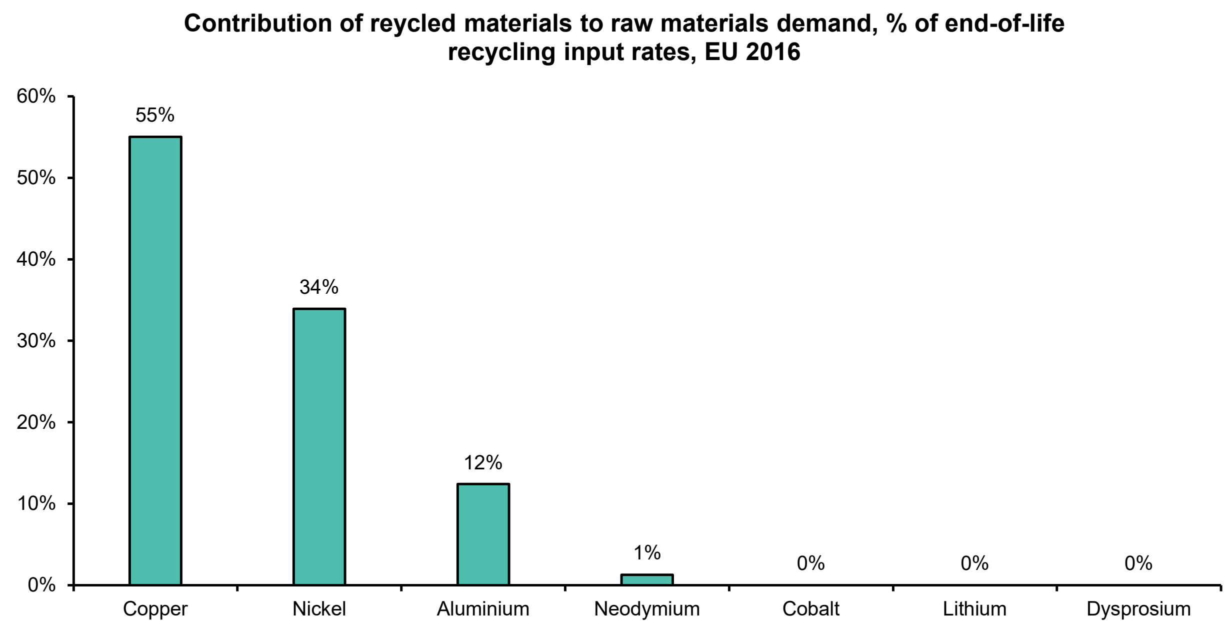
Although EV batteries are currently recycled, it is still a highly fragmented process and not yet cost efficient.[29] But the question is when — not whether — battery recycling will become economical, and the timeline hinges mostly on when large battery packs in EVs will start to

[27] https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/second-life-ev-batteries-the-newest-value-pool-in-energy-storage
[28] Bernstein estimates and analysis — Global Autos, European Industrial & Consumer Chemicals
[29] NREL

enter the reuse/recycling market.[30] High-performance recycling of EV batteries could provide ~10% of key battery materials, which would account for ~US$10bn based on current value. This value is predicted to grow four-fold until 2040. Ultimately, most batteries will need to be recycled for regulatory and environmental reasons in major markets.[31]

In the EU, recycled copper contributed to 55% of the EU's raw material demand in 2016, with nickel following at 34%. Other materials used in the EV battery (lithium and cobalt) contributed to 0% of recycled inputs. Other recycled rare earth metals used in the EV motor, such as neodymium, contributed to 1% of raw metal demand (see Exhibit 54).

EXHIBIT 54: **In 2016, recycled copper contributed to 55% of the EU's raw material demand, with nickel following at 34%; other materials used in the EV battery (lithium and cobalt) contributed to 0% of recycled inputs**

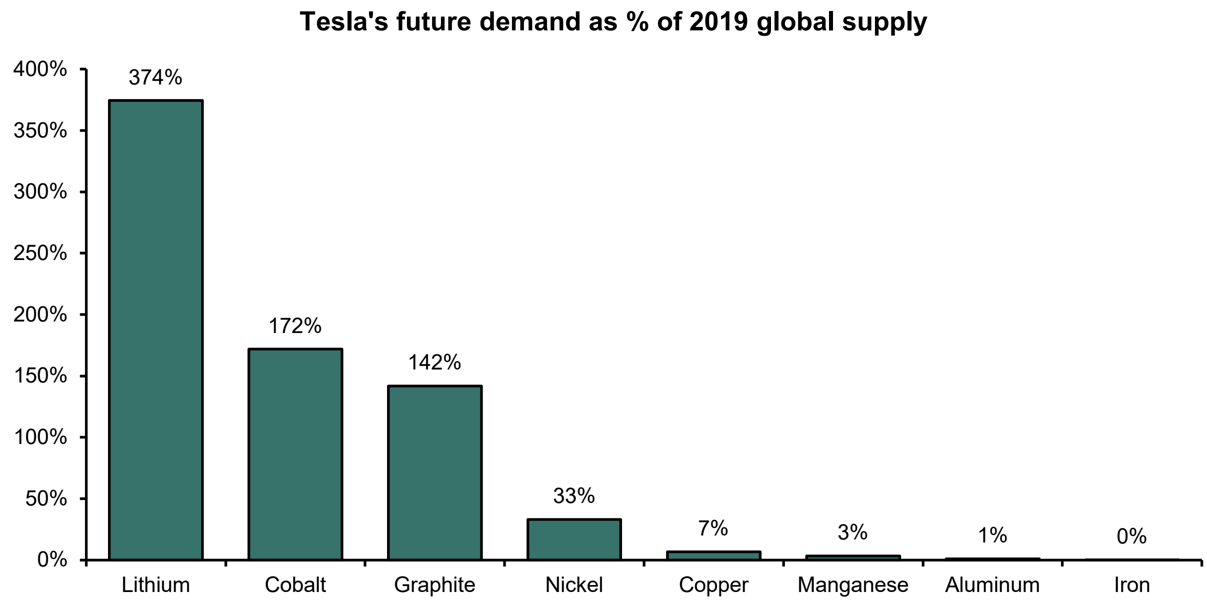


Source: Eurostat Data and Bernstein analysis

While lithium and cobalt contribute to 0% of recycled inputs, demand is expected to increase most significantly for these two metals. Our Global Metals & Mining team's analysis of Tesla's future demand is a snapshot of demand outlook for the metals.[32] Tesla would need nearly 4x as much lithium as is currently produced globally. Similarly, twice as much cobalt (see Exhibit 55). This is just our forecast for one company — it doesn't account for demand from other OEMs as well as other sectors where battery is a key input. If anything, we need more recycled materials in the supply chain to meet increasing demand.

[30] https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/second-life-ev-batteries-the-newest-value-pool-in-energy-storage
[31] World Economic Forum. Framework for Global Batteries
[32] TSLA: Who could/should Tesla buy, if anyone? An OEM, battery maker, miner...?

EXHIBIT 55: **Tesla's future metal demand is one small indicator of the potential future demand for lithium and cobalt, calling for more recycled materials to be used in the battery supply chain**



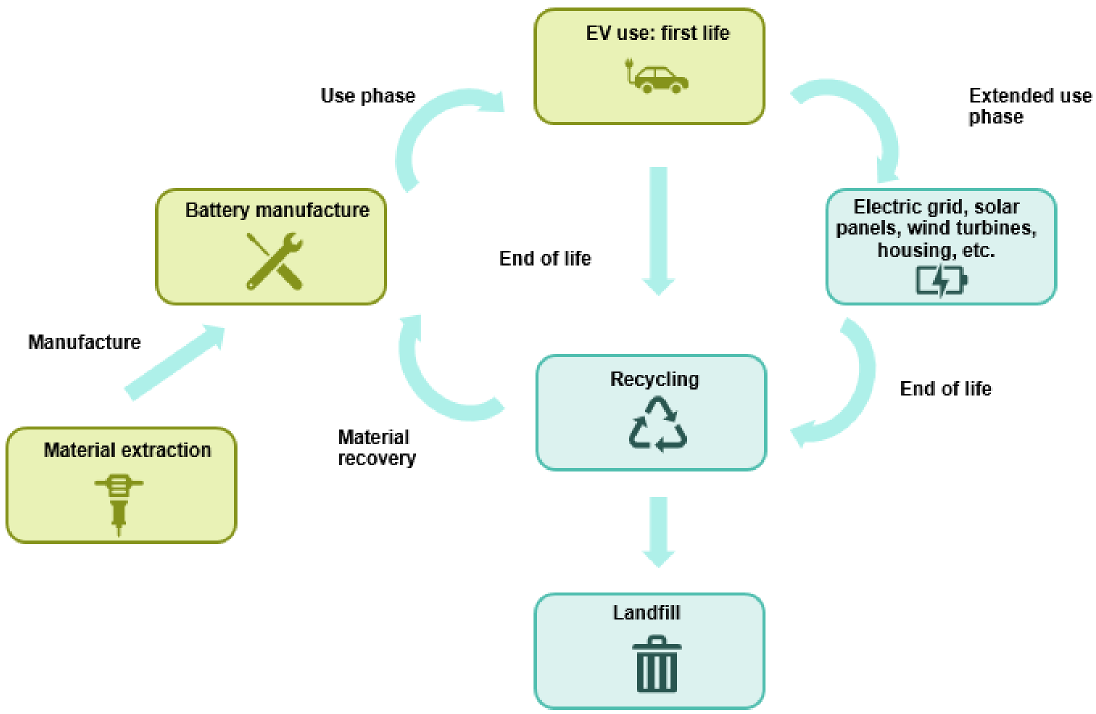
Source: USGS, SNL, and Bloomberg, and Bernstein estimates and analysis

How would a circular supply chain work in practice?

Reuse of batteries in EVs or other second-life applications. In practice, after its first life, the battery's health and capacity are checked to see if it can: (1) be used in a different vehicle (going through the recycling and re-manufacturing phase), (2) be used in a stationary application (to be used in another electrical product such as a wind turbine), or (3) if it needs to be recycled directly. If a second life is possible, the battery is refurbished.[33] The repurposing of used EV batteries (for second life in stationary applications) could provide 60GWh/year by 2030 and provide up to 6% of stationary power storage capacity demand globally in 2030.[34] A circular value chain will require thinking outside the box to make a product compatible with mass electrification (see Exhibit 56).

[33] Olsson et al, 2018. Circular Business Models for Extended EV Battery Life. *Batteries*.
[34] World Economic Forum – Global Battery Framework

EXHIBIT 56: **There are various possible pathways for EV batteries after "first life," including reuse in another EV, secondary application for different equipment, and/or recycling**



Source: MRS Energy & Sustainability and Bernstein analysis

Research carried out by National Renewable Energy Laboratory (NREL) in 2015 suggests EV batteries could last an additional 10 years in energy storage applications after first life, 30 years in power support for EV charging stations, 12 years in home energy storage, and 6-12 years in grid-oriented service (see Exhibit 57).

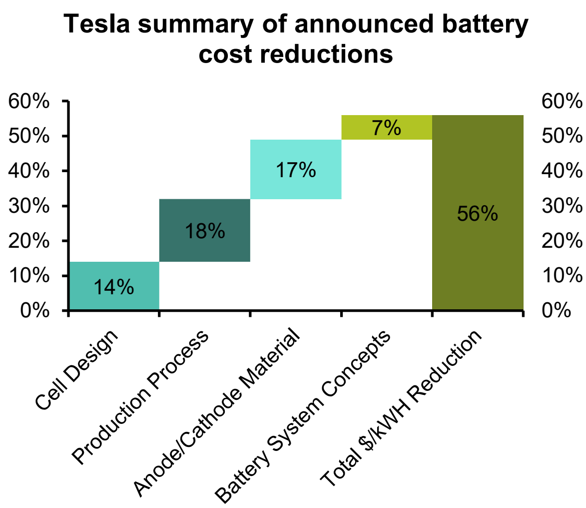
EXHIBIT 57: **Life spans reported for EVs in reuse applications**

Second Life Application of EV Battery	Additional Years of Lifespan After First Use in EV
Energy Storage Systems (ESS)	EV batteries lose an additional 15% of capacity after an additional 10 years of use
Power support to fast EV charging stations	30 years
Home Energy Storage	12 years
Grid oriented service (area regulation and transmission deferral)	6-12 years
Miscellaneous applications	3-15 years and 8-20 years depending on application

Source: Kelleher Research Study on Reuse and Recycling of Batteries, NREL, and Bernstein analysis

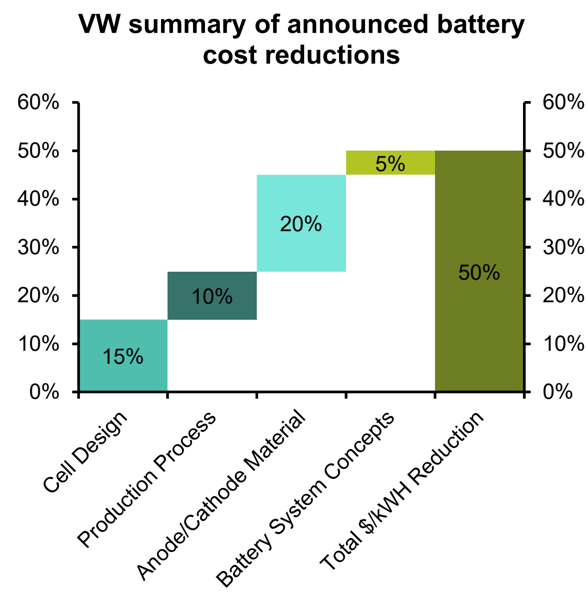
Circular design. A current structural challenge toward battery recycling and reusability is the variety of EV models in the market. To recirculate a battery into the supply chain, the end-product at end-of-life must be compatible with the product at beginning-of-life. A circular business model requires more thoughtful planning at the product design stage. Both Tesla (covered by Toni Sacconaghi) and Volkswagen (covered by Arndt Ellinghorst) are adopting a circular design mindset, which could unlock meaningful cost-saving opportunities (see Exhibit 58 and Exhibit 59).[35]

EXHIBIT 58: **Tesla's announced battery cost reductions at the design (14%), production (18%), and material stages (17%)**



Source: Company reports and Bernstein analysis

EXHIBIT 59: **Volkswagen pledged 15% cost reduction in design, 10% reduction in the production process, and 20% reduction in material**



Source: Company reports and Bernstein analysis

Enhanced communication. Another key factor toward a circular EV battery chain is greater communication across the supply chain — starting from the upstream phase all the way to the end-of-life phase. In the past, individuals collecting materials at the end-of-life stage did not have a great understanding of how to dismantle or refurbish a product, not to mention understanding potential safety issues. However, greater communication can enable better coordination across the value chain.

The EU's new Ecolabel initiative develops product sustainability standards, and the proposals on sustainable batteries include requirements for providing information about batteries and cells to allow repair, reuse, and remanufacturing.[36] The proposal is that the individual battery should carry at all levels (battery system, battery pack, and module) a bar code or a QR code with an European Article Number (EAN) and serial number. This code provides access to a central European database with information on batteries and cells. It's

[35] TSLA Battery Day vs VW Power Day: Comparing and Contrasting the Two EV Heavyweights
[36] https://ecodesignbatteries.eu/documents

the manufacturer or supplier's responsibility to provide and update the information in this database, including:

- Level 1: public access
  - Carbon footprint information in CO2 equivalent terms
  - Battery manufacturer, battery type, and chemistry
  - Percentage of recycled materials used in the cathode and anode material
  - A reference to a recycling method that can be used
- Level 2: Data available to third-party accredited professionals
  - Performance data
  - Battery Management System (BMS) related data
  - Repair & dismantling information
- Level 3: Compliance (information available for market surveillance authorities only, protected access for intellectual property reasons)

Battery passports: In addition to enhanced technologies around battery traceability, existing research discusses the introduction of a battery passport to increase supply chain transparency. A battery passport would be linked to the physical battery as it moves through its first-life into potential second-life applications until the battery, or its component parts, reach end-of-life and is transferred to high-value recycling. Such a digital product passport would allow such information to be stored and shared with multiple actors and facilitate accurate categorization of potential reuse, repurposing, and recycling of EV batteries.[37]

Working with standardization institutions to develop standards for what constitutes a circular product or service and how to assess it — incorporating the product design and business model perspective.[38]

- **The International Organization for Standardization (ISO):** The ISO sets the high watermark for conducting life cycle analysis. The ISO International Standards support sustainable industrialization through internationally agreed upon specifications that meet quality, safety, and sustainability requirements.[39] The ISO 14001 provides requirements with guidance for use that relate to environmental systems. Other standards in the framework focus on specific approaches such as audits, communications, labelling, and life cycle analysis, as well as environmental challenges such as climate change.[40] The ISO 14001 certification is also included in the TCFD climate-related disclosure that requires companies to disclose their number of ISO 14001 certified sites. At the company level, Volkswagen leads auto producers with

[37] World Economic Forum. Framework for Global Batteries
[38] https://pacecircular.org/sites/default/files/2021-04/cep-roadmap.pdf
[39] https://www.iso.org/sdg/SDG09.html
[40] https://www.iso.org/iso-14001-environmental-management.html

107 production sites are ISO certified (out of a total 118 production plants)[41] versus BMW at 29 out of a total 31 production sites.[42]

Circularity is at the heart of the proposal on sustainable products. As seen in the life cycle analysis, the environmental impact of batteries is larger in the early stages of their life cycle, namely the extraction of materials and the manufacturing process. Higher material efficiency of the battery value chains will lead to reduced extractive activities and an overall reduction of the environmental impact.[43]

[41] https://www.volkswagenag.com/en/group/portrait-and-production-plants.html
[42] https://www.bmwgroup-werke.com/en.html
[43] https://ec.europa.eu/commission/presscorner/detail/en/qanda_20_2311

REACHING THE HOLY GRAIL OF BATTERY COST PARITY

OVERVIEW

- **LiB prices declined at a 19% CAGR over the past decade on the back of improvements in battery energy density and production scale-up.** At the pack level, prices declined from over US$1,000/kWh in 2010 to US$137/kWh in 2020. Cell prices have reached close to US$100/kWh and now constitute ~75% of the pack cost following efficiency gains in cell-to-pack (CTP) technology.

- **However, the decline rate of LiB prices has slowed down in the last three years to a 13% CAGR.** We attribute this to production levels reaching economies of scale in large factories and energy density reaching 300Wh/kg, close to the limits of LiB technology.

- **We expect average LiB pack prices to decline by 35% (8% CAGR) over the next five years to US$90/kWh by 2025, which is less than the leading players' target.** VW and Tesla are aiming for a 50% and 56% reduction in costs over the next five years, respectively. Using our battery model, we expect average costs will fall from US$137/kWh to US$90/kWh over 2020-25 as energy density at the cell level approaches 400Wh/kg. The lower cost deflation relative to leading OEMs can be explained partly by new manufacturing processes (wet to dry powder) and better battery-vehicle integration, which we do not fully capture.

- **The greatest risk to our assumption of falling costs is a rise in raw material costs, although we think this delays rather than defers the point of cost parity.** Raw material costs comprise 70% of the cost of a battery cell, although price-sensitive metals (nickel, cobalt, and lithium) which make up the cathode and copper used in the collection plates make up only 40% of the cost in an NMC622 cell and 30% of a battery pack. A 50% rise in key metal prices (lithium, copper, nickel, and cobalt) from current levels would increase the cost of a battery pack by 15%. While this does not offset the 35% cost reduction we expect over the next five years, it will slow down cost reduction and could delay the point of cost parity by two years.

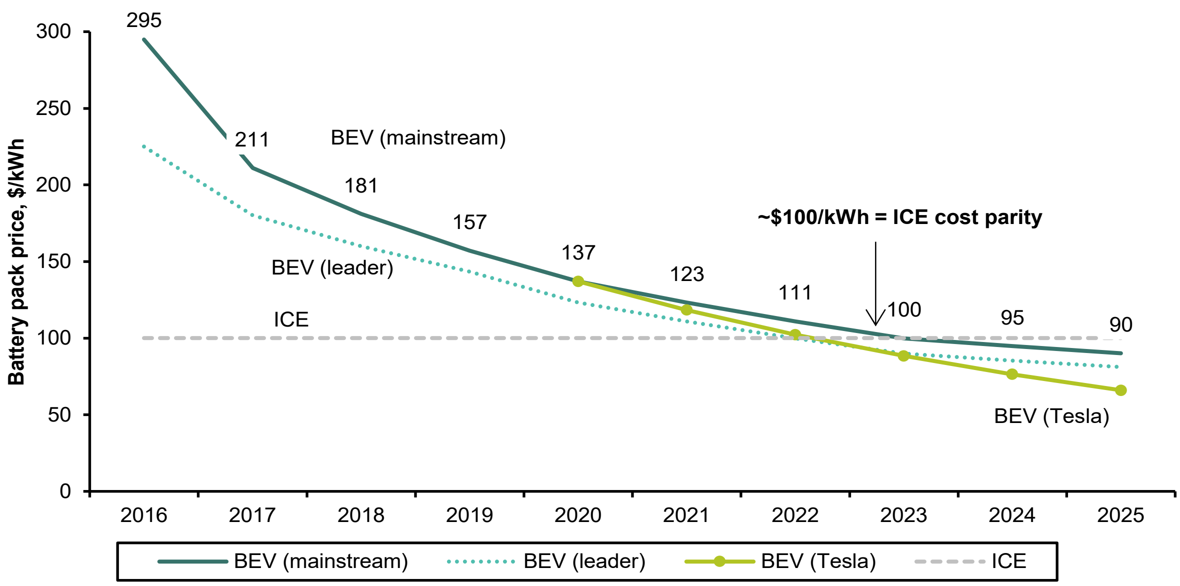
- **Next-generation battery technology offers the potential for a further steep decline in battery prices to reach US$50/kWh by 2050.** SSBs have the potential to increase energy density of batteries by 50% from current levels to beyond 400Wh/kg and up to 500Wh/kg. This could result in a further drastic reduction in battery costs of up to 50% lower from current levels, supported by fewer components (no anode required) and a simpler manufacturing process.

- **We expect BEVs to reach cost parity with internal combustion engine vehicles (ICEVs) by 2023.** Based on our outlook for battery costs, we expect the upfront cost of a BEV will reach parity with an ICEV by 2025. However, including lower maintenance costs and lower fuel costs, we expect parity in TCO with ICEV will be reached by 2023. By 2030, the TCO of a BEV could be 10% cheaper than an ICEV, which should further ease concerns over affordability and drive increased adoption.

FALLING BATTERY PRICES

We forecast average battery pack prices will fall from US$137/kWh in 2020 to around US$90/kWh by 2025, which represents a price reduction of 35% (see Exhibit 60).

EXHIBIT 60: **Battery prices are expected to fall to US$100/kWh by 2023 and US$90/kWh by 2025**



Source: Bloomberg, company data, and Bernstein estimates (2021+) and analysis

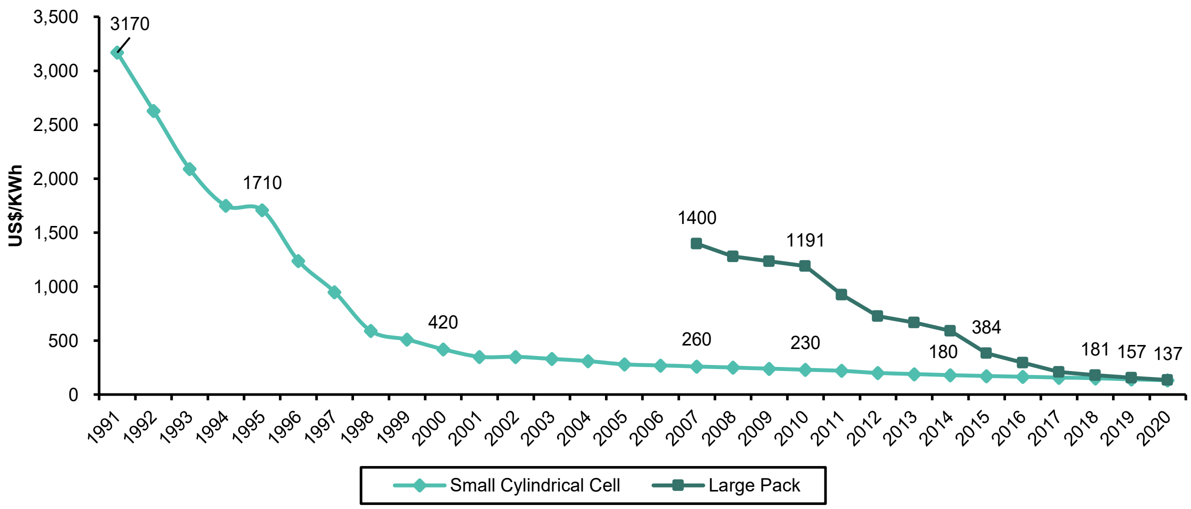
Market leaders may see battery pack prices fall to as much as US$80/kWh by 2025. Battery pack prices are expected to reach US$100/kWh by 2023, which is a major milestone for the industry as this represents the point at which mass EVs will reach upfront price parity with ICEVs. This implies automakers can produce and sell EVs at the same upfront price as an ICEV without any subsidies.

Although we estimate average battery prices will fall to US$90/kWh with market leaders at ~US$80/kWh by 2025, there are, of course, uncertainties. On one hand, surging raw material prices mean there are inflationary pressures on battery cell costs, where raw materials and components can account for up to 70% of the total costs. This has the potential to slow cost reduction trends seen over the past decade. On the other hand, some companies are more bullish on the ability to reduce costs. Tesla is targeting a 56% reduction in battery prices from 2020 to 2025, and could see its battery prices fall to as low as US$65/kWh if it can successfully implement new, more efficient manufacturing processes and better battery-vehicle integration, in addition to the 54% improvement in energy density it is targeting.

BATTERY COST REDUCTIONS

LiB costs have fallen a staggering 96% since 1991, which is an **incredible 10% CAGR cost reduction over 30 years** (see Exhibit 61). Large battery cells, which were only introduced to the market in volume in the last 10 years, have seen an even more dramatic cost improvement with prices **falling at a 19% CAGR over the last 10 years** as the less mature large-cell costs catch up to small cells, which are close to parity on a pack basis today.

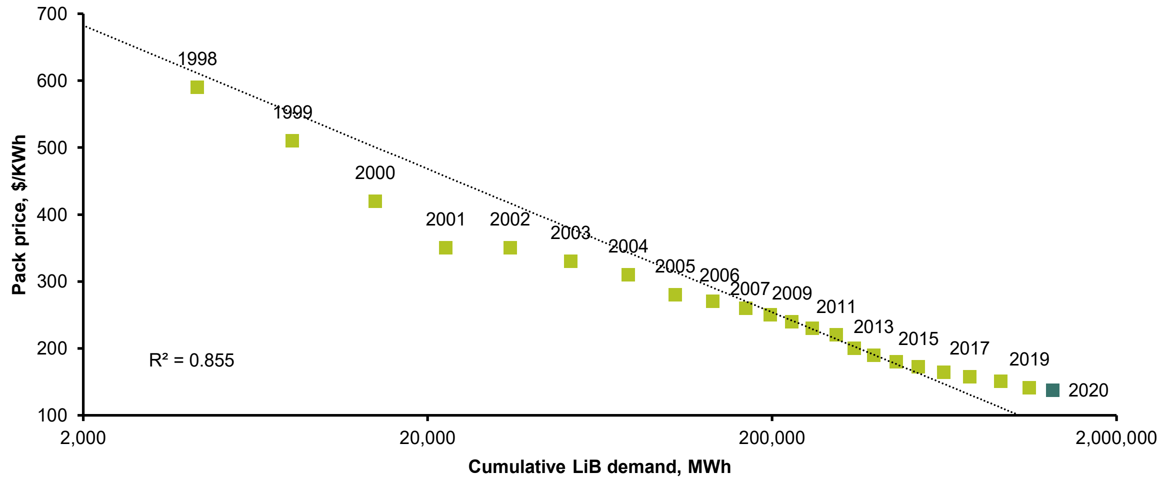
EXHIBIT 61: **LiB small cylindrical cell prices have fallen 96% since 1991 (- 10% CAGR); large-format packs are now close to parity with small cells**



Source: Navigant, Bloomberg NEF (BNEF) survey, and Bernstein analysis

LiB prices have fallen at an observed **18% "learning rate" over the past 20 years**. This implies the price of LiBs has historically fallen by 18% each time cumulative LiB production doubles. While demand growth for LiBs should remain strong over the coming years, the time between each doubling of cumulative demand will naturally take longer as the market continues to mature. More recently, however, there have been signs that cost reduction per unit of output has started to slow from the logarithmic decline witnessed since 2000. A key question is whether the learning rate will continue or whether this trend is now broken (see Exhibit 62)

EXHIBIT 62: **Battery costs have been improving at a learning rate of 18%, but the trend is starting to slow; has the learning rate curve been broken?**



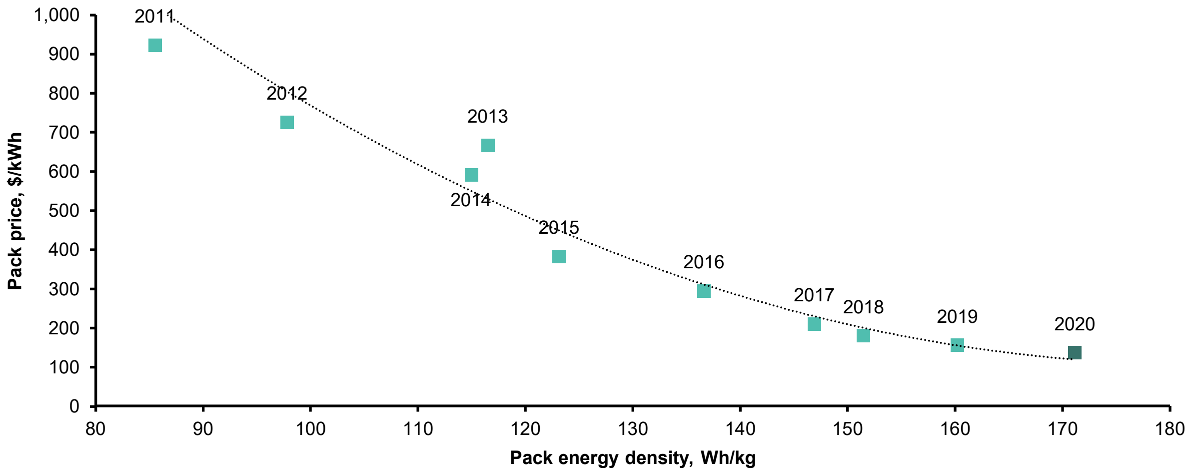
Note: Historical data based on small cylindrical cell prices

Source: Bloomberg and Bernstein analysis

While higher production capacity has significantly reduced the costs of batteries, rising energy density of LiBs has also been a key driver for lower battery costs. The average pack-level energy density has doubled in the last 10 years from 85Wh/kg in 2010 to 170Wh/kg in 2020 (although best in class have energy densities of >250Wh/kg), which has significantly lowered the cost of battery production. Improvements in technology and battery manufacturing will likely continue to drive energy density higher, albeit at a slower rate than in the past (see Exhibit 63).

While energy density has reached 300Wh/kg at the cell level (~230Wh/kg at the pack level), the question is whether we are reaching some sort of natural limit for LiBs. If so, this could be the reason for more incremental reduction in costs. But while gains will certainly be more challenging from here, Tesla believes energy density of 400Wh/kg (at the cell level; 300Wh/kg at the pack level) is possible by 2025 with further optimization of electrode chemistry and other efficiency gains.

EXHIBIT 63: **Higher energy density has been a key driver for the fall in battery prices, but energy density improvements have been more gradual as we approach limits to LiB**



Source: Bloomberg, company data, and Bernstein analysis

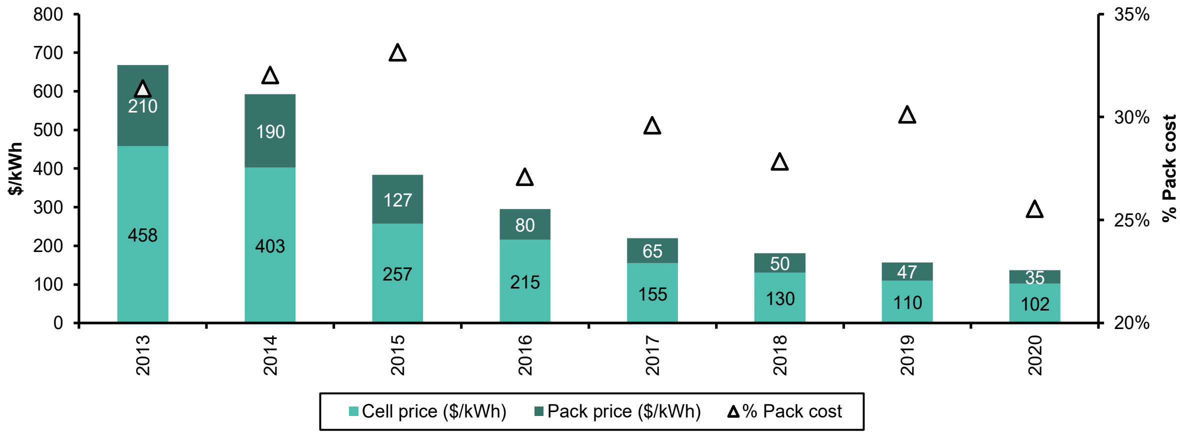
BREAKDOWN OF BATTERY COSTS

Batteries consist of cell, module, and pack, which we define below. For the purpose of this chapter, we assume modules are included within the cell and pack components.

- Cell: Basic unit of the LiB that exerts electrical energy by charging and discharging.
- Module: Battery assembly put into a frame by combining a fixed number of cells to protect the battery cell from external shocks or vibration.
- Pack: Final form of the battery system installed in an EV. Composed of modules or individual cells and various control/protection systems including BMS and cooling system.

The pack adder historically accounted for 30% of total battery pack price, although in 2020, pack adders fell to a low of 26% of total battery price. The deployment of larger cells (higher-range vehicles), optimized battery chemistries (substitution of cobalt with nickel), and lower commodity prices in recent years have significantly reduced the costs of battery cells. Pack adders have come down more significantly, given standardization of pack production, fewer connectors required with larger cells, and CTP technology that has bypassed the need for modules in some cases (see Exhibit 64).

EXHIBIT 64: **Battery prices split by cell and pack cost — pack costs have fallen faster than cell costs**



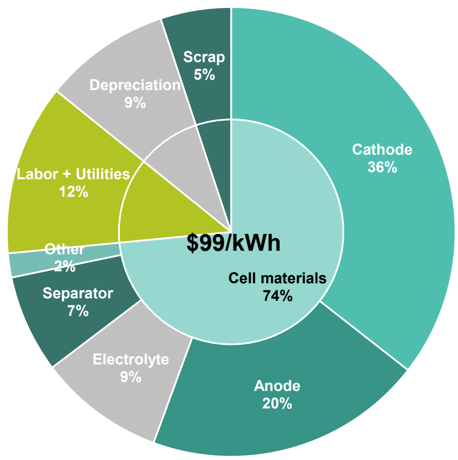
Source: Bloomberg, company data, and Bernstein analysis

Exhibit 65 shows the cost breakdown of an NMC622 pouch battery cell today. Cell materials make up the largest share of 75% of total cell costs, followed by labor and utilities at 12%, depreciation at 9%, and scrap at 5%. Within the cell, electrodes account for 55% of the costs, with the cathode accounting for roughly 35% of the costs, while the anode accounts for 20% of the costs. The remaining parts include active materials, conductive additives, solvents, and collectors. Cathode active materials are particularly exposed to commodity price fluctuations (lithium, nickel, cobalt, manganese), which make up a significant portion of the costs.

Exhibit 67 shows the cost breakdown of an NMC622 battery at the pack level. The battery cell accounts for 77% of total pack costs, followed by pack components at 9%, labor at 8%, shipping at 4%, and other costs at 2%. Pack components account for the remaining 23% and include the battery and thermal management systems, which serve as a structural unit and protector for packed cells.

Exhibit 67 also shows the cost breakdown of the main battery formats today. Lithium iron phosphate (LFP) has the lowest battery pack price of ~US$124/kWh (~US$109/kWh excluding cell maker margin of 15%), given the use of iron, but the energy density of this battery is lower than other chemistries. NMC532 has the highest cost at ~US$153/kWh (~US$134/kWh excluding cell maker margin). Higher nickel-based batteries such as NMC811 and lithium nickel cobalt aluminum oxides (NCA) tend to have lower prices, given the higher battery density and less use of cobalt, which costs 2.5x higher than nickel today. Overall, the average price across these battery packs is US$141/kWh (US$121/kWh excluding the 15% cell maker gross margin).

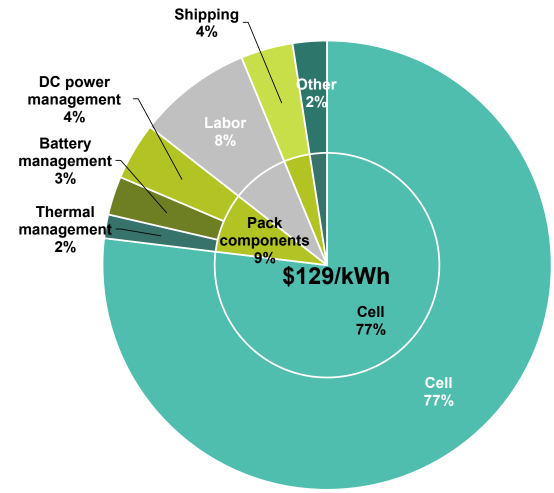
EXHIBIT 65: **Current cell cost (US$/kWh)**



Note: 2020-21 cost for NMC622 pouch battery (excluding cell maker margin)

Source: China Industrial Association of Power Sources (CIAPS), China Bulk Commodity (CBC), Shanghai Xinluo Network (ICCSINO), Bloomberg, and Bernstein analysis

EXHIBIT 66: **Current pack cost (US$/kWh)**



Note: 2020-21 cost for NMC pouch battery (excluding cell maker margin)

Source: CIAPS, CBC, ICCSINO, Bloomberg, and Bernstein analysis

EXHIBIT 67: **Large battery pack costs today: LFP prismatic packs currently offer the cheapest solution, albeit with a slightly lower energy density**

Battery cost breakdown 2020/2021 (USD/KWh)	LFP-Pr	NMC 532-Pr	NMC 622-Po	NMC 811-Po	NCA-Cy
Cell COGS	**86.1**	**110.0**	**98.9**	**94.8**	**93.2**
Cathode	10.5	35.3	34.0	35.0	36.1
Anode	4.6	4.6	4.6	6.8	6.8
Electrolyte	9.8	8.3	9.0	8.6	6.7
Separator	7.7	7.7	7.0	7.0	6.8
Aluminum foil	1.6	1.3	1.1	0.9	0.8
Copper foil	21.8	18.0	15.3	12.9	11.7
Case and Tabs	5.7	5.7	1.7	1.4	2.7
Labor and Utilities	13.5	13.5	12.2	10.0	9.7
Depreciation	6.5	10.0	9.0	7.4	7.2
Scrap	4.2	5.4	5.0	4.8	4.7
Battery Cell Price	**101.3**	**129.4**	**116.3**	**111.5**	**109.6**
Cell Maker GM%	15%	15%	15%	15%	15%
Cell Marker Gross Margin	15.2	19.4	17.4	16.7	16.4
Pack Adder	**22.8**	**23.8**	**29.7**	**30.8**	**30.4**
Thermal Management System	1.0	2.0	2.2	3.3	3.3
Battery Management System	3.6	3.6	3.6	3.6	3.6
DC Power Management System	5.3	5.3	5.3	5.3	5.3
Wiring & Welding	2.6	2.6	3.7	3.7	5.6
Other Assembly Costs	2.3	2.3	6.9	6.9	4.6
Initial Charge Management at Factory	3.2	3.2	3.2	3.2	3.2
Pack Shipment to Car Factory	4.8	4.8	4.8	4.8	4.8
Pack Price (w/o Cell Maker Margin)	**108.9**	**133.8**	**128.5**	**125.5**	**123.5**
Pack Price (w/ Cell Maker Margin)	**124.1**	**153.2**	**146.0**	**142.3**	**140.0**

Source: CIAPS, CBC, ICCSINO, Bloomberg, and Bernstein analysis

WHAT'S THE LONG-TERM PRICE OF BATTERIES?

Battery prices are expected to fall over the next five years, driven by improving manufacturing processes and new technologies that will likely continue to raise pack energy density. There are two key controversies, however. First, what level of improvement in energy density will be achieved over the coming years, and how much will that lower battery costs? Second, is the impact of inflation in commodity prices on battery prices, given 70% of the cost of a cell and 50% of the cost of a pack (70% * 70%) consists of raw materials and components.

Exhibit 68 shows our projected cost breakdown of the main battery formats in 2025 based on our bottom-up analysis of battery costs. We expect NMC811 and NCA batteries will have the lowest costs across battery formats at ~US$94/kWh (~US$83/kWh before cell maker margin). LFP batteries will have slightly higher costs of ~US$97/kWh, while NMC532 and NMC622 are higher at ~US$128/kWh and ~US$113/kWh, respectively.

EXHIBIT 68: **Large battery pack costs by 2025**

Battery cost breakdown 2025 (USD/KWh)	LFP-Pr	NMC 532-Pr	NMC 622-Po	NMC 811-Po	NCA-Cy
Cell COGS	**68.8**	**94.2**	**78.9**	**61.4**	**61.4**
Cathode	7.5	33.5	27.1	19.5	19.3
Anode	3.7	3.6	3.6	3.2	3.2
Electrolyte	7.0	6.0	6.0	4.9	4.8
Separator	7.7	7.5	6.8	4.7	5.4
Aluminum foil	1.3	1.1	0.9	0.7	0.7
Copper foil	17.5	14.4	12.2	10.3	9.4
Case and Tabs	4.6	4.6	1.4	1.1	2.2
Labor and Utilities	10.8	10.8	9.8	8.0	7.8
Depreciation	5.2	8.0	7.2	5.9	5.7
Scrap	3.4	4.6	4.0	3.1	3.1
Battery Cell Price	**81.0**	**110.8**	**92.8**	**72.3**	**72.3**
Cell Maker GM%	15%	15%	15%	15%	15%
Cell Maker Gross Margin	12.1	16.6	13.9	10.8	10.8
Pack Adder	**16.5**	**17.5**	**20.5**	**21.6**	**21.4**
Thermal Management System	1.0	2.0	2.2	3.3	3.3
Battery Management System	3.6	3.6	3.6	3.6	3.6
DC Power Management System	5.3	5.3	5.3	5.3	5.3
Wiring & Welding	1.3	1.3	1.9	1.9	2.8
Other Assembly Costs	1.1	1.1	3.4	3.4	2.3
Initial Charge Management at Factory	3.2	3.2	3.2	3.2	3.2
Pack Shipment to Car Factory	1.0	1.0	1.0	1.0	1.0
Pack Price (w/o Cell Maker Margin)	**85.3**	**111.7**	**99.4**	**83.1**	**82.8**
Pack Price (w/ Cell Maker Margin)	**97.4**	**128.3**	**113.4**	**93.9**	**93.7**

Source: CIAPS, CBC, ICCSINO, Bloomberg, and Bernstein estimates (all data) and analysis

Overall, we expect by 2025 battery pack prices will fall by 34% for NMC811, 33% for NCA, 22% for NMC622, 21% for LFP, and 16% for NMC532 relative to 2020 prices (see Exhibit 69). At the cell level, improvements in cell design and larger batteries are expected to increase energy density, which will lead to an estimated 20% reduction in the cell COGS. Cathode costs for NMC811 and NCA are expected to fall more sharply, given manufacturing costs and margins are expected to mature. For the pack adder, we expect the COGS will fall by roughly 30% across battery formats. The biggest reduction for pack adder costs should come from wider adoption of CTP processes, which will require fewer modules and connectors (non-active materials) in the battery. Contemporary Amperex Technology Co. Ltd. (CATL) claims CTP can raise energy density of the batteries by 10-15% by reducing the space required for non-active materials by 15-20%.

EXHIBIT 69: **2025 battery costs variance to 2020 battery costs**

2025 vs 2020 costs	LFP-Pr	NMC 532-Pr	NMC 622-Po	NMC 811-Po	NCA-Cy
Cell COGS	**-20%**	**-14%**	**-20%**	**-35%**	**-34%**
Cathode	-28%	-5%	-20%	-44%	-47%
Anode	-20%	-22%	-22%	-53%	-53%
Electrolyte	-28%	-28%	-33%	-43%	-28%
Separator	0%	-3%	-3%	-33%	-21%
Aluminum foil	-20%	-20%	-20%	-20%	-20%
Copper foil	-20%	-20%	-20%	-20%	-20%
Case and Tabs	-20%	-20%	-20%	-20%	-20%
Labor and Utilities	-20%	-20%	-20%	-20%	-20%
Depreciation	-20%	-20%	-20%	-20%	-20%
Scrap	-20%	-14%	-20%	-35%	-34%
Battery Cell Price	-20%	-14%	-20%	-35%	-34%
Cell Maker GM%					
Cell Marker Gross Margin	-20%	-14%	-20%	-35%	-34%
Pack Adder	**-28%**	**-27%**	**-31%**	**-30%**	**-29%**
Thermal Management System	0%	0%	0%	0%	0%
Battery Management System	0%	0%	0%	0%	0%
DC Power Management System	0%	0%	0%	0%	0%
Wiring & Welding	-50%	-50%	-50%	-50%	-50%
Other Assembly Costs	-50%	-50%	-50%	-50%	-50%
Initial Charge Management at Factory	0%	0%	0%	0%	0%
Pack Shipment to Car Factory	-80%	-80%	-80%	-80%	-80%
Pack Price (w/o Cell Maker Margin)	**-22%**	**-17%**	**-23%**	**-34%**	**-33%**
Pack Price (w/ Cell Maker Margin)	**-21%**	**-16%**	**-22%**	**-34%**	**-33%**

Source: CIAPS, CBC, ICCSINO, Bloomberg, and Bernstein estimates (for 2025) and analysis

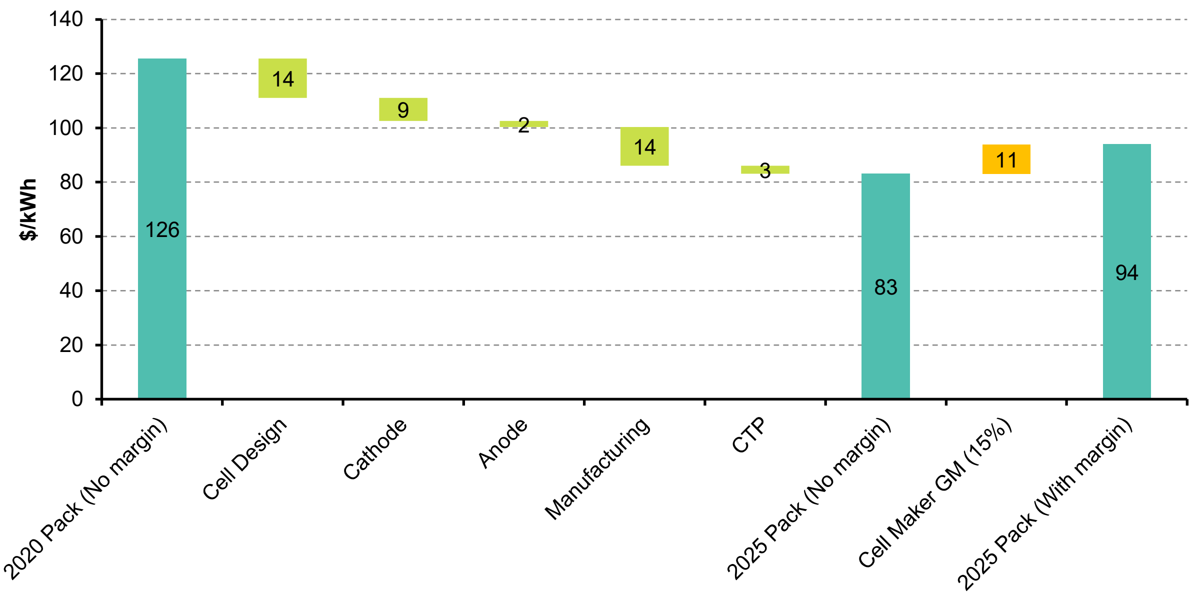
EXHIBIT 70: **Battery costs comparison by battery format and cell design**

		2020/21 Price			2025 Price			%Change		
		Cylindrical	Prismatic	Pouch	Cylindrical	Prismatic	Pouch	Cylindrical	Prismatic	Pouch
No cell maker margin	**LFP**	112	109	111	86	85	85	-23%	-22%	-23%
	NMC 532	137	134	135	113	112	111	-18%	-17%	-18%
	NMC 622	130	126	129	101	99	99	-23%	-21%	-23%
	NMC 811	127	123	126	84	83	83	-34%	-33%	-34%
	NCA	124	120	123	83	81	82	-33%	-32%	-33%
With cell maker margin	**LFP**	127	124	125	98	97	97	-23%	-21%	-23%
	NMC 532	156	153	154	129	128	127	-17%	-16%	-17%
	NMC 622	148	145	146	115	114	113	-22%	-21%	-22%
	NMC 811	144	140	142	95	94	94	-34%	-33%	-34%
	NCA	140	136	139	94	92	93	-33%	-32%	-33%

Source: CIAPS, CBC, ICCSINO, Bloomberg, and Bernstein estimates (for 2025) and analysis

The reduction in battery costs can be summarized by improvements in five areas, namely, cell design (bigger batteries and form), cathode, anode, manufacturing, and CTP technology. Exhibit 71 shows the cost reduction for an NMC811 battery based on these five categories. Improvement in cell design drives higher energy density, which will come from larger batteries, CTP, and advancement in battery chemistry and structure. Higher manufacturing productivity represents the next biggest improvement in battery prices given standardization, improving efficiency, and higher utilization of plants, which will continue to drive down unit costs. Moreover, Tesla has announced a shift from wet to dry manufacturing as a means to reduce manufacturing costs more significantly through the Maxwell technology it acquired.

EXHIBIT 71: **We expect 34% reduction in NMC811 battery prices from 2020 to 2025**



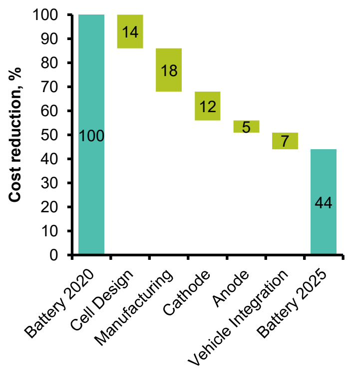
Note: Cost for NMC811 pouch battery

Source: CIAPS, CBC, ICCSINO, Bloomberg, and Bernstein estimates (2025) and analysis

While we expect a cost reduction of 35% over 2020-25, Tesla is targeting a 56% reduction in pack costs, which will require multiple breakthroughs in battery manufacturing processes and technology advancements. VW is also targeting similar improvement in battery costs of 50% reduction by 2025 (see Exhibit 72 to Exhibit 74).

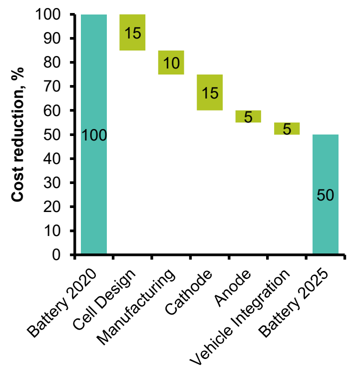
Tesla outlined a new manufacturing process centered around dry electrode coating, the introduction of a new larger-format cylindrical cell (4680), and elimination of tabs on electrodes. Tesla also claims it can reduce anode material costs significantly to US$1.2/kWh using a silicon-based anode versus graphite, which costs roughly US$4/kWh today. On battery packs, Tesla is planning to integrate cells directly into the vehicle chassis, which will simplify the process of pack production.

EXHIBIT 72: **Tesla is targeting 56% reduction in battery pack costs**



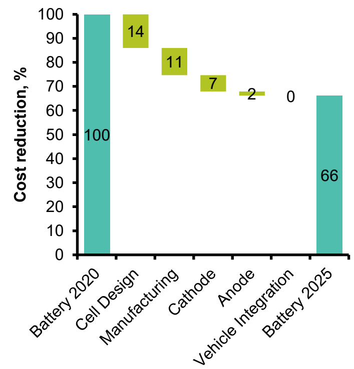
Source: Company data, and Bernstein estimates (2025) and analysis

EXHIBIT 73: **VW is targeting 50% reduction in battery pack costs**



Source: Company data, and Bernstein estimates (2025) and analysis

EXHIBIT 74: **Bernstein forecasts 34% reduction in battery pack costs**



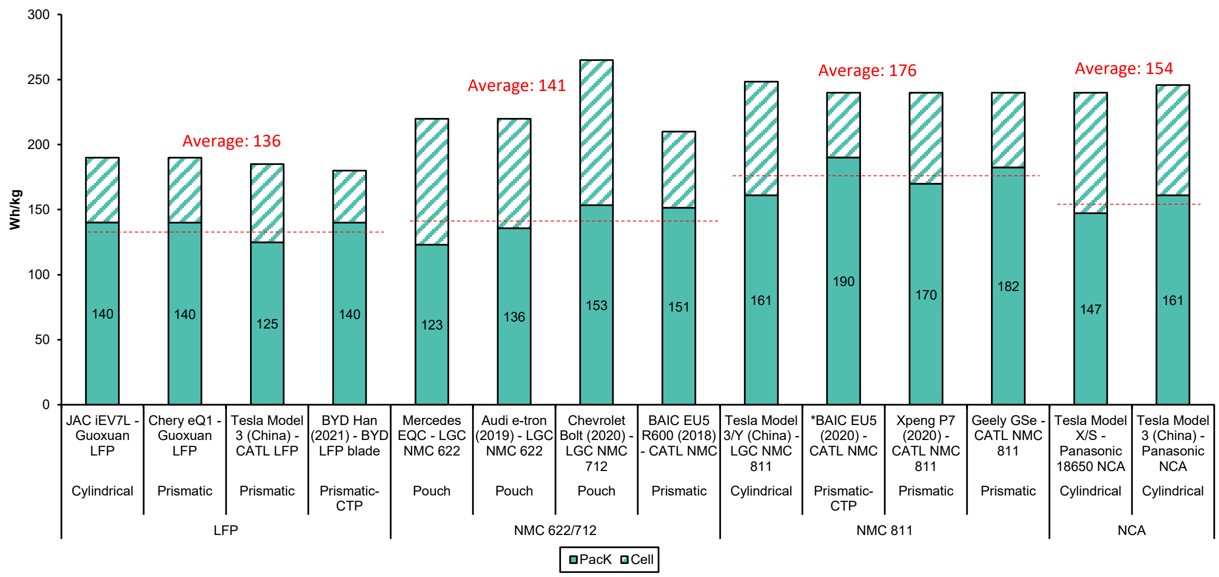
Source: Company data, and Bernstein estimates (2025) and analysis

All in all, material costs can be significantly reduced and energy densities will improve with less inactive materials in the battery pack. Based on these improvements, the energy density of the 4680 battery pack could reach close to 250Wh/kg (cell energy density of 360Wh/kg), which is a 50% improvement from the average today. While Tesla is targeting 56% reduction, which is higher than our 34%, we do not take into account battery-vehicle integration, the change in anode material, or the change in cathode production being implemented by Tesla, given these are unique to the company and will require time to commercialize more broadly.

VW's targeted 50% reduction in cost is similar to that of Tesla, although there are some differences in terms of the cost reduction levers. Probably the biggest area of difference is in manufacturing, where Tesla anticipates a reduction in manufacturing costs of almost double what is being targeted by VW.

The energy density of battery packs is expected to rise on improving battery formats, cell designs, and CTP efficiencies that are being implemented. When we look at the array of EV battery packs in the market today (see Exhibit 75), there is a clear shift in the industry toward high-nickel batteries such as NMC811 and NCA, which have demonstrated higher energy density and lower cost. LFP is also gaining traction in China mainly due to lower costs and longer cycle times, which make it ideal for entry-level vehicles. In terms of cell design, cylindrical and pouch cells continue to deliver the highest cell-level energy density, although the industry is moving toward prismatic cells (given better safety performance). Energy density for prismatic cells has room to improve, driven by CTP, which will reduce pack weight such that there is similar energy density at the pack level between cylindrical, prismatic, and pouch formats. For example, using prismatic CTP with NMC811 cell format, pack energy density could rise to over 200Wh/kg, according to CATL.

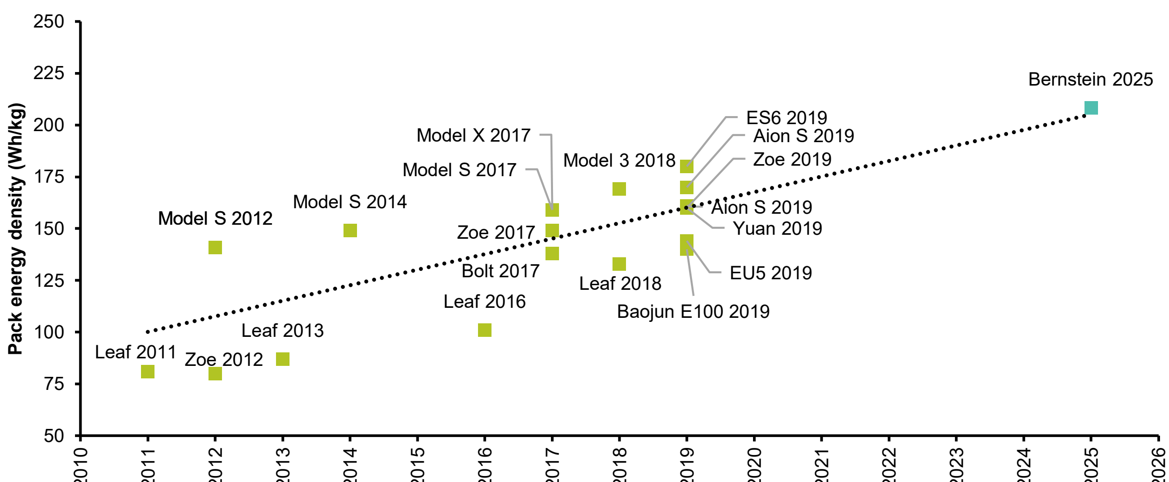
EXHIBIT 75: **Pack energy density is improving, driven by better CTP efficiency and new battery formats**



Source: Company data and Bernstein analysis

Based on the improvement in cell design, we expect the average pack energy density of PVs will reach 210Wh/kg by 2025. This implies cell-level energy density of around 260-280Wh/kg, assuming 75-80% CTP efficiency (although best in class will have an energy density of >350Wh/kg). Our targeted pack energy density of 210Wh/kg represents 4% CAGR improvement or roughly 20% improvement from the average of 170Wh/kg in 2020 for PVs (see Exhibit 76).

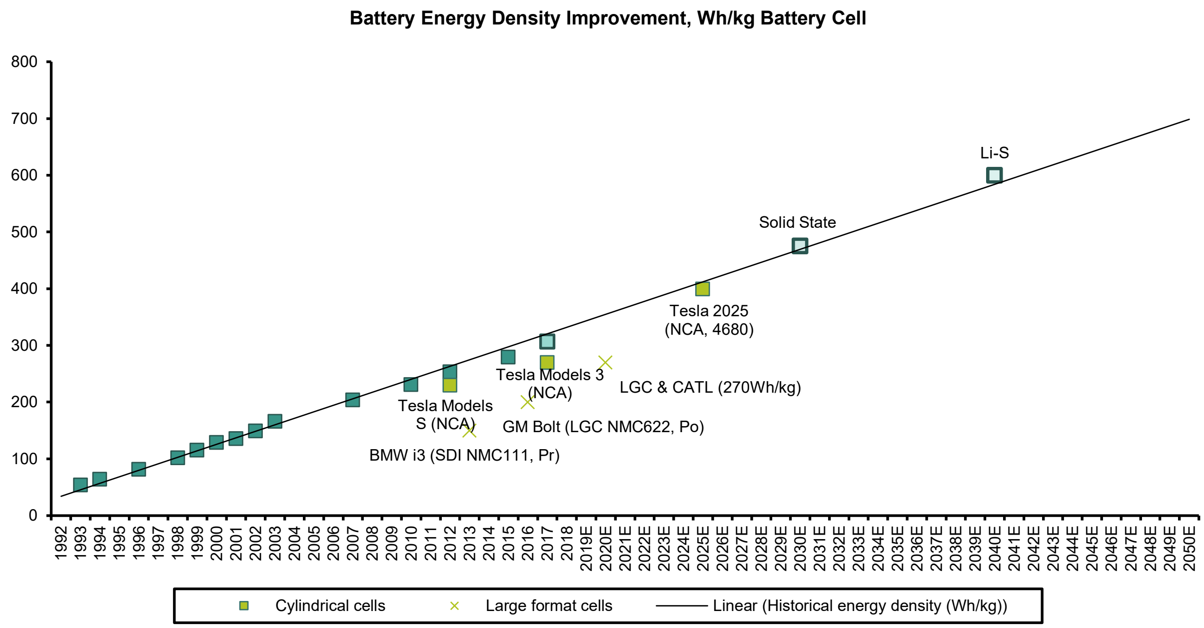
EXHIBIT 76: **Energy density of batteries at the pack level in vehicles is expected to rise with new generations of EVs and batteries**



Source: Bloomberg, company data, and Bernstein estimates (2021+) and analysis

In the long run, we expect cell energy density can still double from the current best-in-class 300Wh/kg, assuming the average learning rate of 11Wh/kg continues to hold true. Further improvements in electrode chemistry could yield energy density for LiB of up to 400Wh/kg by 2025 at the cell level. SSBs are currently being developed and are expected to become mainstream by the late-2020s; they could increase cell energy density to 400-500Wh/kg. The development of lithium sulfur (Li-S) or Li-Air batteries could double cell energy density to 600-700Wh/kg over the long run (see Exhibit 77).

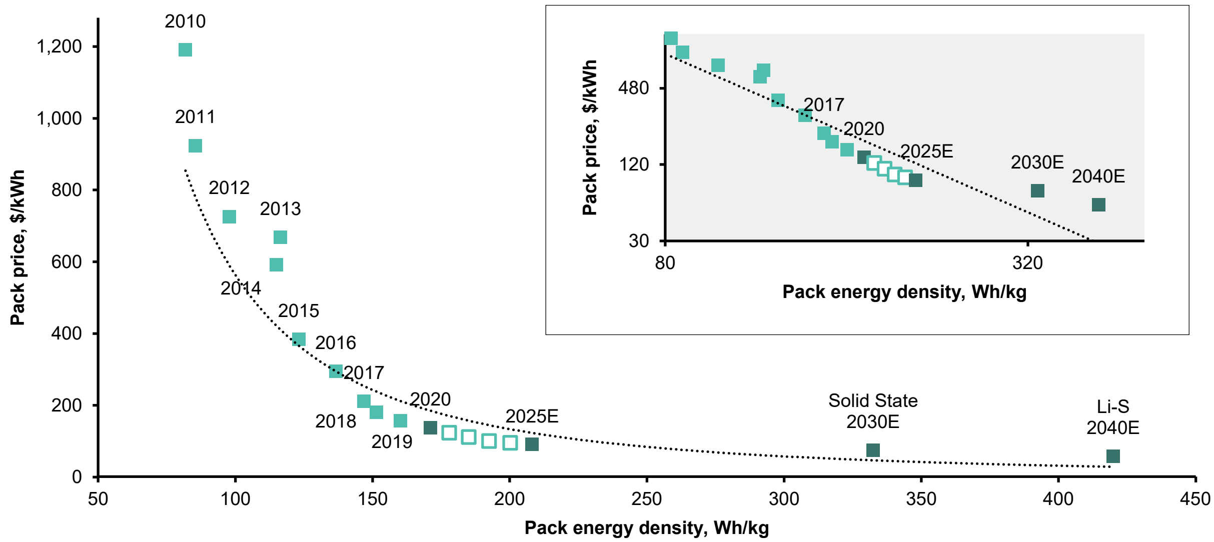
EXHIBIT 77: **Battery energy density could still double from current levels with new technology over the long term**



Source: Shmuel De-Leon Energy, company data, and Bernstein estimates and analysis

Given the increasing trend in energy density and based on our bottom-up analysis of battery costs, we estimate battery prices (at the pack level) will fall by 35% from US$137/kW in 2020 to US$90/kWh by 2025. While we expect battery prices to continue to fall, the annual rate of price cost declines will slow to an 8% CAGR in the next five years from 19% in the last decade and 10% over the last 30 years. We attribute this to production levels now reaching economies of scale in large factories and the energy density of LiBs reaching close to 300Wh/kg at cell level (225Wh/kg at pack level assuming 75% efficiency), which is starting to approach the energy density limits of conventional LiB technology. To improve battery prices significantly beyond US$90/kWh, we expect the adoption of new cell designs, such as SSBs which will lift cell energy density to 400-500Wh/kg, although Tesla believes it may be possible to reach close to 400Wh/kg by 2025 with LiB technology.

EXHIBIT 78: **Strong correlation between pack energy density and pack price, although cost efficiencies will likely diminish**



Source: Bloomberg, company data, and Bernstein estimates and analysis

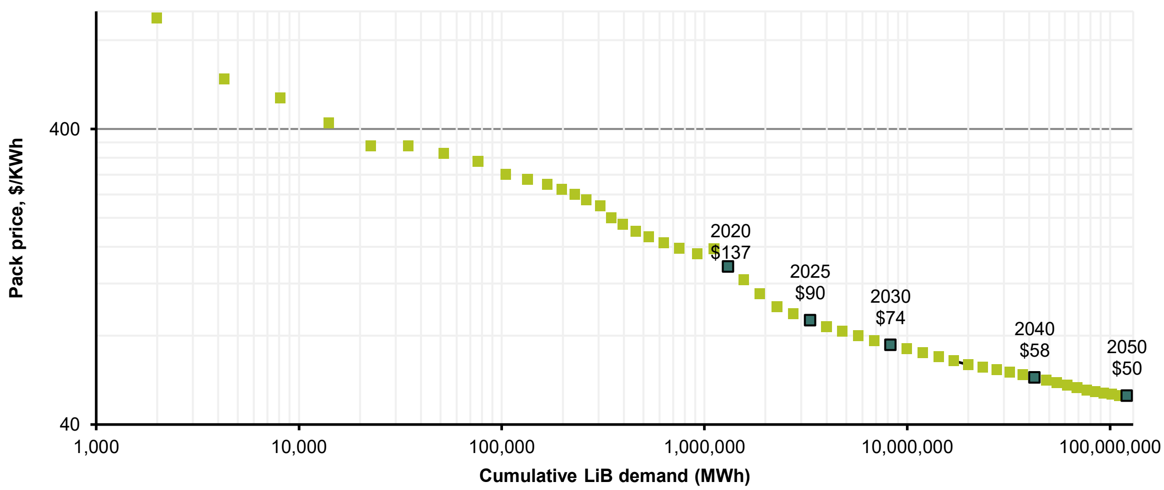
Our forecast for battery prices is consistent with the outlook for battery demand and the 18% learning curve for LiB over the last 20 years. Cumulative LiB demand is expected to nearly quadruple between 2020 and 2025, which is consistent with our forecast of 35% improvement in battery prices (2 * 18%) to US$90/kWh (see Exhibit 79).

Assuming SSBs become mainstream by 2030, we estimate battery prices can fall to US$75/kWh by 2030. Further step change can come from development of Li-S or Li-Air batteries, which could double current energy density to 600Wh/kg and reduce battery prices to US$50/kWh by 2050.

To sum up, we forecast average battery pack prices will fall from US$137/kWh in 2020 to around US$90/kWh by 2025, which represents a price reduction of 35% or an 8% CAGR. Battery pack prices are expected to reach US$100/kWh by 2023, which is a major milestone for the industry as mass EVs will reach upfront price parity with ICEVs.

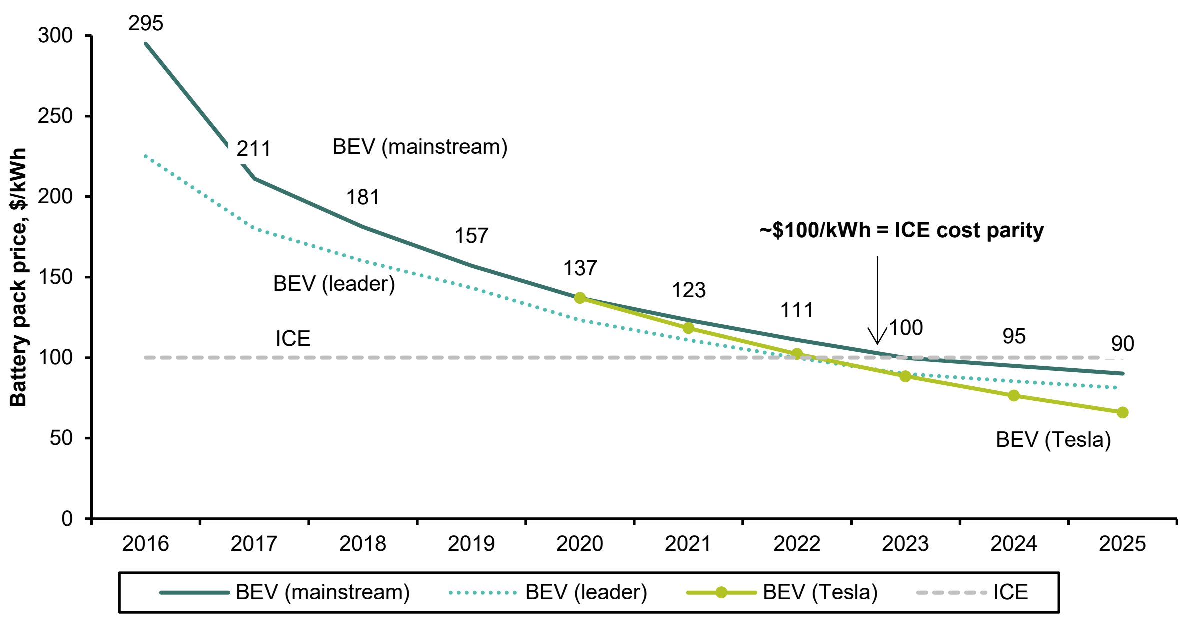
This implies automakers can produce and sell EVs at the same upfront price as ICEVs without any subsidies. By 2025, we estimate average battery prices will fall to US$90/kWh, with market leaders around US$80/kWh. Tesla is targeting a 56% reduction in battery prices from 2020 to 2025, which could see its battery prices fall to US$65/kWh if it can successfully implement new manufacturing processes (wet to dry powder) and better battery-vehicle integration in addition to improvements in energy density (see Exhibit 80).

EXHIBIT 79: **We forecast long-term battery prices of ~US$90/kWh by 2025, falling to US$50/kWh by 2050**



Source: Bloomberg, and Bernstein estimates (all data) and analysis

EXHIBIT 80: **Battery prices are expected to fall to US$100/kWh by 2023 and US$90/kWh by 2025**



Source: Bloomberg, company data, and Bernstein estimates (2021+) and analysis

Our battery price forecasts are largely in line with market expectations over the next five years. For 2025, our US$90/kWh battery price estimate is slightly above Bloomberg's target of US$84/kWh. Tesla and Volkswagen are targeting roughly 20% lower cost than our expectation, although both companies have ambitious targets to reduce prices relative to the average battery makers (see Exhibit 81).

EXHIBIT 81: **Bernstein battery pack prices versus estimates and company targets (US$/kWh)**

Announced Year	Company	2017	2018	2019	2020	2021	2022	2023	2024	2025
2017	Tesla	190								
2017	VW				119					
2017	CATL				229					
2018	China Govt't				140					
2019	VW				100					
2020	Tesla				150					66
2020	Daimler									100
2020	CATL					110		100		
2021	VW									75
Avg. Actual Price		**220**	**181**	**157**	**137**					
Bernstein Forecast						***123***	***111***	***100***	***95***	***90***
Bloomberg Forecast						***125***	***112***	***101***	***92***	***84***

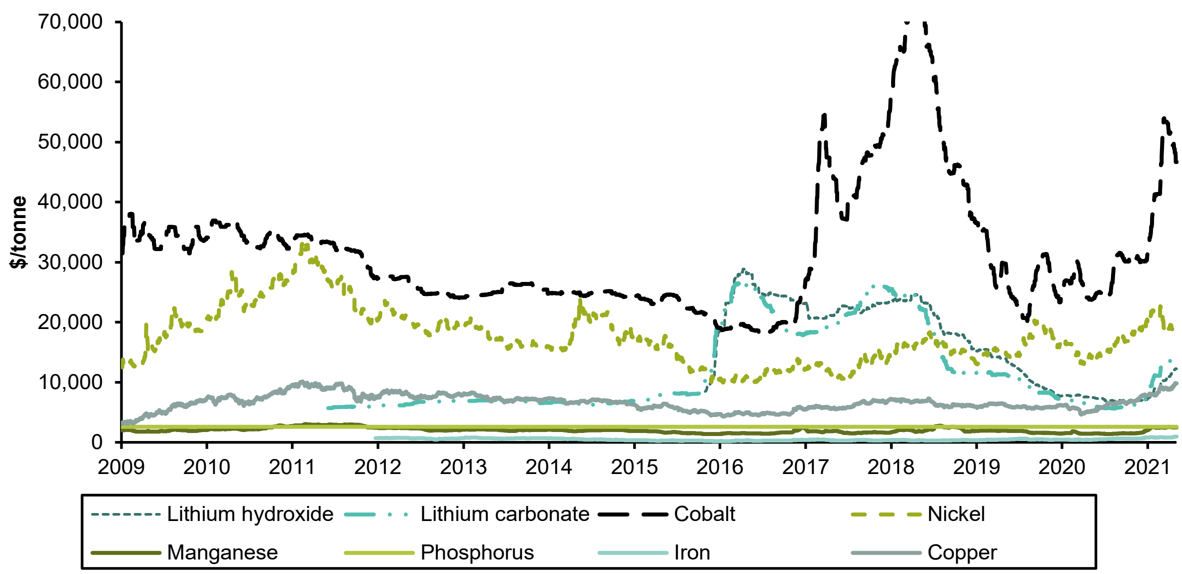
Note: All stocks are covered by Bernstein.

Source: Bloomberg, company data, and Bernstein estimates and analysis

HOW SENSITIVE ARE BATTERY COSTS TO MATERIAL PRICES?

Lower commodity prices have helped reduce battery prices over the past few years, although prices have been on a rise in 2021 due to perceived tightness in the market. If higher material prices are here to stay, how much will this impact future battery prices? Could it be that higher material prices offset the trajectory of battery cost deflation? See Exhibit 82 and Exhibit 83.

EXHIBIT 82: **Pricing for key battery metals; lithium, cobalt, and nickel account for the highest material costs**



Source: Bloomberg and Bernstein analysis

EXHIBIT 83: **Key metal and cathode prices: Cathode prices are up 40% across YoY due to higher metal prices**

	2017	2018	2019	2020	YTD	△YoY	%YoY
Metal prices ($/kg)							
Lithium carbonate	21.8	18.0	9.9	**6.4**	**12.0**	**5.6**	**88%**
Cobalt	43.9	57.6	27.5	**27.7**	**45.4**	**17.6**	**64%**
Nickel	12.6	15.9	16.2	**16.2**	**20.3**	**4.2**	**26%**
Manganese	1.7	2.2	1.8	**1.5**	**2.5**	**0.9**	**61%**
Phosphorus	2.6	2.6	2.6	**2.6**	**2.6**	**0.0**	**0%**
Iron	0.4	0.4	0.5	**0.6**	**0.9**	**0.3**	**55%**
Copper	6.2	6.5	6.0	**6.2**	**8.7**	**2.5**	**40%**
Cathode prices ($/kWh)							
NMC532	51.2	56.0	36.0	**28.9**	**41.2**	**12.4**	**43%**
NMC622	-	54.9	36.4	**29.3**	**40.6**	**11.2**	**38%**
LFP	-	-	-	**8.9**	**12.1**	**3.2**	**36%**

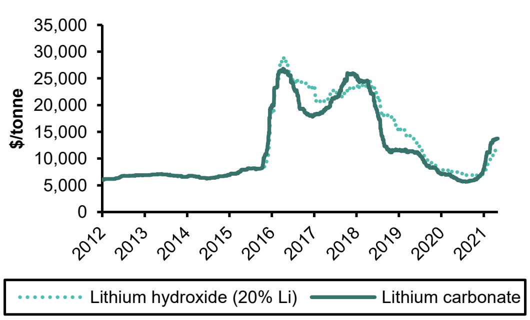
Source: Bloomberg and Bernstein analysis

The four key materials to track when looking at LiB costs are lithium, cobalt, nickel, and copper, given these are the higher-cost materials within the battery. Other key commodities critical for LiB are aluminum, manganese, iron, and graphite, which are lower-cost materials.

Lithium is the most critical component of the LiB, given it is the movement of charged lithium ions that stores or releases energy within the battery. The two main types of lithium used in LiB today are lithium carbonate sourced from brines and lithium hydroxide sourced from hard rock deposits. Both forms of lithium can be used, although hydroxide tends to be preferred for nickel-rich cathodes.

While higher cost metals and materials are used primarily in the cathode, the copper foil used to collect charges from the anode is another major component of the battery, which is directly exposed to copper prices (see Exhibit 84 and Exhibit 85).

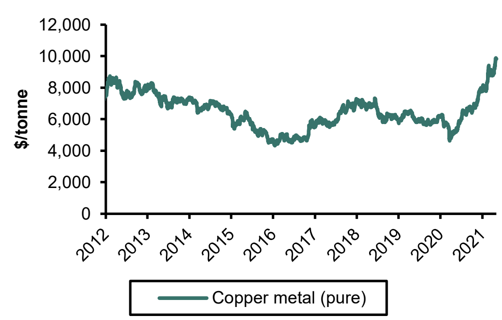
EXHIBIT 84: **Spot lithium prices**



Note: Data as of May 3, 2021

Source: Bloomberg and Bernstein analysis

EXHIBIT 85: **Spot copper prices**

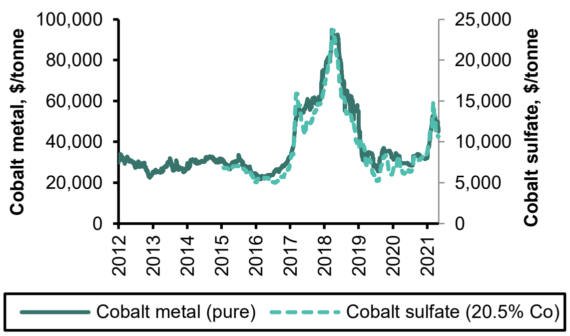


Note: Data as of May 3, 2021

Source: Bloomberg and Bernstein analysis

Cobalt is a key material used to provide stability to the structure of the active material in the cathode. The feedstock used in batteries is cobalt sulfate rather than pure cobalt, which contains roughly 20.5% cobalt content in the salt. Cobalt prices are the key price driver for cobalt sulfate which tends to move in similar magnitude and direction. Nickel is another key material used in the cathodes to increase energy density of the batteries. As battery makers continue to shift from low to high nickel content cathodes, the price and volatility of nickel metal is expected to have a bigger impact on the overall costs of the battery packs. Nickel sulfate (22% nickel content), which is used for the production of cathodes, will continue to track nickel metal prices (see Exhibit 86 and Exhibit 87).

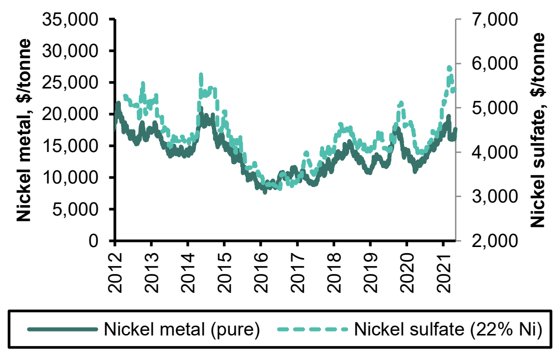
EXHIBIT 86: **Spot cobalt metal and sulfate prices**



Note: Data as of May 3, 2021

Source: Bloomberg and Bernstein analysis

EXHIBIT 87: **Spot nickel metal and sulfate prices**



Note: Data as of May 3, 2021

Source: Bloomberg and Bernstein analysis

The chemistry used in the anode and cathode has a significant impact on the cost and performance of the battery packs. Energy-dense cathodes such as NMC or NCA account for the largest share of EV markets. LFP will also play a major role in EVs that require less energy density, although it is used primarily for stationary storage, given its longer cycle life. Given the different characteristics of the batteries, the materials used in each battery also vary significantly (see Exhibit 88).

EXHIBIT 88: **Raw material requirement by battery type (kg/kWh)**

Kg/Kwh	NMC (111)	NMC (523)	NMC (622)	NMC (811)	NMC (271)	Hi Ni / NMCA	eLNO	LS	NCA	LFP	LMO
Lithium	**0.177**	**0.147**	**0.147**	**0.147**	**0.147**	**0.147**	**0.147**	**0.130**	**0.116**	**0.151**	**0.132**
Cobalt	**0.484**	**0.361**	**0.217**	**0.086**	**0.080**	**0.038**	**0.008**	**0.000**	**0.048**	**0.000**	**0.000**
Nickel	**0.482**	**0.600**	**0.648**	**0.689**	**0.160**	**0.721**	**0.772**	**0.000**	**0.853**	**0.000**	**0.000**
Manganese	**0.452**	**0.225**	**0.202**	**0.081**	**0.525**	**0.035**	**0.000**	**0.000**	**0.000**	**0.000**	**1.971**
Copper	0.750	0.625	0.563	0.540	0.573	0.573	0.573	0.573	0.489	1.023	1.023
Graphite	1.047	0.872	0.785	0.628	0.571	0.571	0.571	0.000	0.683	1.428	1.428
Oxygen	0.789	0.654	0.589	0.469	0.437	0.414	0.425	0.585	0.517	1.316	1.148
Aluminium	0.346	0.288	0.259	0.207	0.188	0.188	0.188	0.188	0.247	0.471	0.471
Iron	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.148	0.000
S	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.586	0.000	0.000	0.000
Phosphorous	0.026	0.021	0.019	0.015	0.014	0.014	0.014	0.014	0.017	0.672	0.035

Source: Ellingsen, Majeau-Bettez et al., and Bernstein analysis

Looking at the materials used in the primary forms of cathodes, NMC532 has the highest exposure to cobalt at 0.36kg/kWh or 18% of the total cathode. Compared to NMC811, the cobalt content is significantly reduced to 0.09kg/kWh or 6% of total active material in the cathode. NCA has the highest exposure to nickel at 0.85kg/kWh or 55% of total cathode material, while NMC532 is at 30% and NMC811 is at 46%. The lithium content is fairly similar across the battery types at 0.12-0.15kg/kWh or around 7-10% of the cathode. Note LFP is exposed largely to iron and phosphorus, which are not higher-cost metals (see Exhibit 89 to Exhibit 92).

EXHIBIT 89: **Cathode active material, kg/kWh**

	NCA	NMC811	NMC622	NMC532	LFP
Li	0.12	0.15	0.15	0.15	0.15
Co	0.05	0.09	0.22	0.36	0.00
Ni	0.85	0.69	0.65	0.60	0.00
Mn	0.00	0.08	0.20	0.22	0.00
PO4	0.02	0.02	0.02	0.02	0.67
Fe	0.00	0.00	0.00	0.00	1.15

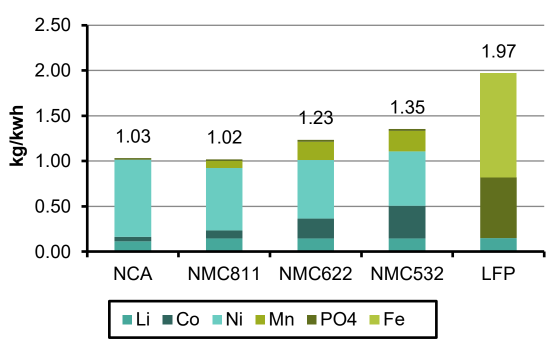
Source: Ellingsen, Majeau-Bettez et al., and Bernstein analysis

EXHIBIT 90: **Percentage of active material in cathode**

	NCA	NMC811	NMC622	NMC532	LFP
Li	11%	14%	12%	11%	8%
Co	5%	8%	18%	27%	0%
Ni	83%	68%	53%	44%	0%
Mn	0%	8%	16%	17%	0%
PO4	2%	2%	2%	2%	34%
Fe	0%	0%	0%	0%	58%

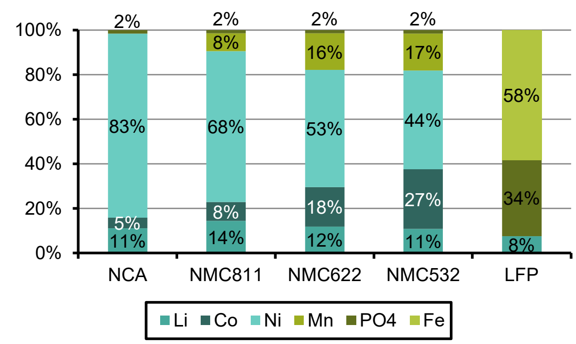
Source: Ellingsen, Majeau-Bettez et al., and Bernstein analysis

EXHIBIT 91: **Cathode active material, kg/kWh**



Source: Ellingsen, Majeau-Bettez et al., and Bernstein analysis

EXHIBIT 92: **Percentage of active material**



Source: Ellingsen, Majeau-Bettez et al., and Bernstein analysis

Based on the material content of the cathodes and material prices today, we have calculated the cathode costs of each battery format in Exhibit 93. Comparing the material costs of each battery format, LFP has the lowest material costs at ~US$4/kg, while NMC532 has the highest at ~US$20/kg (see Exhibit 95).

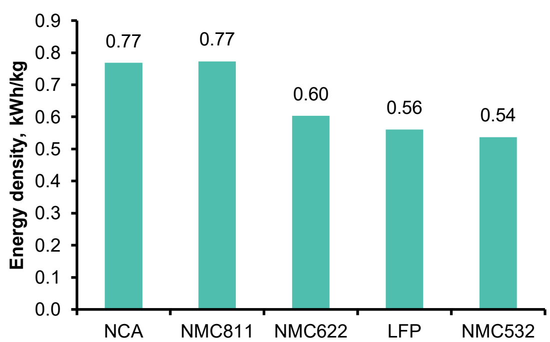
Taking into account the energy density of cathodes, NMC532 has the highest cathode costs at US$41/kWh, while LFP is the lowest at US$13/kWh. While cathode prices are higher for NMC811 and NCA on a US$/kg basis, the higher energy density of the materials takes the costs down to around US$35/kWh for the two battery formats (see Exhibit 94).

EXHIBIT 93: **Cathode cost and market price**

	Price $/kg	NCA	NMC811	NMC622	NMC532	LFP
Li	65.1	4.9	6.4	5.2	4.8	3.0
Co	46.7	1.4	2.7	5.6	8.4	0.0
Ni	20.2	11.1	9.4	7.2	6.0	0.0
Mn	2.5	0.0	0.1	0.3	0.3	0.0
PO4	2.6	0.0	0.0	0.0	0.0	0.5
Fe	0.2	0.0	0.0	0.0	0.0	0.1
Material cost ($/kg)		**17.5**	**18.7**	**18.9**	**20.1**	**3.9**
Market price ($/kg)		**27.9**	**27.2**	**24.3**	**22.0**	**7.5**
Market premium (%)		60%	46%	29%	10%	89%
Energy density (kwh/kg)		0.768	0.773	0.603	0.537	0.561
Cathode material cost ($/kWh)		***22.7***	***24.1***	***31.4***	***37.4***	***7.0***
Cathode market price ($/kWh)		***36.3***	***35.2***	***40.3***	***41.0***	***13.3***

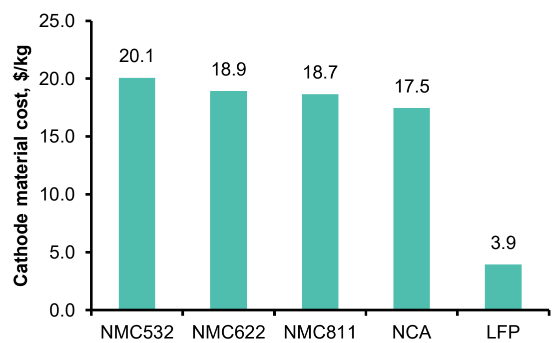
Source: Bloomberg and Bernstein analysis

EXHIBIT 94: **Cathode energy density, kWh/kg**



Source: Bloomberg and Bernstein analysis

EXHIBIT 95: **Cathode material cost, US$/kg**

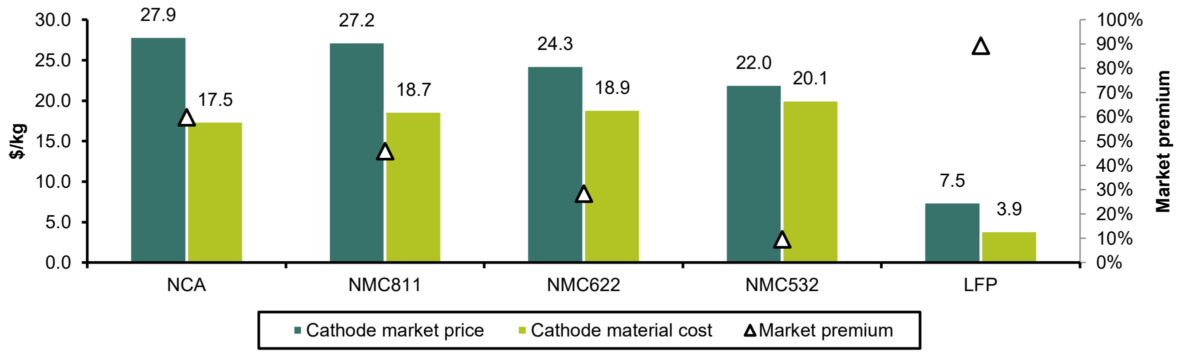


Source: Bloomberg and Bernstein analysis

While raw material accounts for the largest share of the cathode cost, expenses such as processing, manufacturing, labor, and margin also need to be added to the cost of cathodes.

Looking at the market prices of cathodes today (which account for all the major costs), NCA has the highest cost at ~US$28/kg or a 60% premium to the raw material costs, while LFP has the lowest market price at US$7.5/kg, although this is an 89% premium (defined as market premium) to raw material costs (see Exhibit 96).

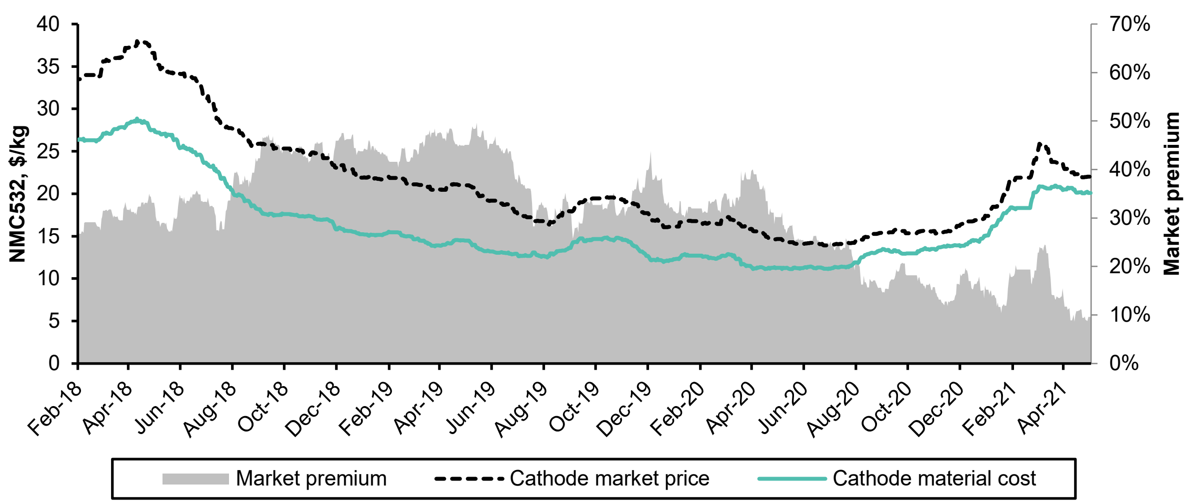
EXHIBIT 96: **Commodity NMC (NMC532) cathodes sell at a 10% market price premium over the cost of all cathode materials, with other Hi-Ni NMC/NCA chemistries selling at a huge premium**



Source: CBC, ICCSINO, Bloomberg, and Bernstein analysis

While cathodes sell at a premium or a margin above the material costs, we expect this spread will narrow over time as manufacturing productivity scales. Looking at the material and cathode prices of NMC532 (see Exhibit 97), the premium has fallen from around 30-40% in 2019 to 10% currently above the material costs. We expect NMC formats will fall toward a normalized margin of around 10% in the long run.

EXHIBIT 97: **Cathodes sell at a premium over cost among all raw materials, although this premium has narrowed**



Source: Bloomberg and Bernstein analysis

One of the key questions is how much will battery prices rise if material costs move up significantly? Exhibit 98 shows key battery material prices as of May 2021 and changes by 10% increments.

EXHIBIT 98: **Key material prices and sensitivity (US$/kg)**

Change	LiOH	LCE	Co	Ni	Mn	O2	PO4	Fe	Cu
-50%	$33	$36	$23	$10	$1	$0	$1	$0	$5
-40%	$39	$44	$28	$12	$2	$0	$2	$0	$6
-30%	$46	$51	$33	$14	$2	$0	$2	$0	$7
-20%	$52	$58	$37	$16	$2	$0	$2	$0	$8
-10%	$59	$66	$42	$18	$2	$0	$2	$0	$9
Spot	**$65**	**$73**	**$47**	**$20**	**$3**	**$0**	**$3**	**$0**	**$10**
10%	$72	$80	$51	$22	$3	$0	$3	$0	$11
20%	$78	$87	$56	$24	$3	$0	$3	$0	$12
30%	$85	$95	$61	$26	$3	$0	$3	$0	$13
40%	$91	$102	$65	$28	$4	$0	$4	$0	$14
50%	$98	$109	$70	$30	$4	$0	$4	$0	$15

Source: Bloomberg and Bernstein analysis

Based on material price sensitivity, we have calculated the impact of the changes to battery costs. Exhibit 99 shows the sensitivity of 2025 battery prices to lithium, cobalt, nickel, and copper prices, which are the high-cost active materials within a battery.

EXHIBIT 99: **2025 battery pack price sensitivity to lithium, cobalt, nickel, and copper prices**

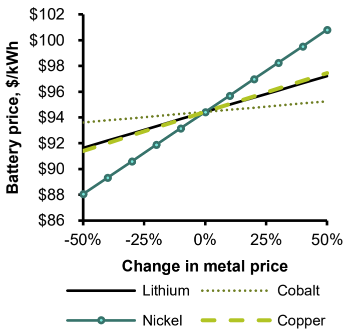
	Lithium				Cobalt				Nickel				Copper			
Price	Metal $/kg	NCA $/kwh	NMC811 $/kwh	LFP $/kwh	Metal $/kg	NCA $/kwh	NMC811 $/kwh	LFP $/kwh	Metal $/kg	NCA $/kwh	NMC811 $/kwh	LFP $/kwh	Metal $/kg	NCA $/kwh	NMC811 $/kwh	LFP $/kwh
-50%	**$33**	$92	$90	$94	**$23**	$94	$92	$97	**$10**	$88	$89	$97	**$5**	$91	$90	$92
-40%	**$39**	$92	$91	$95	**$28**	$94	$93	$97	**$12**	$89	$90	$97	**$6**	$92	$91	$93
-30%	**$46**	$93	$92	$95	**$33**	$94	$93	$97	**$14**	$91	$91	$97	**$7**	$93	$92	$94
-20%	**$52**	$93	$92	$96	**$37**	$94	$93	$97	**$16**	$92	$92	$97	**$8**	$93	$92	$95
-10%	**$59**	$94	$93	$97	**$42**	$94	$93	$97	**$18**	$93	$93	$97	**$9**	$94	$93	$96
Spot	**$65**	**$94**	**$94**	**$97**	**$47**	**$94**	**$94**	**$97**	**$20**	**$94**	**$94**	**$97**	**$10**	**$94**	**$94**	**$97**
10%	**$72**	$95	$94	$98	**$51**	$95	$94	$97	**$22**	$96	$95	$97	**$11**	$95	$94	$98
20%	**$78**	$96	$95	$98	**$56**	$95	$94	$97	**$24**	$97	$96	$97	**$12**	$96	$95	$99
30%	**$85**	$96	$96	$99	**$61**	$95	$95	$97	**$26**	$98	$97	$97	**$13**	$96	$96	$101
40%	**$91**	$97	$96	$100	**$65**	$95	$95	$97	**$28**	$100	$98	$97	**$14**	$97	$96	$102
50%	**$98**	$97	$97	$100	**$70**	$95	$95	$97	**$30**	$101	$99	$97	**$15**	$97	$97	$103

%Chg	Price %	NCA %	NMC811 %	LFP %	Price %	NCA %	NMC811 %	LFP %	Price %	NCA %	NMC811 %	LFP %	Price %	NCA %	NMC811 %	LFP %
-50%	**-50%**	-3%	-4%	-3%	**-50%**	-1%	-1%	0%	**-50%**	-7%	-5%	0%	**-50%**	-3%	-4%	-6%
-40%	**-40%**	-2%	-3%	-3%	**-40%**	-1%	-1%	0%	**-40%**	-5%	-4%	0%	**-40%**	-3%	-3%	-5%
-30%	**-30%**	-2%	-2%	-2%	**-30%**	-1%	-1%	0%	**-30%**	-4%	-3%	0%	**-30%**	-2%	-2%	-3%
-20%	**-20%**	-1%	-1%	-1%	**-20%**	0%	-1%	0%	**-20%**	-3%	-2%	0%	**-20%**	-1%	-1%	-2%
-10%	**-10%**	-1%	-1%	-1%	**-10%**	0%	0%	0%	**-10%**	-1%	-1%	0%	**-10%**	-1%	-1%	-1%
Spot	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
10%	**10%**	1%	1%	1%	**10%**	0%	0%	0%	**10%**	1%	1%	0%	**10%**	1%	1%	1%
20%	**20%**	1%	1%	1%	**20%**	0%	1%	0%	**20%**	3%	2%	0%	**20%**	1%	1%	2%
30%	**30%**	2%	2%	2%	**30%**	1%	1%	0%	**30%**	4%	3%	0%	**30%**	2%	2%	3%
40%	**40%**	2%	3%	3%	**40%**	1%	1%	0%	**40%**	5%	4%	0%	**40%**	3%	3%	5%
50%	**50%**	3%	4%	3%	**50%**	1%	1%	0%	**50%**	7%	5%	0%	**50%**	3%	4%	6%

Source: Bloomberg, and Bernstein estimates (2025 data) and analysis

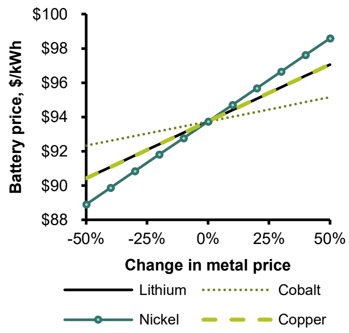
For NCA, a 50% increase in lithium, cobalt, nickel, and copper (individually) will result in a 3%, 1%, 7%, and 3% rise in battery prices, respectively. This highlights that for current batteries, nickel prices are now the key determinant of battery costs. For NMC811, a 50% increase in lithium, cobalt, nickel, and copper prices will result in a 4%, 1%, 5%, and 4% rise in battery prices, respectively. For LFP, a 50% increase in lithium and copper will result in a 3% and 6% rise in battery prices, respectively (see Exhibit 100 to Exhibit 105).

EXHIBIT 100: **NCA battery price sensitivity to metal prices**



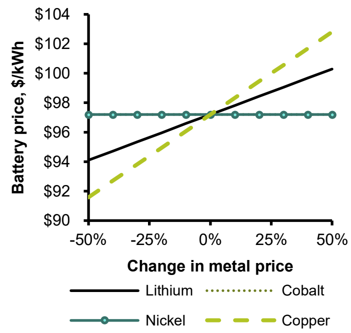
Source: Bloomberg and Bernstein analysis

EXHIBIT 101: **NMC811 battery price sensitivity to metal prices**



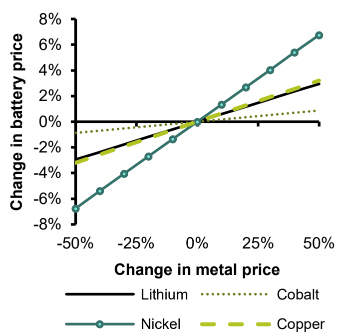
Source: Bloomberg and Bernstein analysis

EXHIBIT 102: **LFP battery price sensitivity to metal prices**



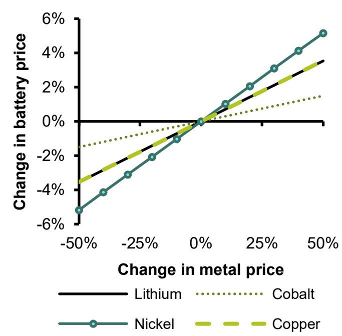
Source: Bloomberg and Bernstein analysis

EXHIBIT 103: **Change in NCA battery price to metal prices**



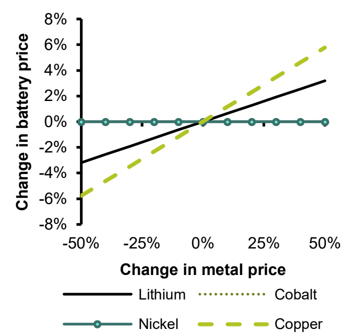
Source: Bloomberg and Bernstein analysis

EXHIBIT 104: **Change in NMC811 battery price to metal prices**



Source: Bloomberg and Bernstein analysis

EXHIBIT 105: **Change in LFP battery price to metal prices**



Source: Bloomberg and Bernstein analysis

Taking the combined impact of the changes in material prices, we expect average battery prices will rise by 15% across battery formats, assuming a 50% increase in all material costs. This makes intuitive sense, given cathode accounts for about 35% of the cell cost and 30% of pack costs. LFP will likely see less impact at a 10% increase, while NMC532 will see the highest change in battery pack price at 17% (see Exhibit 106).

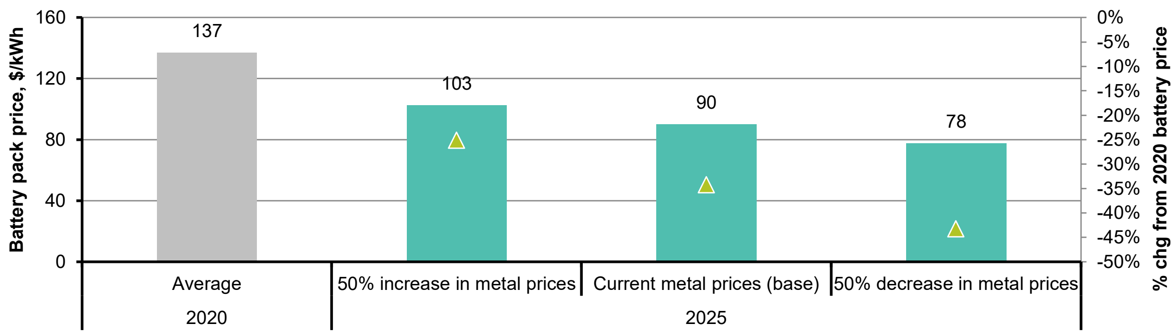
EXHIBIT 106: **2025 battery pack price sensitivity to all material prices**

	2025 battery pack price ($/kWh)					Change from base price ($/kWh)				
Price	**NCA**	**NMC811**	**NMC622**	**NMC532**	**LFP**	**NCA**	**NMC811**	**NMC622**	**NMC532**	**LFP**
-50%	$81	$81	$96	$107	$88	-14%	-14%	-15%	-17%	-10%
-40%	$84	$83	$99	$111	$90	-11%	-11%	-12%	-13%	-8%
-30%	$87	$86	$103	$115	$92	-8%	-8%	-9%	-10%	-6%
-20%	$89	$89	$106	$120	$93	-6%	-6%	-6%	-7%	-4%
-10%	$92	$91	$109	$124	$95	-3%	-3%	-3%	-3%	-2%
Spot	**$94**	**$94**	**$113**	**$128**	**$97**	**0%**	**0%**	**0%**	**0%**	**0%**
10%	$97	$96	$116	$133	$99	3%	3%	3%	3%	2%
20%	$100	$99	$120	$137	$101	6%	6%	6%	7%	4%
30%	$102	$102	$123	$141	$103	8%	8%	9%	10%	6%
40%	$105	$104	$127	$145	$105	11%	11%	12%	13%	8%
50%	$107	$107	$130	$150	$106	14%	14%	15%	17%	10%

Source: Bloomberg, and Bernstein estimates (all data) and analysis

Our base case is weighted-average battery pack prices will fall from US$137/kWh in 2020 to US$90/kWh by 2025, which represents a decline of 35%. However, if material costs rise by 50% from 2020 levels and remain at these levels, we expect battery pack prices will average US$103/kWh by 2025, which is a 25% decline from 2020 prices. If, on the other hand, material costs fall by 50%, battery pack prices will fall to US$78/kWh or a decline of 43% from 2020 levels (see Exhibit 107).

EXHIBIT 107: **Battery price outlook sensitivity to metal prices**



Source: Bloomberg, and Bernstein estimates (2025) and analysis

BATTERY PRICE AND TCO OF EV VERSUS ICEV

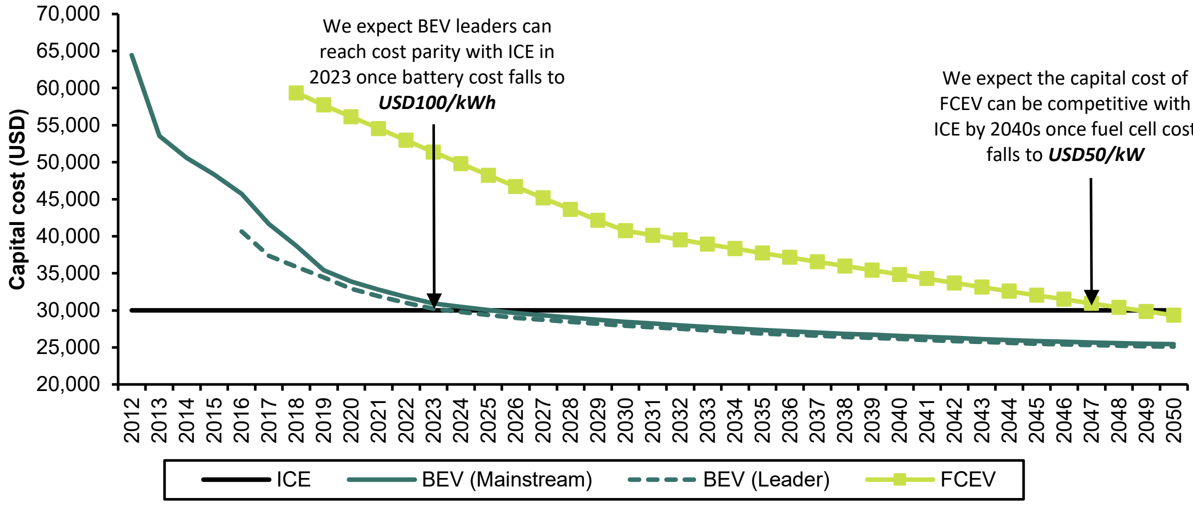
The TCO for a vehicle can be summarized into three broad areas: (1) capital costs of a vehicle, which is the biggest part and roughly 70% of TCO, (2) fuel costs over the lifetime, and (3) maintenance costs. While vehicle costs for BEV are higher than ICEV today, BEV currently has lower fuel and maintenance costs. Capital costs of BEV are also expected to fall below those of ICEV by 2023. As such, BEV has lower TCO than ICEV today for countries with lower electricity prices, and will likely be more competitive broadly with ICEV by 2023.

CAPITAL COST

ICEVs currently have the lowest capital costs at around US$30,000 compared to BEVs at US$34,000 today (assuming a 90kWh battery). We expect the capital costs of BEV to fall to US$30,000 before 2025, which will be at cost parity with ICEV. This should largely be driven by lower battery costs (from US$137/kWh today to US$90/kWh by 2025) and higher manufacturing EV manufacturing capacity (see Exhibit 108).

Exhibit 109 shows our assumptions for capital costs by vehicle type. The glider (the components excluding the powertrain) accounts for the highest costs, which we assume will be similar across ICEV and BEV. For BEV, the biggest cost reduction should come from falling battery pack prices, which we assume will be reduced from US$137/kWh currently to US$50/kWh by 2050. As such, battery pack costs will likely fall from US$8,000 to US$3,000 by 2050. Overall, we expect BEV costs will fall from US$34,000 today to US$25,000 by 2050 and be more competitive with ICEVs.

EXHIBIT 108: **We expect the capital cost of BEVs can become competitive with ICEVs by 2023, when battery cost reaches US$100/kWh**



Source: IEA, Bloomberg, and Bernstein estimates (2021+) and analysis

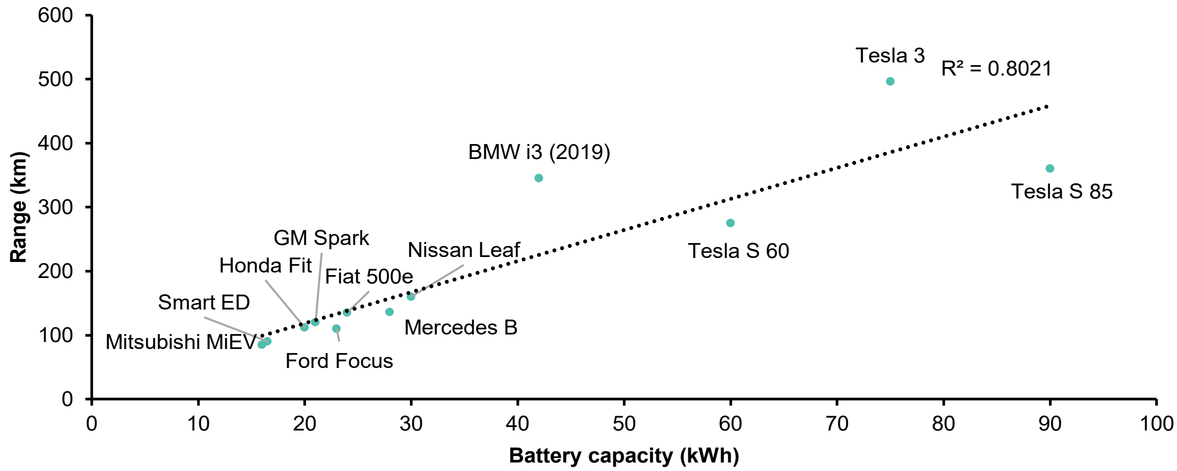
EXHIBIT 109: **Standardized cost of ICE, BEV, and fuel-cell electric vehicle (FCEV) for SUV (400km range)**

Assumption	Units	2020	2025	2030	2035	2040	2045	2050
BEV								
Battery cost	*USD/kWh*	*137*	*90*	*74*	*64*	*58*	*52*	*50*
Battery pack	kWh	90	90	90	90	90	90	90
Battery cost	USD	8,220	5,408	4,455	3,826	3,458	3,126	3,003
Electric motor & inverter	USD	2,070	1,778	1,526	1,311	1,126	967	830
Glider	USD	18,000	18,000	18,000	18,000	18,000	18,000	18,000
Overhead and profit	USD	5,596	4,844	4,482	4,197	3,973	3,766	3,602
Total capital cost	**USD**	**33,886**	**30,030**	**28,463**	**27,334**	**26,557**	**25,859**	**25,435**
ICEV								
Internal Combustion Engine	USD	7,000	7,000	7,000	7,000	7,000	7,000	7,000
Glider	USD	18,000	18,000	18,000	18,000	18,000	18,000	18,000
Overhead and profit	USD	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Total capital cost	**USD**	**30,000**	**30,000**	**30,000**	**30,000**	**30,000**	**30,000**	**30,000**
FCEV								
Fuel cell system	kW	95	95	95	95	95	95	95
Fuel cell cost	USD/kW	208	154	100	83	65	48	30
Hydrogen storage tank	USD/kwh	14	13	12	11	11	10	9
Electric motor & inverter	USD	2,070	1,778	1,526	1,311	1,126	967	830
Overhead and profit	USD	11,868	9,679	7,720	6,718	5,792	4,938	4,155
Total capital cost	**USD'000**	**56,129**	**48,253**	**40,746**	**37,742**	**34,842**	**32,042**	**29,335**

Source: IEA, Bloomberg, and Bernstein estimates (2021+) and analysis

Our assumption for a 90kWh battery is largely driven by the market trend toward larger batteries to boost the range and battery life of EVs. At 90kWh, EVs can reach a range of around 500km, assuming efficiency of approximately 3.5 mile/kWh (5.6km/kWh), in line with a Tesla (see Exhibit 110).

EXHIBIT 110: **For battery vehicles, battery capacity needs to increase in order to achieve longer driving range**

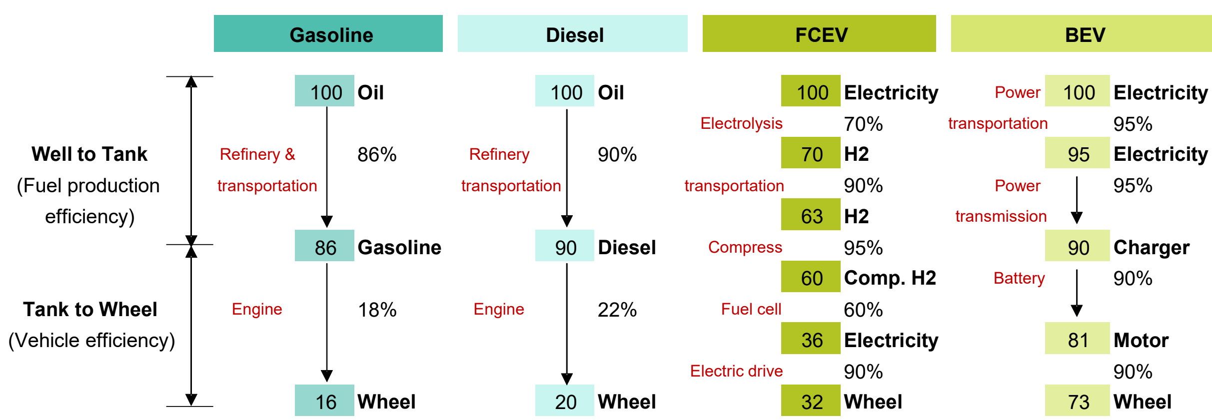


Source: Company presentations and Bernstein analysis

FUEL COST

Energy efficiency is a key factor when considering fuel costs over the lifetime of the vehicle. The tank to wheel (TTW) efficiency of BEV is the highest at 73% compared to ICEVs at 20% for diesel fuel and 16% for gasoline fuel. BEV has the highest TTW efficiency at 81%, compared to diesel vehicles at 22% and gasoline vehicles at 18% (see Exhibit 111).

EXHIBIT 111: **BEVs have higher TTW efficiency compared to both FCEVs and diesel vehicles**

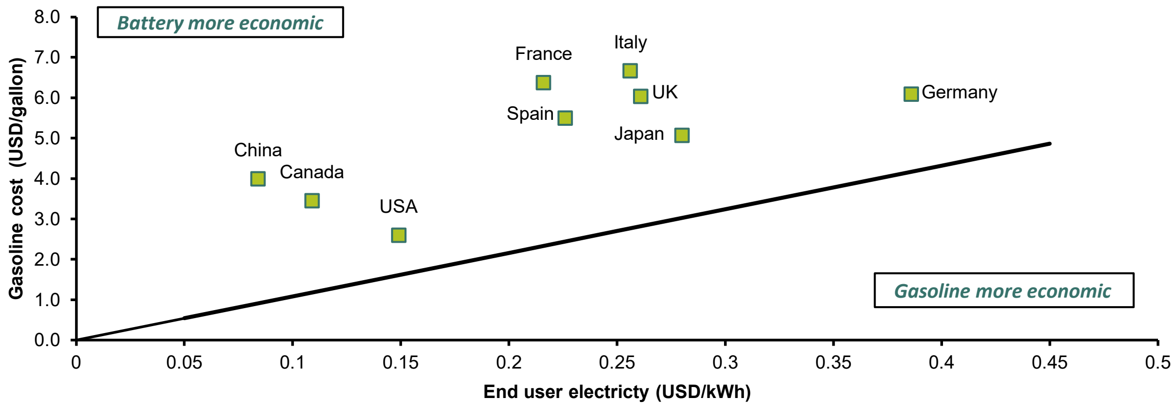


Source: IEA, company data, and Bernstein analysis

Given the higher TTW efficiency, it is easier for BEVs to achieve fuel parity with diesel and gasoline vehicles. In most countries, end-user electricity price is lesser compared to gasoline prices, and fuel cost is significantly cheaper compared to gasoline.

Fuel efficiency for a BEV is around 0.75MJ/km, while for an ICEV it is around 2.7MJ/km (72% more efficient). This means that a BEV can have an efficiency of 0.2kWh/km or travel 5km/kWh. For gasoline vehicles, it means that a vehicle can have an efficiency of 0.0184 gallon/km or can travel 54km/gallon. Given the difference in energy efficiencies, an end-user electricity price of US$0.2/kWh will be competitive with US$2/gallon gasoline at the pump for BEV (see Exhibit 112).

EXHIBIT 112: **Fuel cost for BEV is cheaper compared to gasoline in most countries, if the impact of higher energy efficiency is included**



Note: Using 2019 end-user gasoline price (IEA) and end-user electricity price

Source: IEA, Bloomberg, and Bernstein analysis

TOTAL COST OF OWNERSHIP

Exhibit 113 shows the key costs and assumptions used for our TCO analysis of a 400km-range PV. For capital costs, we assume battery pack prices falling from US$137/kWh to US$50/kWh over the long term for BEV. For fuel costs, we assume an end-user electricity price of US$0.11-US$0.15/kWh (fuel cost parity of US$1.5/gallon with ICEV) and gasoline price at the pump of US$3/gallon. For maintenance, we estimate BEV has 7% lower maintenance cost than ICEV today.

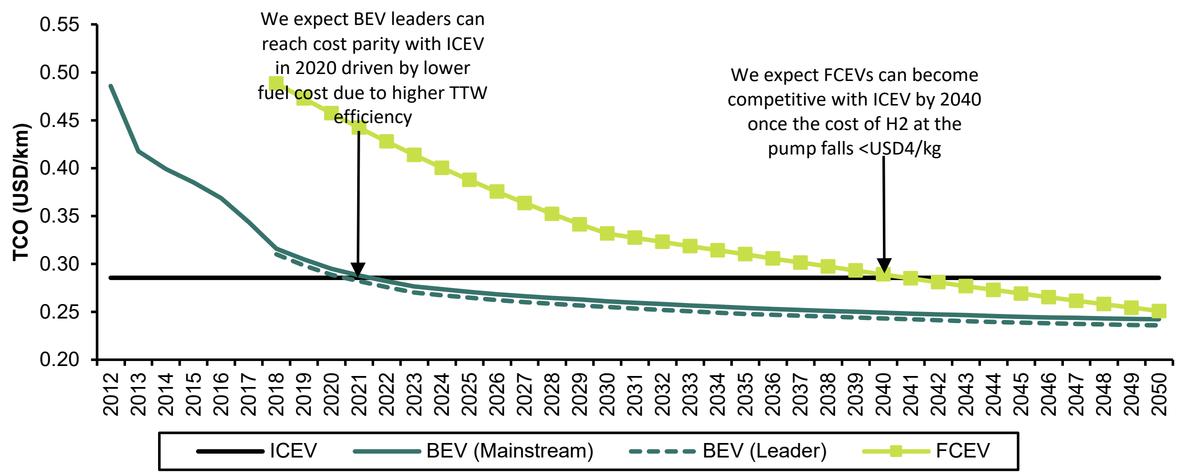
EXHIBIT 113: **TCO analysis for vehicles**

Output	Units	2020	2025	2030	2035	2040	2045	2050
Cost of vehicle								
ICEV	USD	30,000	30,000	30,000	30,000	30,000	30,000	30,000
BEV	USD	33,886	30,030	28,463	27,334	26,557	25,859	25,435
FCEV	USD	56,129	48,253	40,746	37,742	34,842	32,042	29,335
Maintenance								
ICEV	USD	1,120	1,120	1,120	1,120	1,120	1,120	1,120
BEV	USD	1,040	1,040	1,040	1,040	1,040	1,040	1,040
FCEV	USD	1,218	1,201	1,185	1,169	1,153	1,136	1,120
Fuel cost								
ICEV	USD/gal	3.00	3.00	3.00	3.00	3.00	3.00	3.00
BEV	USD/kWh	0.15	0.14	0.14	0.13	0.12	0.12	0.11
FCEV	USD/kg H2	8.86	6.00	4.00	3.75	3.50	3.25	3.00
Total cost								
ICEV	USD/km	0.29	0.29	0.29	0.29	0.29	0.29	0.29
BEV	USD/km	0.33	0.29	0.28	0.27	0.26	0.26	0.25
FCEV	USD/km	0.46	0.39	0.33	0.31	0.29	0.27	0.25

Source: IEA, Bloomberg, and Bernstein estimates (2025+) and analysis

Given these assumptions, we expect BEV has lower TCO than ICEV today for countries with lower electricity prices and will be more competitive broadly with ICEV by 2023 (see Exhibit 114).

EXHIBIT 114: **With electricity price of US$0.15/kWh and gasoline price of US$3/gallon, we expect BEVs can already be cost competitive with ICEVs, driven by lower fuel cost and a closing gap in capital cost**



Source: IEA, Bloomberg, and Bernstein estimates (2021+) and analysis

Exhibit 115 shows the sensitivity of our TCO analysis based on various vehicle ranges and electricity prices. Based on our analysis, we expect BEV will be competitive with ICEV in 2025 across all electricity prices (US$0.1-US$0.3/kWh) and vehicle ranges (300-600km) on a TCO basis.

EXHIBIT 115: **For TCO, we expect leading BEVs are already competitive with ICEVs from a TCO perspective, with an electricity price of US$0.1-US$0.3/kWh**

	2020			2025			2030			2035		
Passenger EV	600km	450km	300km	600km	450km	300km	600km	450km	300km	600km	450km	300km
Upfront Cost (K $)												
BEV (Mainstream)	42.1	38.8	33.9	35.4	33.3	30.0	32.9	31.1	28.5	31.1	29.6	27.3
BEV (Leader)	40.3	37.3	32.9	34.2	32.3	29.4	31.9	30.3	27.9	30.3	28.9	26.9
FCEV	56.6	56.4	56.1	48.8	48.5	48.3	41.3	41.0	40.7	38.2	38.0	37.7
ICEV	33.0	31.5	30.0	33.0	31.5	30.0	33.0	31.5	30.0	33.0	31.5	30.0
TCO ($/km) - USD0.10/kWh												
BEV (Mainstream)	0.32	0.30	0.27	0.28	0.26	0.24	0.26	0.25	0.24	0.26	0.25	0.23
BEV (Leader)	0.31	0.29	0.26	0.27	0.26	0.24	0.26	0.25	0.23	0.25	0.24	0.22
FCEV	0.46	0.45	0.46	0.39	0.38	0.39	0.34	0.33	0.33	0.32	0.31	0.31
ICEV	0.31	0.30	0.28	0.31	0.30	0.28	0.31	0.30	0.28	0.31	0.30	0.28
TCO ($/km) - USD0.20/kWh												
BEV (Mainstream)	0.33	0.31	0.28	0.29	0.28	0.26	0.28	0.27	0.25	0.27	0.26	0.24
BEV (Leader)	0.33	0.31	0.28	0.29	0.27	0.25	0.27	0.26	0.24	0.26	0.25	0.24
FCEV	0.46	0.45	0.46	0.39	0.38	0.39	0.34	0.33	0.33	0.32	0.31	0.31
ICEV	0.31	0.30	0.28	0.31	0.30	0.28	0.31	0.30	0.28	0.31	0.30	0.28
TCO ($/km) - USD0.30/kWh												
BEV (Mainstream)	0.35	0.33	0.29	0.30	0.29	0.27	0.29	0.28	0.26	0.28	0.27	0.25
BEV (Leader)	0.34	0.32	0.29	0.30	0.28	0.26	0.28	0.27	0.25	0.27	0.26	0.25
FCEV	0.46	0.45	0.46	0.39	0.38	0.39	0.34	0.33	0.33	0.32	0.31	0.31
ICEV	0.31	0.30	0.28	0.31	0.30	0.28	0.31	0.30	0.28	0.31	0.30	0.28

Note: Across all scenarios, we assume a hydrogen cost of US$5/kg for FCEVs and a gasoline cost of US$/gallon for ICE vehicles.

Source: IEA, Bloomberg, and Bernstein estimates (2025+) and analysis

INVESTMENT IMPLICATIONS

The last 10 years have seen dramatic falls in battery prices. This will likely continue, albeit at a slower pace. We estimate an 8% CAGR reduction in costs over the next five years to US$90/kWh, although VW and Tesla are targeting cost reduction at a 10% CAGR which, if realized, would result in batteries falling another 50% in costs (~US$70/kWh) through to 2025. Assuming this is delivered, BEVs will reach cost parity with ICEVs by or before the middle of this decade. This will be a seminal moment for the battery industry. The biggest risk is a dramatic rise in raw material costs, although this should delay the point of cost parity by no more than a couple of years. New-generation batteries offer the opportunity for a further step-change reduction in costs beyond 2025. Assuming SSBs become mainstream by 2030, we estimate battery prices can fall to US$75/kWh by 2030. Further step change can come from development of Li-S or Li-Air batteries, which could double current energy density to 600Wh/kg and reduce battery prices to US$50/kWh.

We rate CATL Outperform with a target price of CNY520, LG Chem Outperform with a target price of KRW1,340,000, and Samsung SDI Market-Perform with a target price of KRW684,000. For a detailed view of the battery sector, see our initiation note dated June 21, 2021: Global Energy Storage: Batteries Included. Initiating on CATL (OP), LG Chem (OP), and Samsung SDI (MP).

LASHING OUT THE ACTION, RETURNING THE REACTION; BATTERIES STAYING, METAL MASTER

OVERVIEW

- **The metals & mining sector will likely play an important role in providing the raw materials (metals) that will underpin the Electric Revolution to displace the ICE.** Addressing climate challenge will likely create a trillion-dollar metals opportunity.

- Exhibit 116 and Exhibit 117 describe our Bernstein Global Auto forecast of EV sales penetration and inventory. Based on that, we calculate the implied call on metals demand for several battery metals. We consider two evolutionary paths — one in which advances in battery chemistry continue and one more "business as usual."

- The primary goal of battery chemistry research is to provide new batteries with improved performance (be it charge, cycling, density, or safety) per unit cost of inputs. A the most expensive inputs can be metals, it should come as no surprise that metal demand (while innovating itself) "competes" with chemistry innovation and adoption. To the extent that chemistry research doesn't keep up, our base numbers for metal demand are higher.

- First, **batteries do (and will) consume significant metals**. The average metal weight in a battery today is ~50-200kg (see Exhibit 121), which compares with the amount of copper in a typical home at 200kg. Multiply this by one billion vehicles (see Exhibit 127) and you can see the potential for tremendous demand.

- Combine that with the typical cost of these metals (see Exhibit 123) of ~US$756-US$2,818 per vehicle (as of August 19, 2021 spot prices), and one sees a **trillion-dollar addressable market**. We also note that typical EV prices are in the US$40,000 range. Thus, the **EV purchase price has the ability to absorb significant metals price inflation** in its cost (~4% or US$1,600 per vehicle), i.e., the battery metal.

- Our forecasts imply the most pressure on copper, nickel, and cobalt and relatively less for manganese, lithium, and graphite (see Exhibit 134 to Exhibit 141). We direct readers to a more complete view of copper and nickel here:

  Global Metals & Mining Primer: Nickel is a first class ticket to the EV revolution

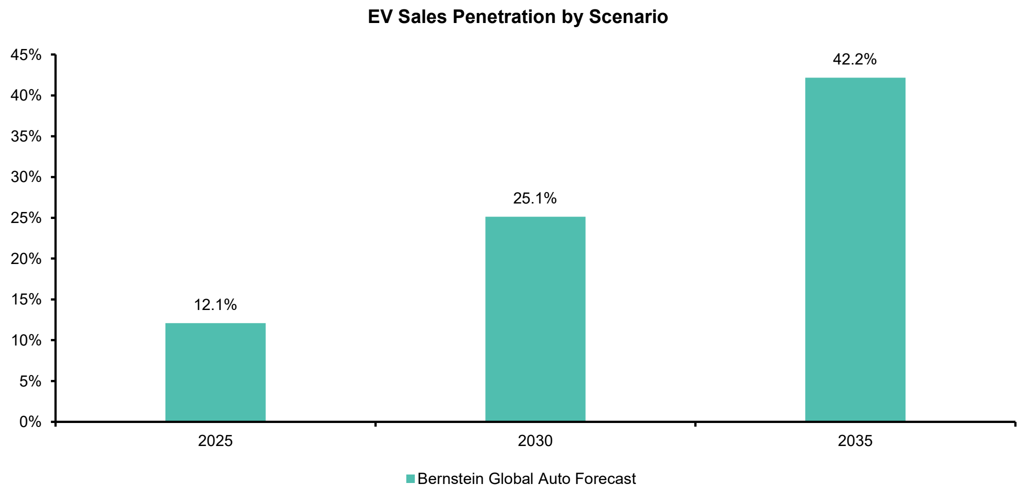
  Global Metals & Mining: King Copper once and future

  TSLA: Who could/should Tesla buy, if anyone? An OEM, battery maker, miner...?

BATTERY METALS DEMAND AND TECHNOLOGY MIX FOR EV ADOPTION

We adopt the EV targets based on the Bernstein Global Autos team's forecasts, which are being uniformly adopted by other Bernstein analysts contributing to this *Blackbook* (see Exhibit 116). It encompasses 25+% sales penetration by 2030 (and >40% by 2035).

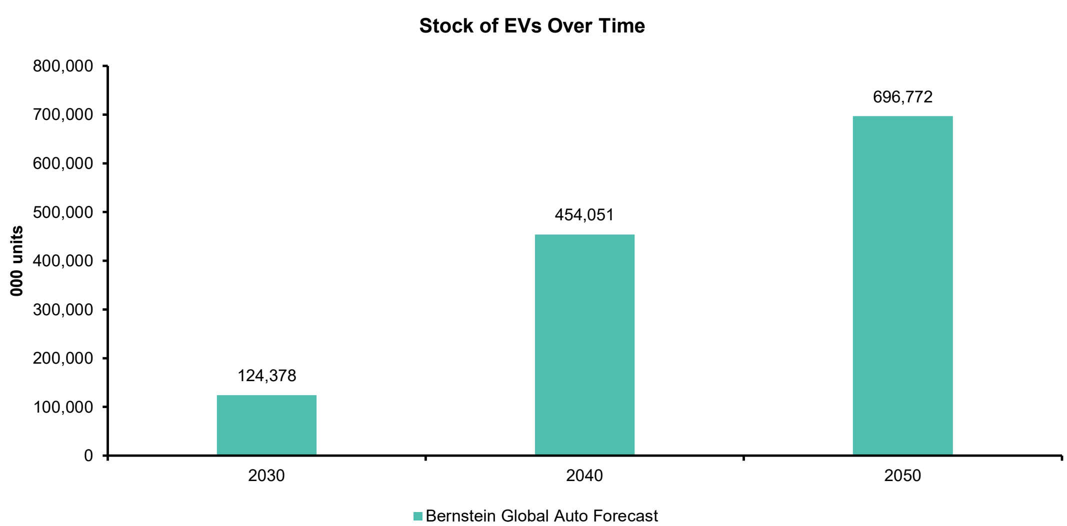
EXHIBIT 116: **EV sales penetration rates by scenario — EV percentage of sales could be 15-60%**



Source: SNL, Bloomberg, and Bernstein estimates and analysis

In Exhibit 117, we estimate EV sales based on the fleet (stock) of cars on the road.

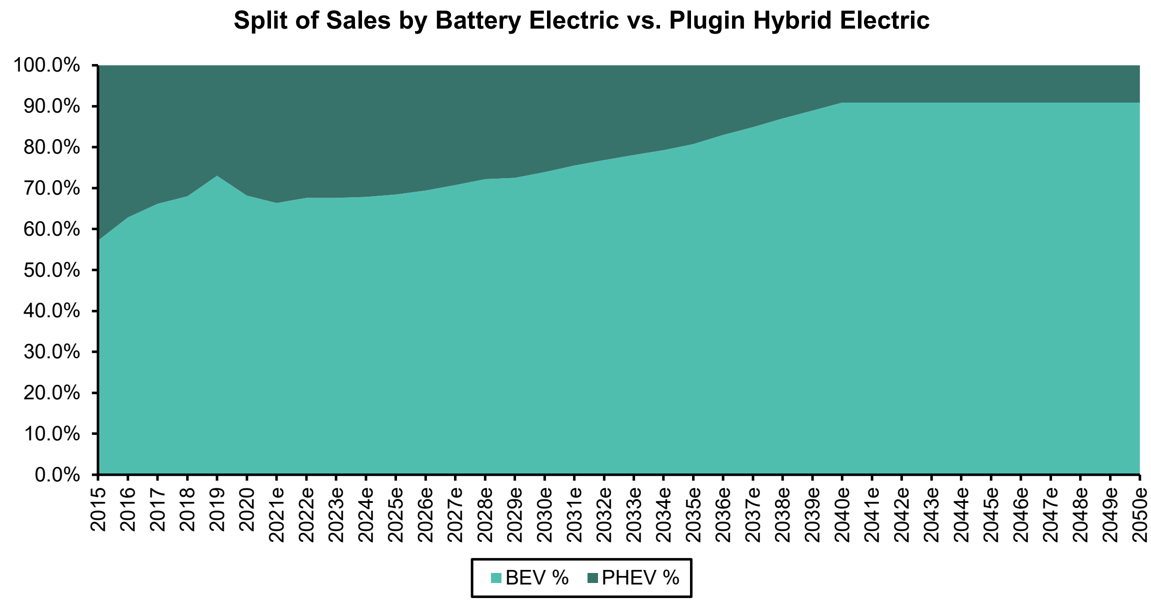
EXHIBIT 117: **We estimate EV sales to reach over 120 million by 2030 and ~700 million by 2050**



Source: SNL, Bloomberg, and Bernstein estimates and analysis

The EV fleet will include BEVs and PHEVs (see Exhibit 118), with BEVs dominating in our view.

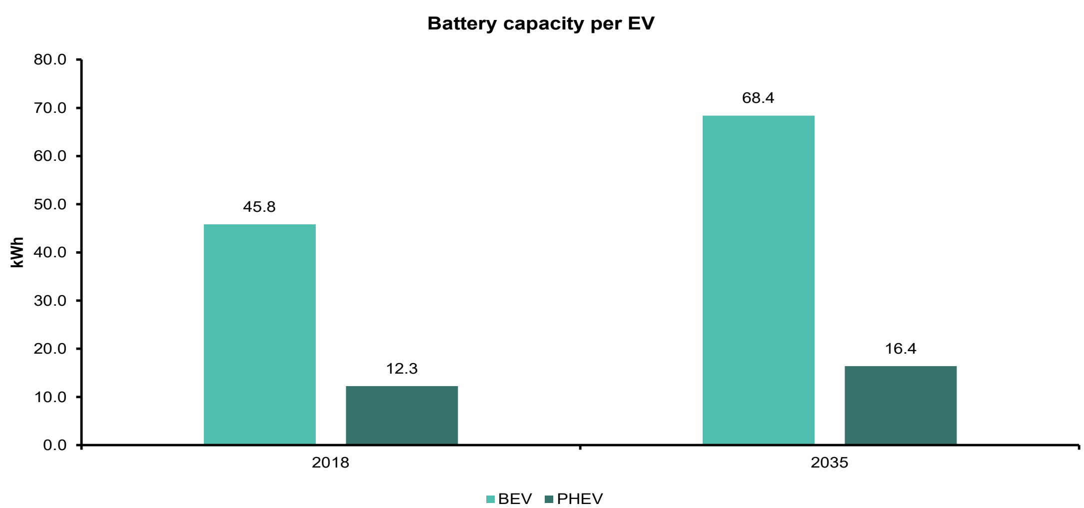
EXHIBIT 118: **BEVs will likely dominate EV sales**



Source: SNL, Bloomberg, and Bernstein estimates and analysis

The batteries in BEVs have higher energy requirements than those in PHEVs (see Exhibit 119). The "average battery" of the future will likely be ~50kWh as a useful back-of-the-envelope number.

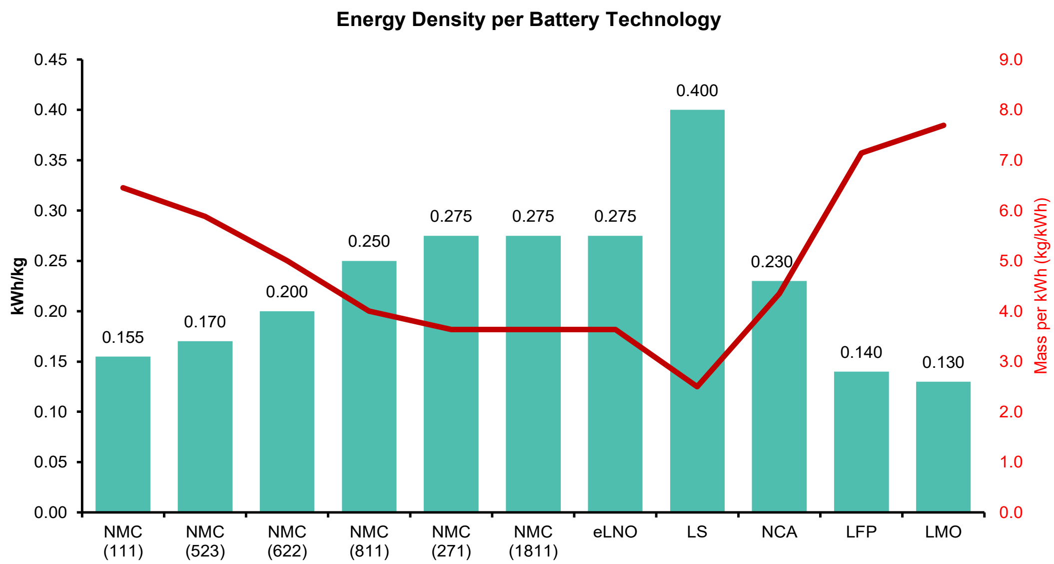
EXHIBIT 119: **Average energy capacity of batteries of EVs (kWh) — BEVs host much larger batteries than PHEVs; for context, the Tesla S today hosts a 100kWh battery, the Tesla Model 3 a 54-75kWh battery, and the Prius Prime has a 9kWh battery**



Source: SNL, Bloomberg, and Bernstein estimates (2035) and analysis

The earlier analyses allow us to calculate the kWh needed; in other words, battery technology will determine the mass required to meet those needs (see Exhibit 120).

EXHIBIT 120: **Battery technology determines the energy density (or conversely mass needed per kWh on the right axis); a 50kWh battery will need anywhere from 150kg to 400kg of "mass," depending on the technology**



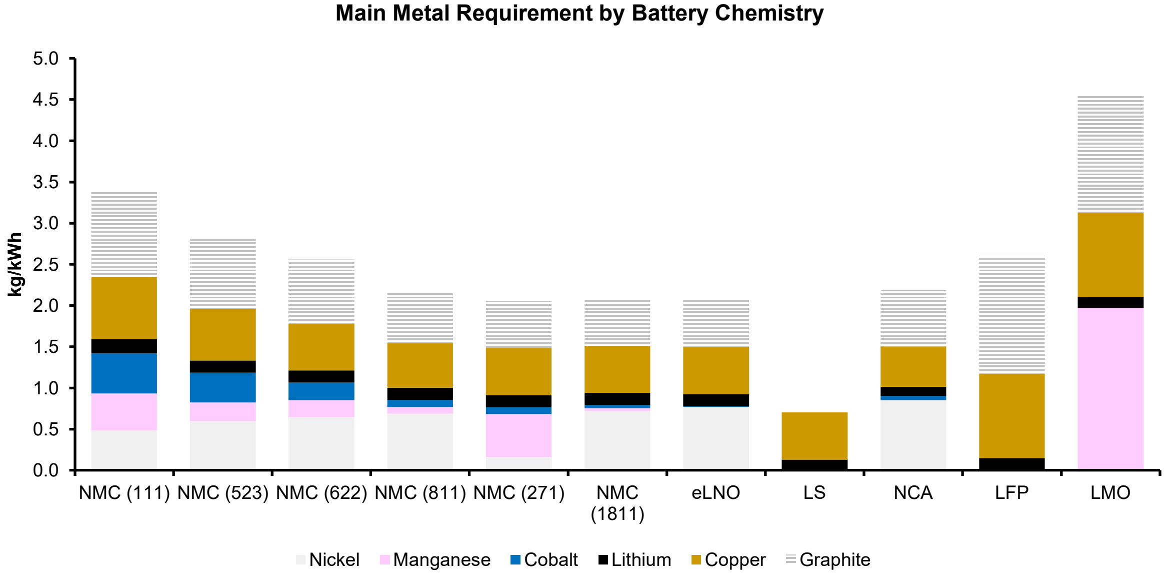
Source: SNL, Bloomberg, and Bernstein analysis

Exhibit 121 color codes the metals roughly by their native state (nice touch no?) and shows requirements by chemistry. Note the difference between the mass needed per kWh (see Exhibit 120) and the metal requirements in Exhibit 121 — this include the other materials needed for battery construction.

Also note that copper is present in all batteries (and in the stator, inverter, and charger as well). Other metals trade off in terms of dominance by chemistry type.

Said another way, we can find a battery chemistry without cobalt, manganese, or nickel, or with variable amounts of lithium and copper (but we'll always need some). Of course, not all batteries are created equal in terms of commerciality, performance, safety, etc. But to the extent that batteries are substitutable, the cost of raw materials will influence decisions.

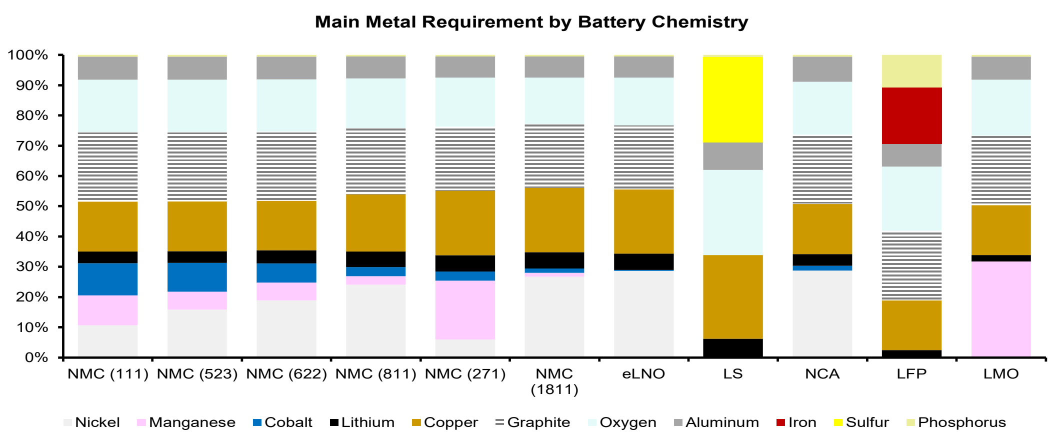
EXHIBIT 121: **If we concentrate on the "metal/graphite" mass requirements, we see variation in mass needed and in composition, depending on which chemistry technology wins; a 50kWh battery per EV requires from <50kg to >200kg of these materials...**



Source: SNL, Bloomberg, and Bernstein analysis

Exhibit 122 shows the complete chemistry, which allows us to guess the mnemonics of the battery chemistry — N = nickel, M = manganese, C = cobalt, A =aluminum, S = sulfur, F = (f)errous iron, and P = phosphorus. Numbers of course correspond to ratios (NMC523 is five parts nickel, two parts manganese, and three parts cobalt).

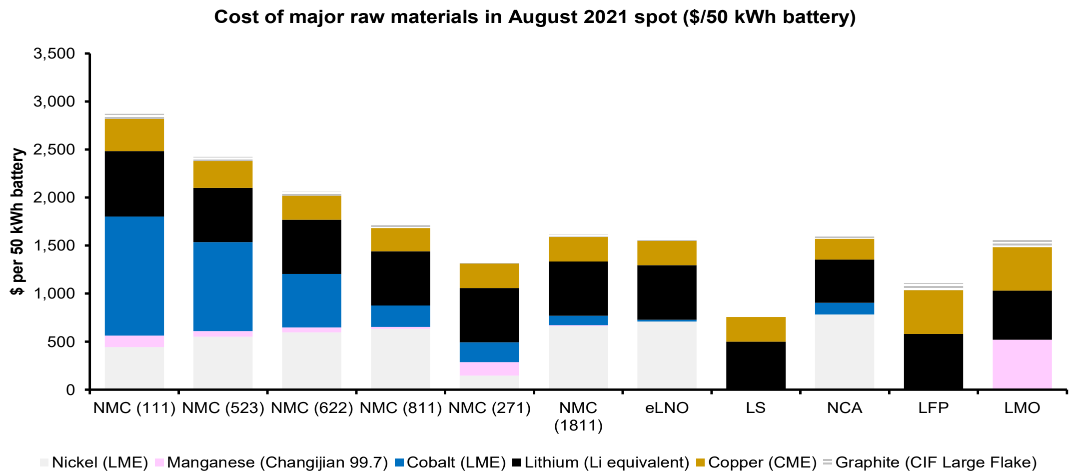
EXHIBIT 122: **...shown as 100% of mass (including low-cost components)**



Source: SNL, Bloomberg, and Bernstein analysis

To give a sense of the economics (see Exhibit 123), we can use current spot prices and the masses required to scale the cost of major raw materials. The cost of raw materials ranged from ~US$756 to ~US$2,818 as of August 19, 2021 spot prices.

EXHIBIT 123: **Cost of major raw materials at spot prices**

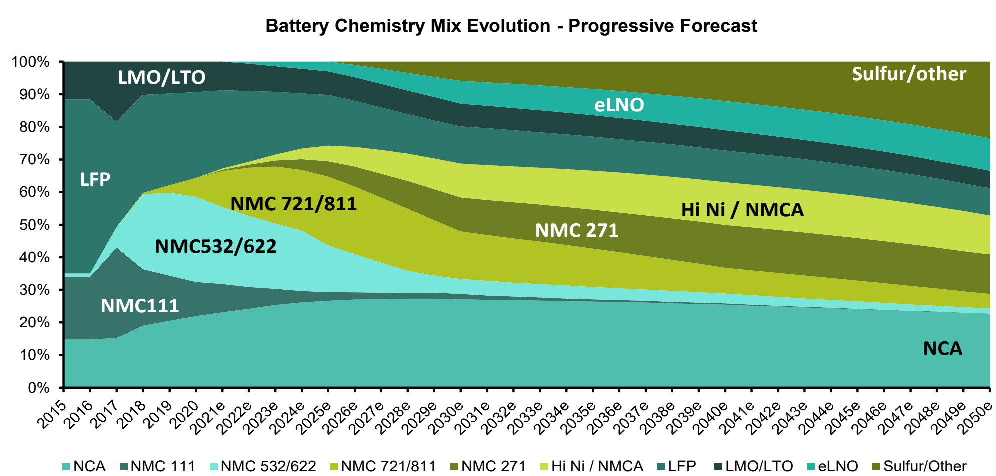


Note: Spot price at a hub is not equivalent to delivered purchase price by a battery manufacturer; we are making simplifying assumptions on lithium (converting to molar equivalent assuming carbonate prices versus hydroxide).

Source: SNL, Bloomberg, and Bernstein analysis

Our battery chemistry forecast (see Exhibit 124) shows competition among chemistries for the foreseeable future, assuming a progressive forecast (e.g., sulfur-rich technologies currently have no share, but we estimate it to account for ~25% share by 2050). Two points — first, economics matter (the shrinkage in NMC111 is more expensive than that of NCA), and second, there is no winner-takes-all technology; there will be competition.

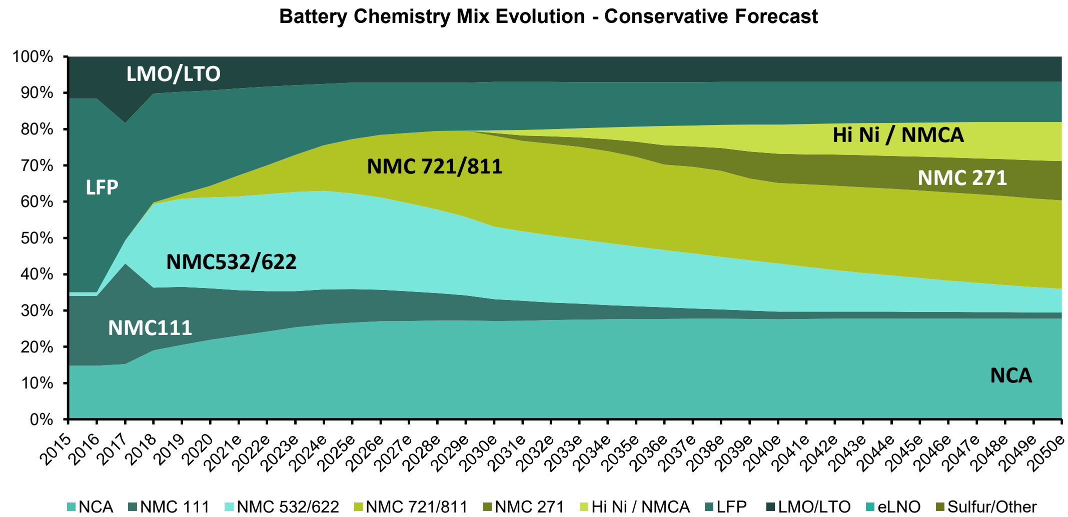
EXHIBIT 124: **Battery chemistry mix (progressive forecast) — sulfur/other encompasses a range of potential chemistries that share zero Ni Mn Co as their characteristic**



Source: SNL, Bloomberg, and Bernstein estimates and analysis

We also consider a more conservative forecast for contrast. Again, no winner takes all; our view of the future more resembles the present (see Exhibit 125).

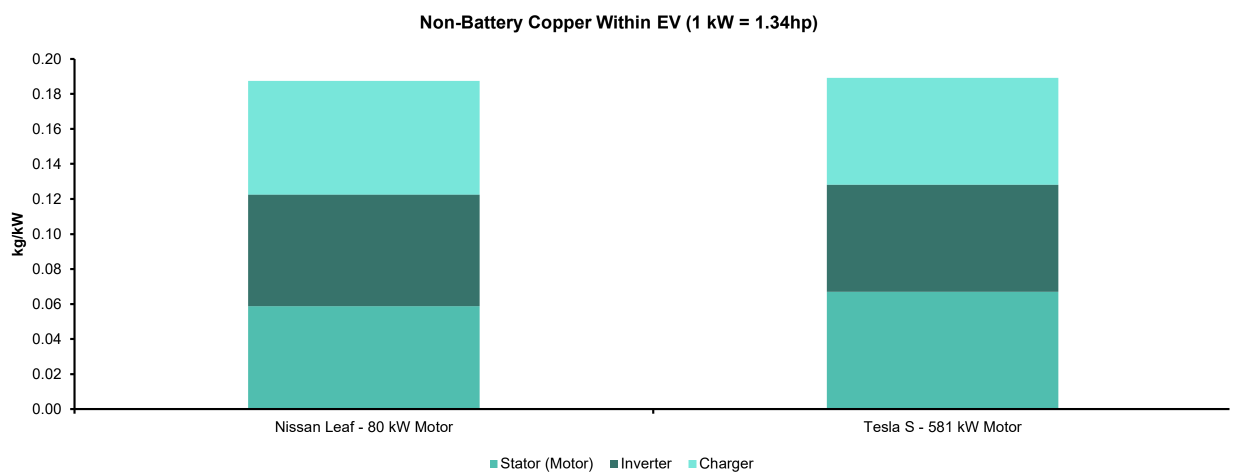
EXHIBIT 125: **Battery chemistry mix (conservative forecast)**



Source: SNL, Bloomberg, and Bernstein estimates and analysis

Exhibit 126 provides our final point on forecasting metals demand — copper is required not only for just the battery, but also for the stator, inverter, and charger.

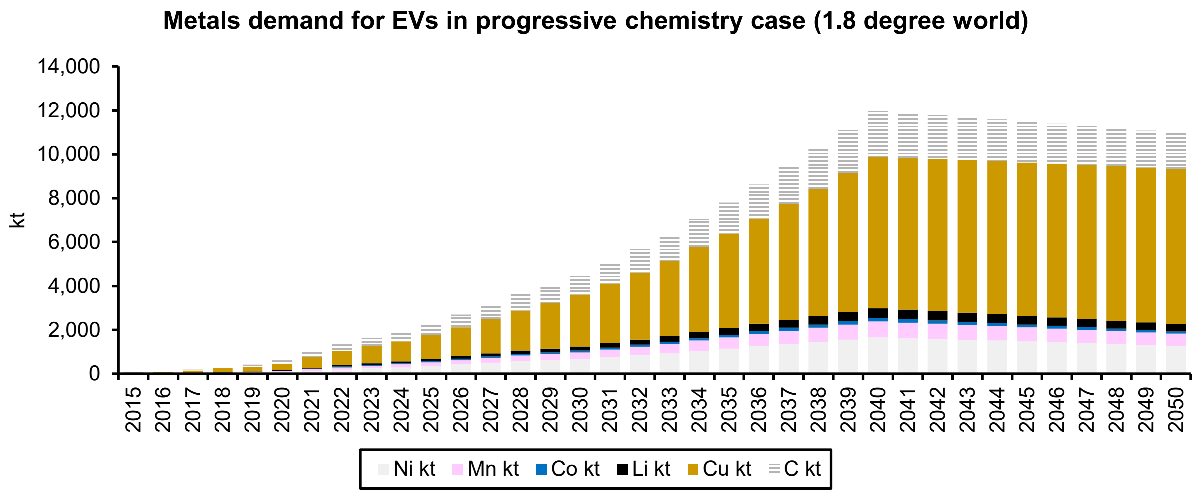
EXHIBIT 126: **Copper is required not only for the battery, but also for the motor, the inverter/converter, and internal charging requirements; copper is also associated with the external charging of EVs as well as investment in the grid**



Source: Ellingsen, Majeau-Bettez et al., and Bernstein analysis

Exhibit 127 shows an annual demand by product by combining our EV forecast with our battery chemistry forecast. Note that annual demand peaks in 2040 when sales start to saturate and when the chemistry mix shift flattens metal requirements. In subsequent years, changes in battery chemistry lead to modest declines in demand for some metals. Copper dominates by volume.

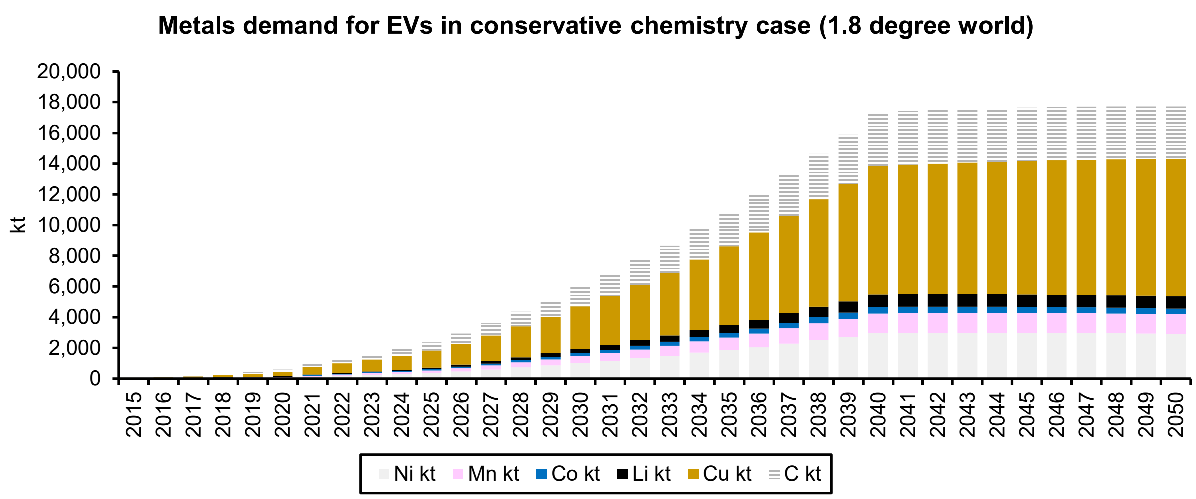
EXHIBIT 127: **Annual metal demand for EVs...a plateau and gradual fall as chemistry innovation wins**



Source: SNL, Bloomberg, and Bernstein estimates (2021+) and analysis

Exhibit 128 assumes a less successful level of innovation in battery chemistry (more akin to business as usual) and yields greater demand.

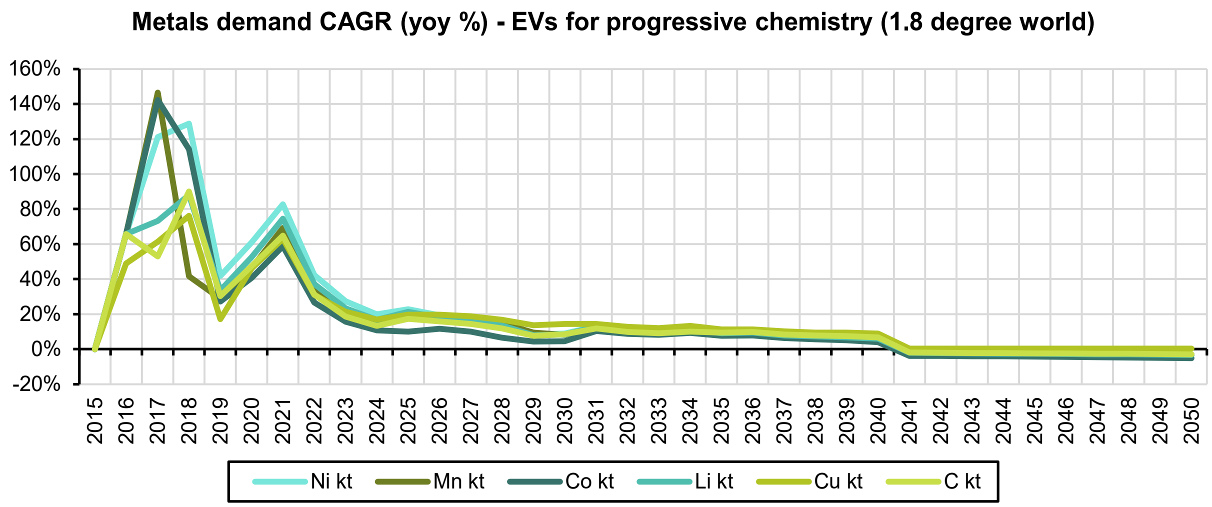
EXHIBIT 128: **If battery technologies don't advance, a much greater (and flatter) call on metal will ensue**



Source: SNL, Bloomberg, and Bernstein estimates (2021+) and analysis

Exhibit 129 shows growth rates for metals demand — from triple digits to healthy double digits until 2030s.

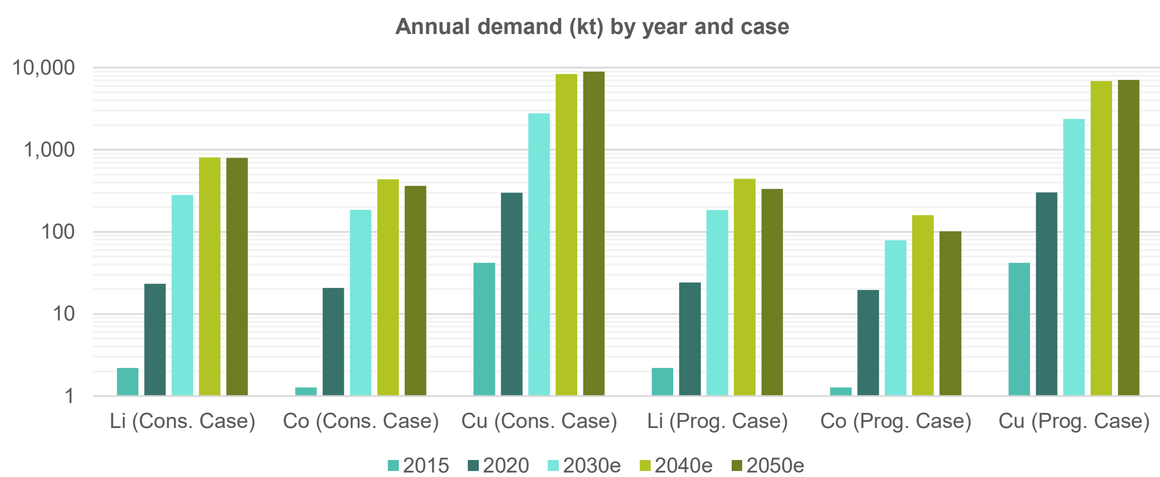
EXHIBIT 129: **Growth rates for metals demand into the EV market remain positive until the 2040s**



Source: SNL, Bloomberg, and Bernstein estimates (2021+) and analysis

We compare our two adoption cases for battery chemistry. One, our more **progressive case** yields lower metal intensities and, thus, lower demand (see Exhibit 130). Note that the log scale in the exhibit somewhat visually dampens the differences in demand.

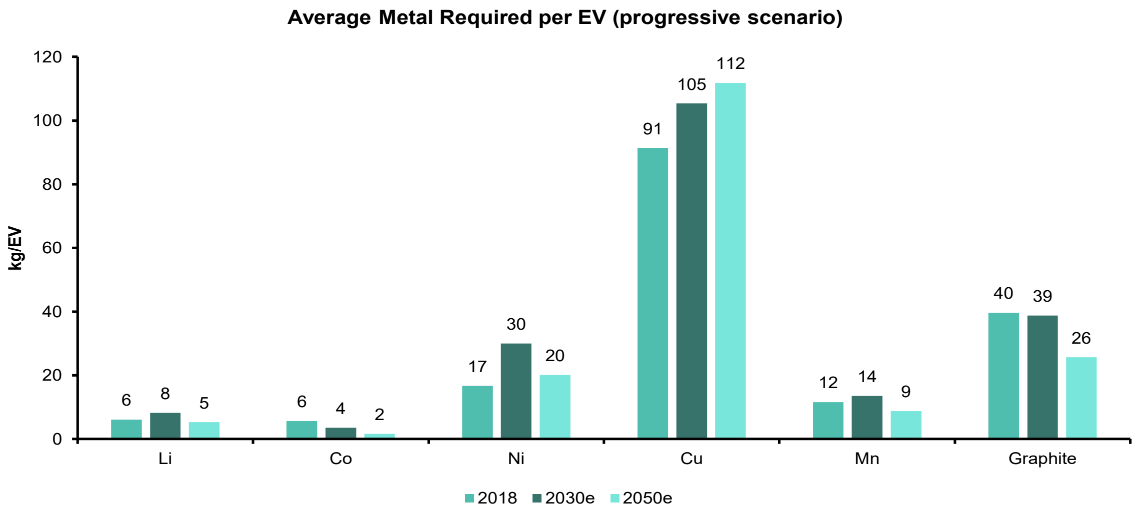
EXHIBIT 130: **Metal consumption higher in the conservative case (more metal-intensive battery technology) than a more progressive case**



Source: SNL, Bloomberg, and Bernstein estimates and analysis

On a per-vehicle basis (see Exhibit 131), note that transitions in battery chemistry to lower metal requirements mean that the absolute mass of metals per EV falls in out years (except for copper).

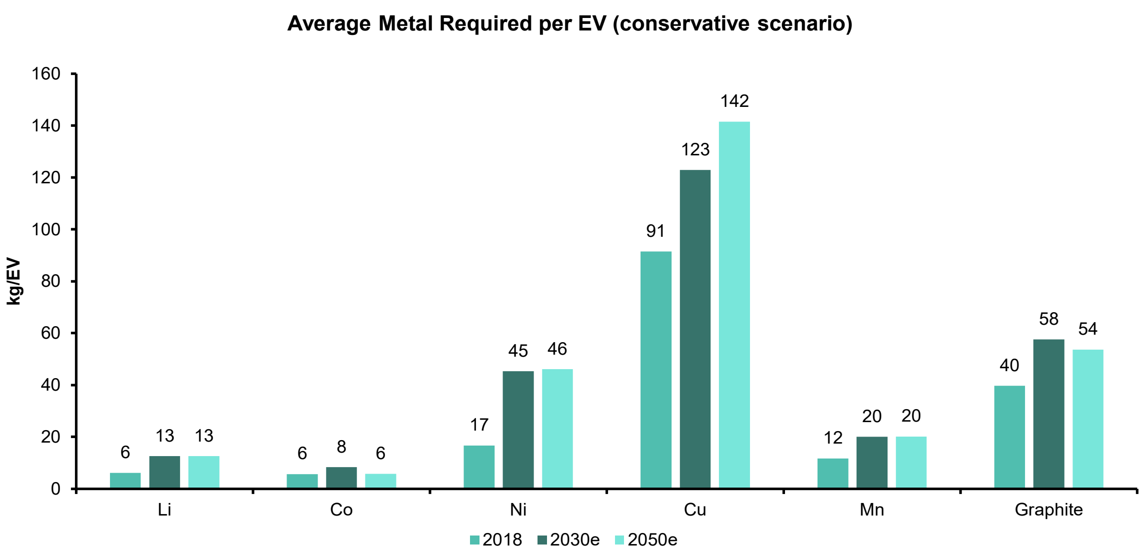
EXHIBIT 131: **Demand for metals per EV to rise in the mid-term, but battery chemistry efficiencies reduce demand in the out years**



Source: SNL, Bloomberg, and Bernstein estimates and analysis

Two, our more **conservative assumptions** (see Exhibit 132) around the evolution of battery chemistry technology yields higher metal demand and a more sustained trend of that demand.

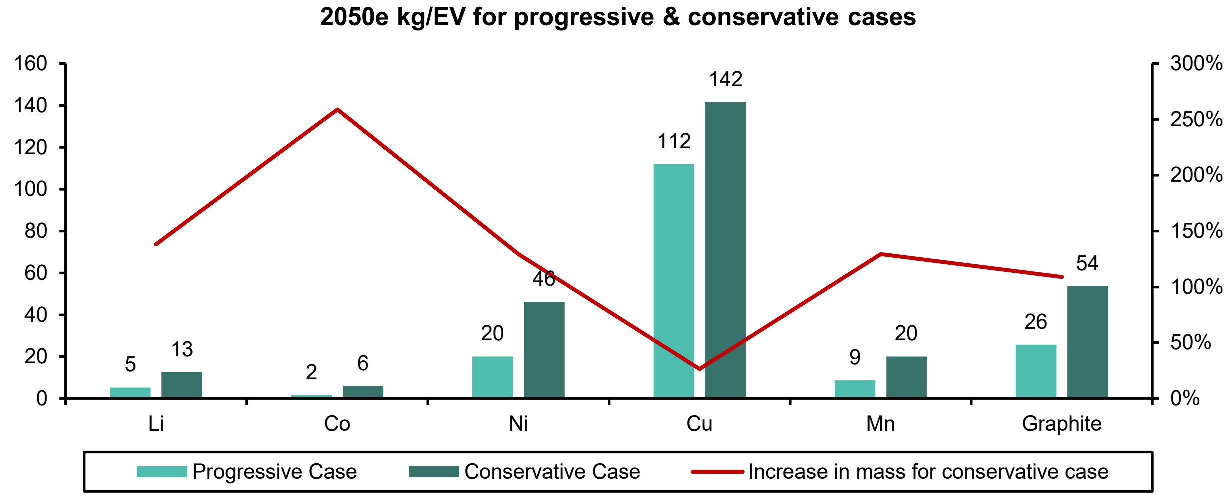
EXHIBIT 132: **Under a more conservative scenario for battery chemistry technology, demand for metals per EV will rise in the mid-term but flatten in out years**



Source: SNL, Bloomberg, and Bernstein estimates and analysis

Comparing the two battery chemistry scenarios shows significant differences in metals demand (see Exhibit 133).

EXHIBIT 133: **Belief in battery chemistry revolution pushes you toward lower metals demand**

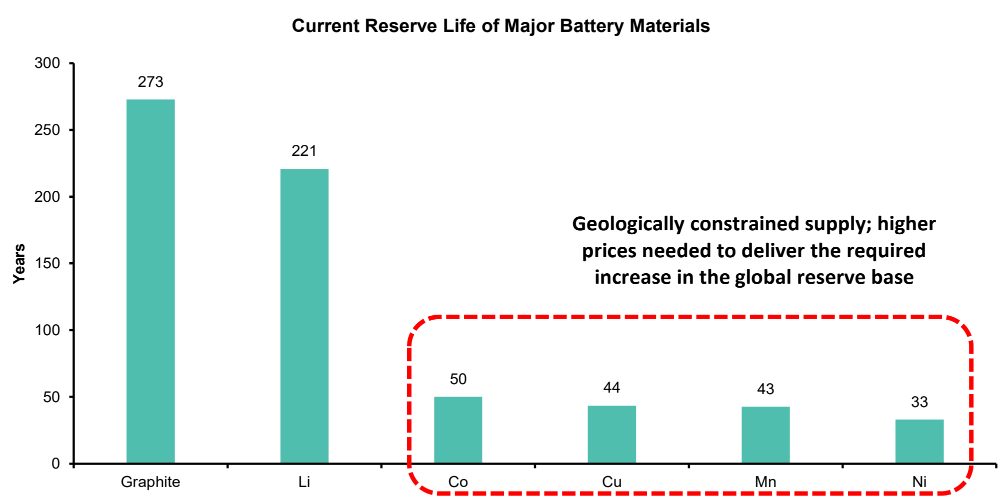


Source: SNL, Bloomberg, and Bernstein estimates and analysis

IMPLICATIONS FOR METALS & MINING

Today, we need plenty of metals for EVs to meet current demand (both for current EV demand and non-EV demand) (see Exhibit 134). The metals on the right side of the exhibit are obviously more constrained.

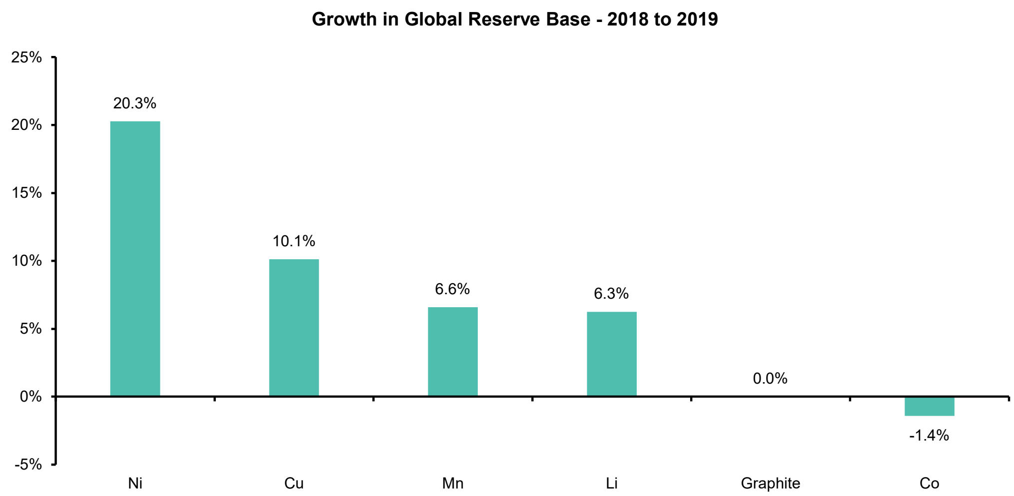
EXHIBIT 134: **Current reserve life shows that it is copper, cobalt, manganese, and nickel that face the most immediate challenge in terms of raw material supply...a world without EVs would be satisfied by current reserves**



Source: USGS and Bernstein analysis

Single-digit to low-double-digit reserves growth was observed in most metals (see Exhibit 135); reserves are not static but depend on exploration, technology, and price.

EXHIBIT 135: **All but cobalt grew the reserve base**

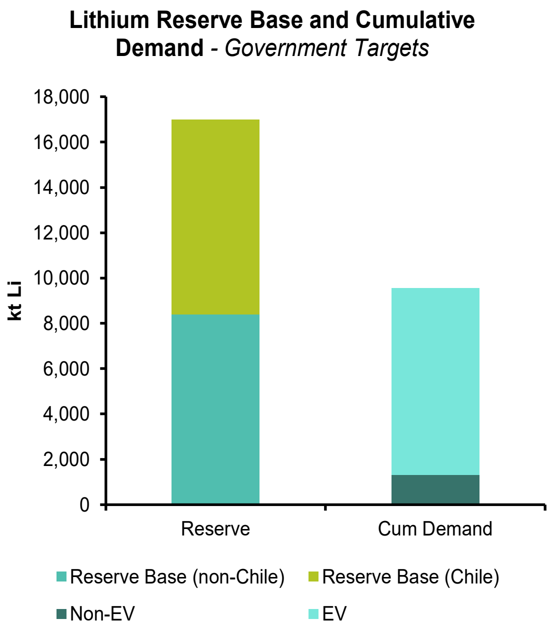


Source: USGS and Bernstein analysis

We take metal reserves from the most recent (2020) USGS mineral commodity summaries. For "monopolized" metals (in which one country plays a critical role in supply), we highlight that country. We compare that potential "supply" against demand. For non-EV demand, we again take USGS 2020 total production estimates, back out an estimate of current EV demand (typically small) and assume no major stock changes (i.e., production is a reasonable estimate of demand). We grow non-EV demand at 2% out to 2050 to estimate the cumulative demand from 2020 to 2050. We use our model to determine cumulative demand for metals from EVs.

EV demand dominates the lithium market (see Exhibit 136) and Chile is a critical source of supply. In the case of copper (see Exhibit 137), we see that EVs form a significant portion of all demand and Chile is likewise important.

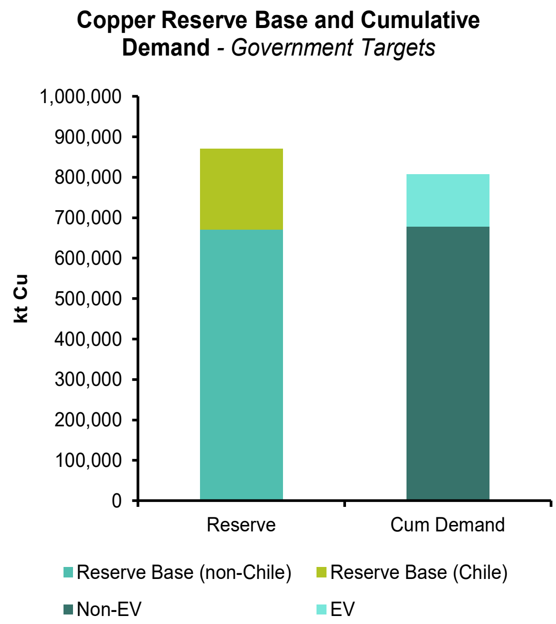
EXHIBIT 136: **We can't have EVs without Chile's permission; EV demand consumes more than all of current non-Chile lithium reserves**



Note: Reserve base for both Chile and non-Chile are current and lithium demand (kt) for both EV and non-EV are sum from 2020 to 2050.

Source: USGS, SNL, CRU, Wood Mackenzie, and Bernstein estimates and analysis

EXHIBIT 137: **Chile will also feature heavily in future copper demand**

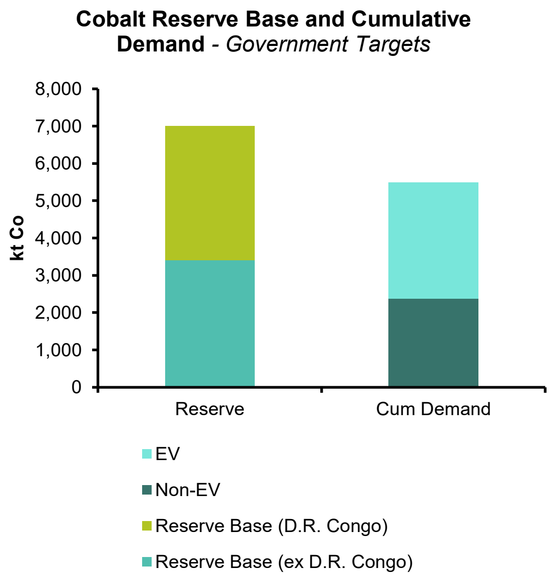


Note: Reserve base for both Chile and non-Chile are current and copper demand (kt) for both EV and non-EV are sum from 2020 to 2050.

Source: USGS, SNL, CRU, Wood Mackenzie, and Bernstein estimates and analysis

Even with our progressive battery chemistry case, there is insufficient cobalt outside the DRC to meet a fraction of EV demand (see Exhibit 138). As shown in Exhibit 139, the world needs more nickel regardless of EVs (again under a 2% growth in the non-EV demand world).

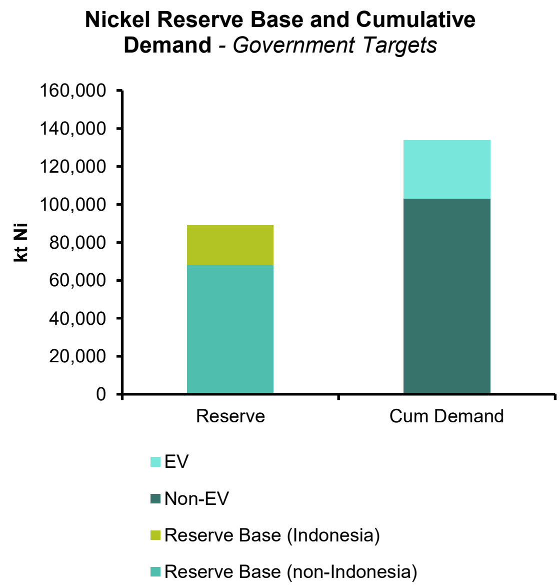
EXHIBIT 138: **DRC cobalt needed for our progressive battery chemistry case — we can't have EVs without DRC's permission**



Note: Reserve base for both DRC and ex DRC are current and cobalt demand (kt) for both EV and non-EV are sum from 2020 to 2050.

Source: USGS, SNL, CRU, Wood Mackenzie, and Bernstein estimates and analysis

EXHIBIT 139: **A 2% growth world needs to find more nickel, regardless of EVs**

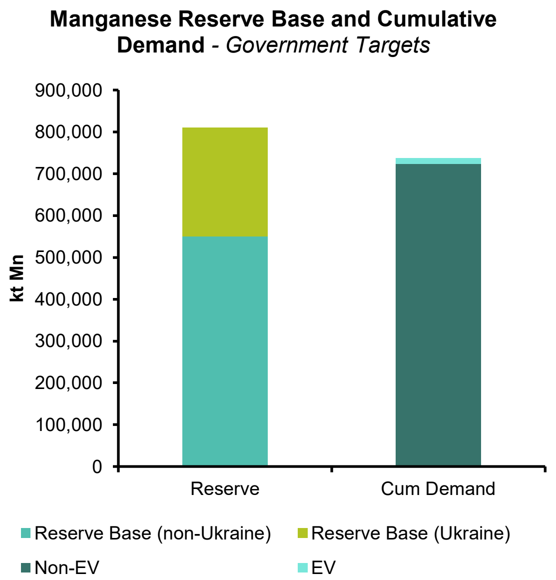


Note: Reserve base for both Indonesia and non-Indonesia are current and nickel demand (kt) for both EV and non-EV are sum from 2020 to 2050.

Source: USGS, SNL, CRU, Wood Mackenzie, and Bernstein estimates and analysis

Again, because we are (simplistically) growing non-EV demand by 2%, we see rough balance in manganese (see Exhibit 140) and no obvious bottlenecks in graphite (see Exhibit 141).

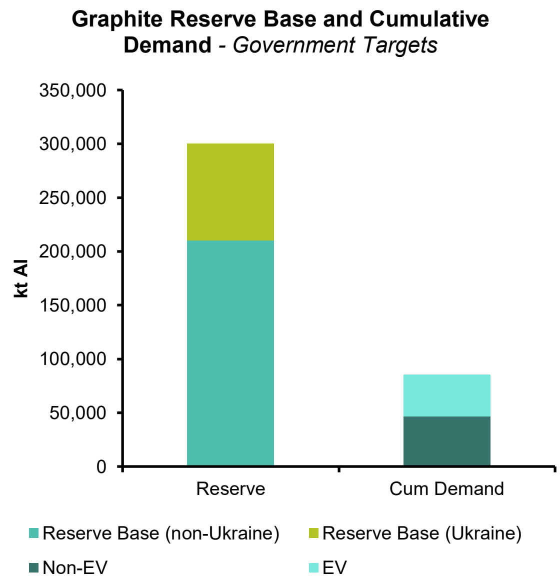
EXHIBIT 140: **Manganese roughly balanced in a 2% growth world**



Note: Reserve base for both Ukraine and non-Ukraine are current and manganese demand (kt) for both EV and non-EV are sum from 2020 to 2050.

Source: USGS, SNL, CRU, Wood Mackenzie, and Bernstein estimates and analysis

EXHIBIT 141: **No obvious bottlenecks for graphite**



Note: Reserve base for both Ukraine and non-Ukraine are current and graphite demand (kt) for both EV and non-EV are sum from 2020 to 2050.

Source: USGS, SNL, CRU, Wood Mackenzie, and Bernstein estimates and analysis

INVESTMENT IMPLICATIONS

We rate Anglo American, Antofagasta, Barrick Gold, BHP Group, and Newmont Mining Outperform.

ANODES: TAKING EV BATTERIES TO ANOTHER ENERGY LEVEL

OVERVIEW

The anode is the bottleneck to advancing battery energy density. The cost of LiBs on a US$/kWh basis has decreased ~31x over the past two decades. However, cost reductions are slowing — over the past three years, cumulative production doubled while costs decreased by only 13% and leveled out at ~US$100/kWh. As cathode energy density increases, so must the size of the anode, thereby outweighing the Wh/kg benefits. Adding silicon can help but must be limited to 5-10%, as adding more causes swelling and rupturing of the anode surface, thus decreasing cycle life.

- **Innovations in high-content silicon anodes are very promising.** Companies are developing technologies such as porous particles (e.g., Nexeon) or nanoparticles (e.g., Sila Nanotechnologies) to mitigate the effects of swelling. These allow up to 30-50% silicon to be used in the anode without materially affecting performance and increase energy density by >30%. More excitingly, companies such as Amprius and Leyden Jar have developed 100% silicon anodes that can deliver up to 2x the energy density of typical LiBs with graphite anodes (~450kWh/kg). These claim to maintain a cycle life of 570 (number of charges and discharges before the battery falls below 80%), which is close to that of traditional Li-ion used today.

- **Solid-state Li-metal batteries have a safety and cost advantage over high-silicon batteries.** The next generation of battery is the SSB, where the liquid electrolyte is replaced with a solid material, thus reducing fire risk. Anodes used in batteries of this form can be replaced with an ultra-thin Li-metal that further increases the Wh/kg energy density to 400-500kWh/kg. Li-metal SSBs also have the added benefit of lower cost of manufacturing thanks to one less electrode, which takes up a large proportion (~40%) of manufacturing costs. At scale, this benefit is estimated to be ~14% versus LiBs using graphite anodes.

- **High-silicon anodes will likely be adopted more quickly than SSBs.** As exciting as SSBs sound, even leading developers (e.g., QuantumScape, Solid Power, and SES) are only at testing or pilot stages. The technology has long been in development (~40 years), but has so far suffered myriad technical challenges such as dendrite formation at high charge rates and micro-cracking. Despite optimistic scaling plans for both companies, we don't see Li-metal taking a meaningful share of anode chemistry until the next decade. By this time, high-silicon anodes, such as those produced by Amprius and Leyden Jar, should reach nearly one-fourth of the anode chemistry mix.

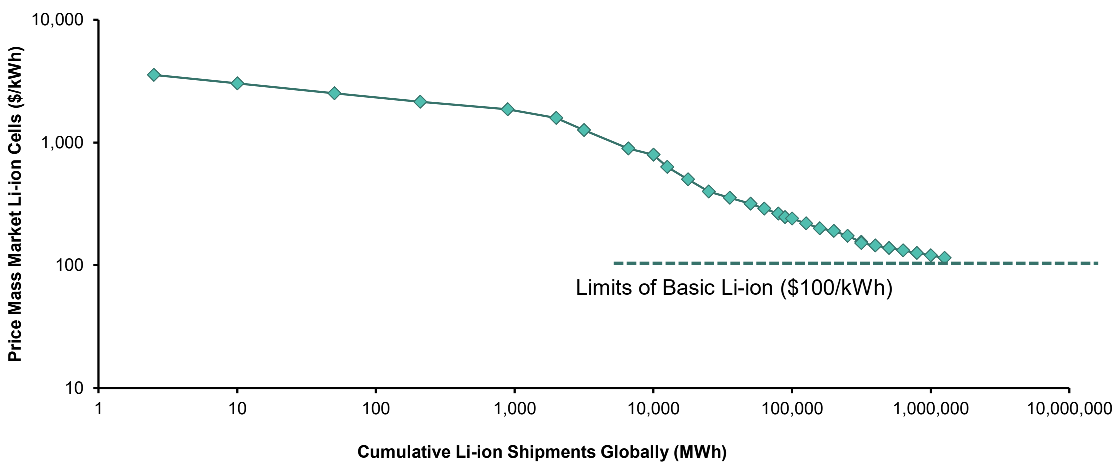
- **Advancements in battery technology are supportive of Umicore and BASF.** Anode developments are cathode agnostic, and battery advancements are in the interest of cathode manufacturers. Anode development will likely form part of their long-term R&D pipeline.

STATE OF PLAY FOR LI-ION BATTERIES

Cost reductions are flattening. Over the past two decades, the cost of LiBs on a US$/kWh basis has decreased ~31x, making passenger electric vehicles affordable. Cost decreases have been achieved through scaling of production, which has accelerated over the past 10 years, and improvements in the energy density of batteries. However, cost reductions have started flattening out despite increasing growth in production. This suggests traditional LiBs have reached their limit (~US$100/kWh) and the next generation of battery is required to achieve higher cost reductions (see Exhibit 142).

An observed learning rate of 18% implies battery pack prices could fall below US$58/kWh by 2030, according to BNEF. This, however, will require significant advancements in battery technology such as high-voltage cathodes, solid electrolytes, Li-metal anodes, and more advanced manufacturing processes.

EXHIBIT 142: **Learning rate of basic LiBs is leveling out at US$100/kWh; innovations in anodes are required to achieve further price decreases**



Source: Sila Nanotechnologies and Bernstein analysis

ANODES ENABLING NEXT-GEN BATTERIES

To achieve the required step-up in energy density to accelerate the adoption of EVs, either the anode needs to be improved or the electrolyte needs to be replaced. The anode, typically a mixture of natural and synthetic graphite, is the bottleneck in the advancement of energy density. While the cathode has improved in terms of energy density, the anode has not — to the extent that it now takes up more space than any other component in the battery cell.

SILICON ANODE

Alternatives to graphite including silicon, lithium, aluminum, and tin have been considered to increase energy density. Of these, silicon offers the best trade-off in terms of increased energy density over graphite (~10x), swelling, and stability. Lithium provides the highest energy density of the materials (3,862mAh/g); however, it is very unstable and takes a long time to charge. Aluminum, with a specific capacity of 2,235mAh/g, swells twice as much as silicon. Other materials such as tin do not give the required energy uplift (see Exhibit 143).

Silicon also has the added advantage that it can be used in smaller volumes than graphite, which allows for much faster charging times as lithium-ions can reach electrodes more quickly.

Swelling is a key challenge for silicon. The swelling of the silicon is the key reason silicon anodes have not replaced graphite more readily in battery cells. This effect causes the surface of the anode to crack and, consequently, the performance of the battery to drop. Most cell manufacturers (including OEMs such as Tesla and VW) get around this by adding small quantities of silicon to the graphite anode, but no more than 3-10% as battery cycle times would reduce beyond a practical level. In addition to reduced cycle life, side reactions between lithium and silicon as a result of the cracking lower the voltage of the overall cell.

EXHIBIT 143: **Of the potential alternatives, silicon offers the best trade-off between capacity, volume change, and stability**

Anode Material	Specific Capacity (mA h)/g	Volume Change, %	Benefits	Challenges
Lithium	3,862	None	+ Highest energy density + Light	+ Unstable; + Slow charge rate; + Scarce metal
Silicon	3,600	320	+ Highest energy density	+ Capacity fade due to expansion & contraction
Aluminium	2,235	604	+ Better energy density than graphite	+ Lower energy density and more expansion than silicon
Tin	990	252	+ Stabler than silicon	+ Worse energy density than silicon
Graphite	372	10	+ Stable + Widely used	+ Poor energy density

Source: C&EN Research and Bernstein analysis

COMPANIES USING SILICON ANODE TECHNOLOGIES

Many companies, however, are exploring ways of increasing the quantity of silicon used through either nanoparticles or porous structures that allow for swelling. We note, however, that some of these companies, such as Sila Nanotechnologies, have been developing these technologies for >10 years. Thus, entering this market will take time unless patents and knowledge are acquired.

UK-based Nexeon has developed two types of anode materials based on both concepts, i.e., NSP-1 and NSP-2. The first, NSP-1, is a powdered silicon compound with particles up to 10µm in size. Its use is limited to about 10% loading by weight in a graphite anode, like the current amounts of silicon added. The company says it can increase anode capacity by about 30% and cell energy density of up to 15% versus graphite-only anodes.

The second type, NSP-2, can increase energy density further. It is a silicon compound with engineered porosity at the particle level and can be used at concentrations higher than 10%, increasing cell energy density up to 30% versus graphite. Nexeon is a year into a three-year project to develop NSP-2 in association with specialty chemical firm Synthomer and University College, London. The company also recently announced it would lead the UK's £1.5mn Silicon Anode Battery for Rapid Electrification (SABRE) project, which started in July 2021 and will go on for one year.

Other alternatives are also being developed, such as those by Sila Nanotechnologies. The company has developed nano structures made of 50% silicon and another non-graphite material — these are porous structures, sealed to prevent electrolyte leaking in. The porous structure allows the silicon to expand and contract without damaging the coating. The company has a strategic partnership with Daimler, which owns a minority stake and raised US$590mn in January 2021, valuing it at US$3.3bn. The funds raised will be used to build capacity of 100GWh for smartphones and EVs, with material likely being in EVs by 2025. It plans to further expand to 2,00GWh by 2030 and 30,000GWh by 2035.

Wacker Chemie (not covered), which holds an option to buy a stake in Nexeon, is commercializing its own silicon anode material in Li-ion button batteries expected to debut later on in 2021. It estimates its technology could enhance the energy density of such a battery by about 20%, but reveals little detail on the type of technology.

Amprius has a novel approach, using a 100% silicon nanowire that reduces swelling to 30% and resists cracking. Being 100% silicon, it has the highest energy density of all the silicon anode technologies discussed — the company claims it is 2x that of LiBs using graphite. It claims excellent cycle life, which was demonstrated by its successful testing by Airbus in LiBs for the Zephyr S pseudo-satellite. According to the company, the batteries used have an energy density of over 435Wh/kg.

Leyden Jar is a Dutch company that also uses 100% silicon, using the plasma vapor deposition technique borrowed from the semiconductor industry, whereby silicon is deposited onto a copper column. The porous structure allows it to swell during lithiation. Its claims of energy density are impressive — 450Wh/kg in energy density with a capacity of 1,350Wh/L — although this is in testing. Its cycle time of 570 is impressive too, and the company targets to reach 800 by the end of 2021, which would make it comparable with LiBs. Of all the high-silicon anode technologies discussed, Leyden Jar shows the most promise (see Exhibit 144).

EXHIBIT 144: **Comparison of emerging silicon anode technologies**

	Unit	Graphite	Nexeon	Sila Nanotech nologies	Amprius	Leyden Jar
Anode Thickness	µm	62	31	N/A	31	10
Energy Density	Wh/kg	~200	N/A	240-280	435-465	450
Cell capacity	Wh/L	577	710	N/A	~1,200	1,350
Life Time*	Cycles	1,000	>300	N/A	>300	570
Silicon quantity	%	0%	>10%	50%	100%	100%

*Number of cycles until the battery reaches 80% capacity

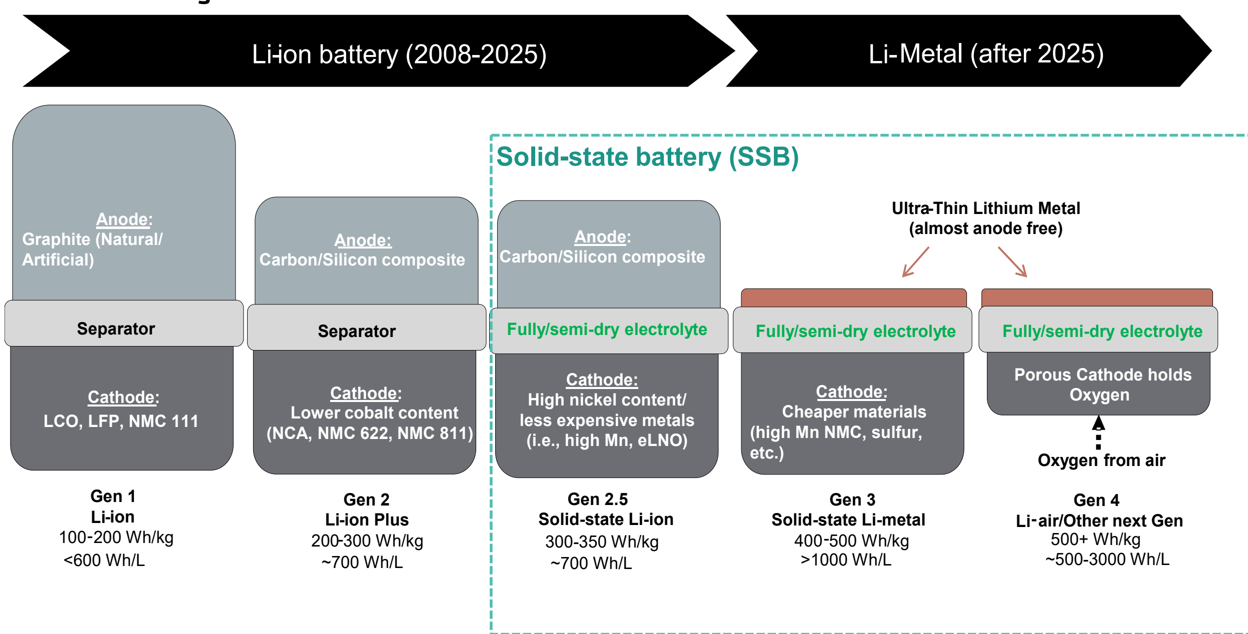
Note: Sila Nanotechnologies, Nexeon , Leyden Jar, Amprius, and Graphite are private companies.

Source: Faraday institute, Chemical & Engineering News, company websites, and Bernstein analysis

SOLID-STATE BATTERIES

Another level of energy density. An even higher level of energy density can be achieved by replacing the liquid electrolyte used in LiBs with a solid or semi-solid electrolyte, creating an SSB. In the SSB, the solid electrolyte requires much less space, i.e., ~10x less than that of Li-ion. As a result, many more cells can be packed into the same battery and energy density increases to 2-2.5x that of Li-ion. The presence of a solid electrolyte also allows for the use of an ultra-thin Li-metal anode, which can further increase energy density (see Exhibit 145). We discuss this in more detail later in this section.

EXHIBIT 145: **Next-gen batteries include SSBs with ultra-thin Li-metal anodes**



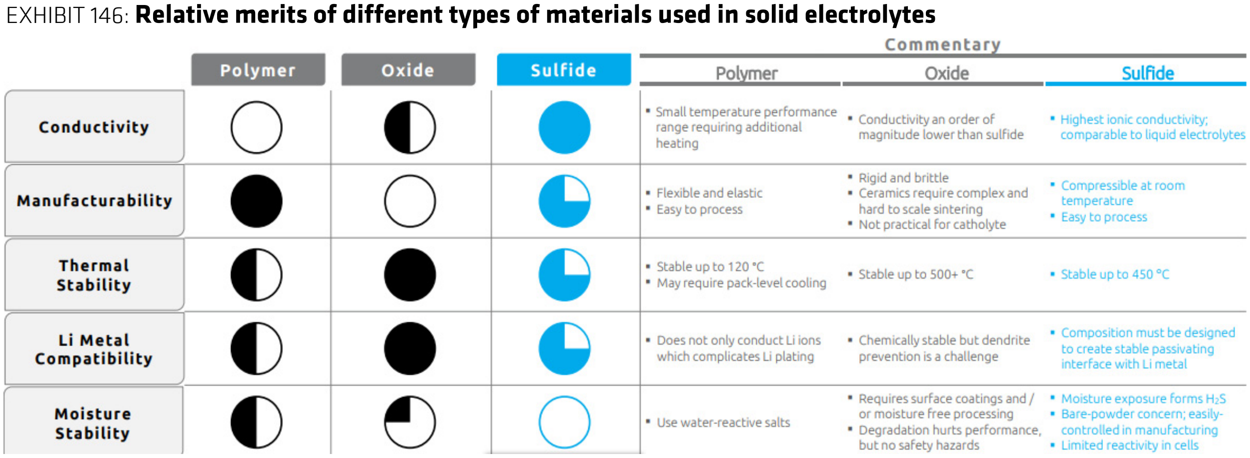
Source: Bernstein analysis

Performance benefits of SSBs. The solid electrolyte prevents metal deposits, known as dendrites, forming around the electrodes during charging, which can cause a typical LiB to short. The liquid electrolyte in LiBs slowly degrades the electrodes, forcing the battery to be replaced, which explains its short battery life compared to SSBs. SSB also has the additional benefits of being not flammable as liquid electrolyte causes battery fires, and the charging times are higher (15-20 minutes to reach 80% charge versus ~40% for Li-ion) as the ions have lesser distance to travel.

Electrolyte materials must balance conductivity and stability. Solid electrolytes are made of fast ion conductor solids, which can be thought of as a material somewhere between a crystalline solid and a structure-less liquid. Examples are gels, glasses, and crystals. A solid separator should have: (1) high Li-ion conductivity, (2) low internal resistance, (3) chemical stability to lithium (if used with Li-metal anodes), and (4) dendrite resistance. The types of materials used include polymers, sulfides, oxides, and composites, each with varying pros and cons (see Exhibit 146).

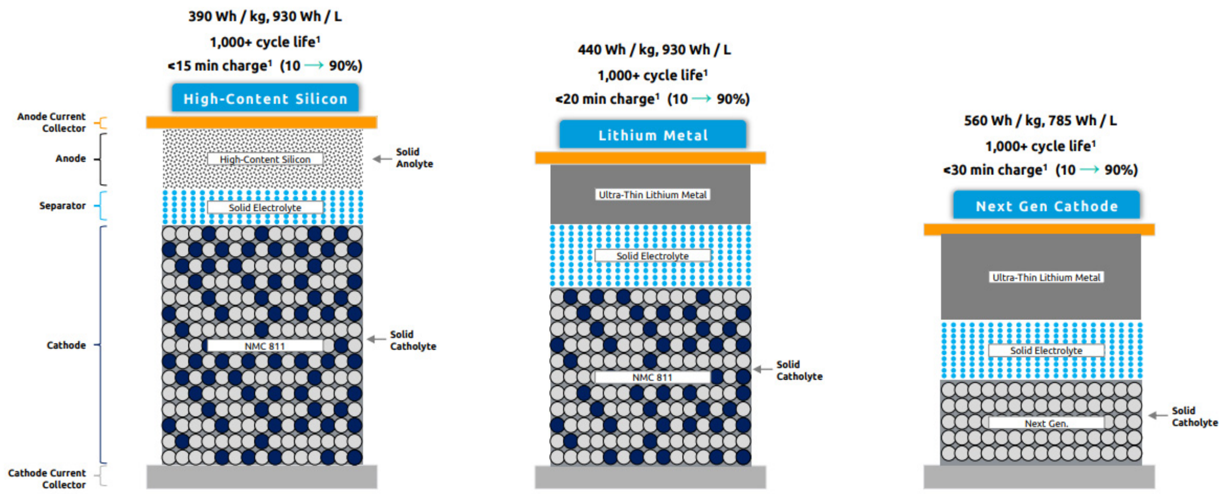
Solid Power uses a sulfide-based solid electrode due to its high conductivity and relative ease of manufacturing compared to other materials. It is a flexible platform that can be used with either silicon or Li-metal anodes and can be used on both intercalation and conversion type cathodes. Using high-silicon-content anodes with an NMC811 cathode targets 390Wh/kg and >1,000 cycle life. The companies claim that this will improve to 440Wh/kg and 930Wh/L with Li-metal, and reach 560Wh/kg, but reduce to 785Wh/L for next-gen cathodes (see Exhibit 147). It is currently manufacturing at pilot scale (currently 100kg per month) and aims to be in commercial production by 2026 for high-silicon anode material and 2027 for Li-metal material. The company announced its intentions to go public via Special Purpose Acquisition Company (SPAC) in 2021 at a pro-forma valuation of US$1.2bn.

EXHIBIT 146: **Relative merits of different types of materials used in solid electrolytes**



Source: Solid Power and Bernstein analysis

EXHIBIT 147: **Solid Power's product roadmap using sulfide-based solid electrodes and varying types of anodes and electrodes**

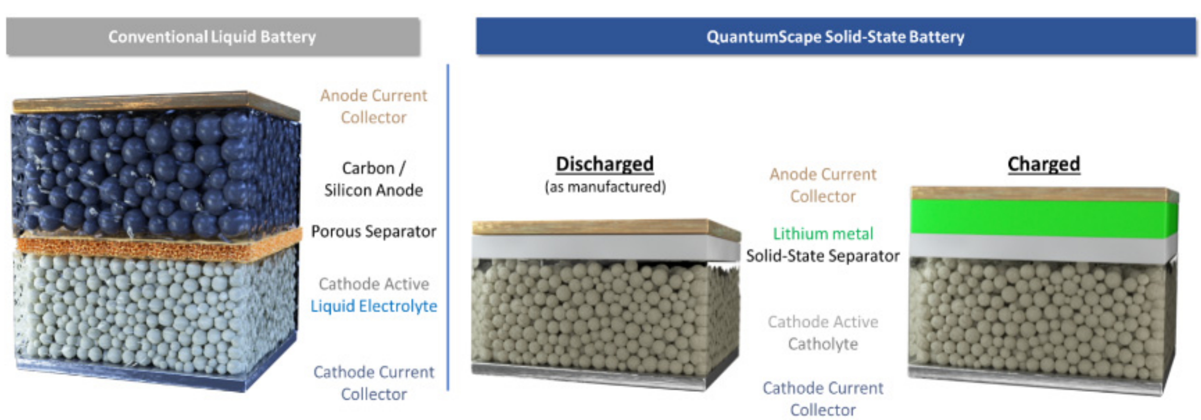


Source: Solid Power and Bernstein analysis

LI-METAL ANODE WITH SSBS

As shown in Exhibit 145, the next generation of battery is the ultra-thin Li-metal, which promises to take energy density to ~2x that of LiBs. As cathode materials used in traditional LiBs increase in energy density, they require a corresponding increase in the anode side (unless, of course, ultra-thin silicon anodes are used). This increase in the anode side offsets the benefits of improved energy density on the cathode side. In a typical LiB, lithium-ions are "hosted" within the carbon or silicon anode material when the battery is being charged, traveling through a porous separator from the cathode. However, if a pure Li-metal anode is used, the carbon or silicon material can be removed completely and replaced by a much thinner layer of Li-metal as no hosting is required. This dramatically increases the energy density of the cell on a Wh/kg basis (see Exhibit 148). We note Li-metal batteries have been in development for even longer than high-silicon anodes, with most technologies being developed over +40 years.

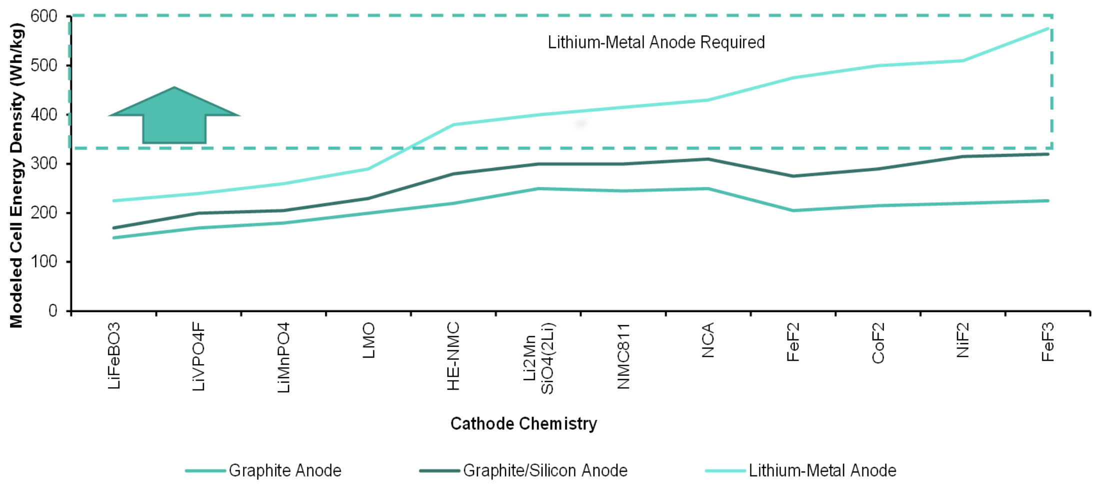
EXHIBIT 148: **Overview of how a Li-metal SSB works**



Source: QuantumScape and Bernstein analysis

Anode bottlenecks. BMW Group published data comparing the energy density of various types of cathode chemistries with different anodes, showing clearly that Li-metal anodes can unlock another level of energy density. We note, however, that the quantity or type of silicon is not verified in their comparison and, based on data from Amprius and Leyden Jar, these could reach some of the energy density levels achieved by Li-metal anodes (see Exhibit 149).

EXHIBIT 149: **Li-metal anode is required to take battery cell density above ~US$320Wh/kg**



Source: QuantumScape from BMW Group and Bernstein analysis

LEADING LI-METAL BATTERY TECHNOLOGIES

There are a plethora of start-ups developing SSB technologies using sulfur, ceramic, and polymer separators. However, none are fully commercial and are either at prototyping or testing stages. Results of tests and prototypes show impressive levels of energy density can be achieved. However, for SSBs, cycle life remains a challenge and is a technical aspect these companies will need to address before the technology is more rapidly adopted.

QuantumScape, the only listed SSB company, is developing a ceramic-based Li-metal SSB. It listed through a SPAC last year and has backing from Volkswagen (US$300mn funding commitment). Testing has shown it can reach >1,000 cycles for one layer and >800 cycles for four layers. It targets energy densities in the range of 400-500Wh/kg, but no testing data has been shared yet.

SES produces a hybrid Li-metal battery that uses a polymer separator and a high concentration solvent-in-salt liquid electrolyte that is nonflammable. Typical LiBs have a low-concentration solvent that allows the solvent molecules to be free and, therefore, flammable. The USP of this SSB is the manufacturability of its technology — it can be manufactured in existing Li-ion facilities. This has been a challenge for most SSBs. The company projects its cells will achieve energy capacity of 1,000Wh/L, density of 400Wh/kg, and potential range of ~540km. It has announced its intention to go public through a SPAC in 3Q2021 or 4Q2021 with an expected EV of US$2.7bn. However, it is still in the prototyping stage and will likely not start production at its pilot plant until 2023 and commercialization until 2028 (see Exhibit 150).

ProLogium uses a ceramic-based electrolyte and Li-metal anode and has achieved an energy density of 715Wh/L and 218Wh/kg in R&D samples. The company claims it has the potential to reach 1,033Wh/L and 380Wh/kg by 2025. According to industry sources, ProLogium is considering a SPAC at the end of 2021.

Ionic Materials uses a polymer-based separator and Li-metal anode and has previously partnered with Hyundai and battery maker A123 Systems, although it discloses little detail on prototype energy density.

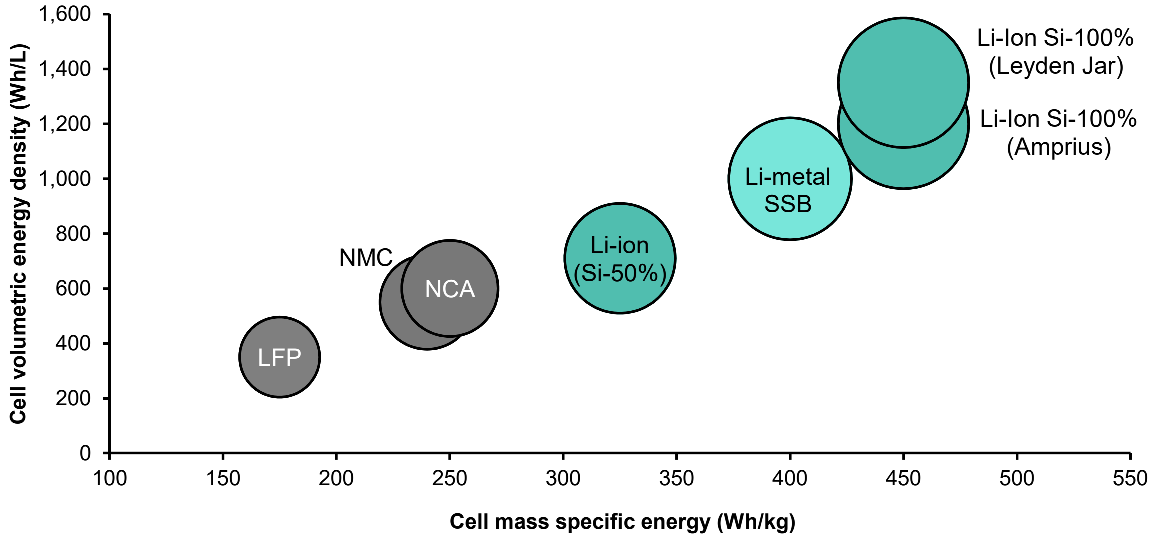
EXHIBIT 150: **SSB landscape**

		SES	**Quantum Scape**	**Solid Power**
3rd party validated		✓	✗	✗
Room Temperature Energy Density	***overcharge***	**4 Ah (25+ layer) at 25o C(Wh/kg)**	**1 Layer and 4 Layer**	**2Ah (10 layer) amd 2 layer at 290C (wh/kg)**
	Low Power C/20	>375	n/a	330
	Low Power C/10	375	n/a	-264
	Medium Power 1C	339	n/a	-33
	High Power 5C	321	n/a	n/a
0 ^{0}C Low Temperature Energy Density	Low Power C/20	324	n/a	n/a
	Medium Power 1C	298	n/a	n/a
	High Power 5C	282	n/a	n/a
Lifetime	1-2 Layer	n/a	100 cycles (>80% retention)	>250 cycles(>80% retention)
	3-4 Layer	779 cycles(70% retention)	>450n cycles (>90% retention)	n/a
	10 Layer	n/a	n/a	>32 cycles(>80% retention)
	25+ Layer	550 cycles (90% retention)	n/a	n/a
Fast Charging	1 Layer	n/a	80% in <15 min	n/a
	10 Layer	n/a	n/a	n/a
	25+ layer	80% in <15 min	n/a	n/a
Safety	Thermal	Electrolyte is stable with Li above Li melting poiint	Electrolyte is stable with Li above Li melting poiint	n/a
	Nail	Pass Test	n/a	n/a
	Overcharge	Pass Test	n/a	n/a
	External	Pass Test	n/a	n/a
	Short Circuit	Pass Test	n/a	n/a
Manufacturability		*(Highly similar process to Li-ion)*	*(unproven and complex for proprietary separator)*	(Significant process changes v/s Li-ion)
Commercialization Timeline		Li-Metal:2025	Li-Metal:2026	*Silicon:2026* *Li-Mtetal after 2026*
Source		3rd party data(Eclipse and exponenet) and SES internal data	Investor presentation: SEC filings	Company udate Dec 2020 and company press releases

Source: QuantumScape and Bernstein analysis

High silicon content challenging the energy density of SSBs. Broadly, Li-metal SSBs have a higher energy density than SSBs with high-silicon anode, the second most energy dense after carbon-anode LiBs. However, some emerging technologies such as those developed by Leyden Jar and Amprius are managing to reach similar — or indeed higher — energy densities than Li-metal SSBs at 450Wh/kg and capacity of 1,350Wh/L (see Exhibit 151).

EXHIBIT 151: **Although Li-metal batteries can achieve high energy densities, innovations in 100% silicon anodes are showing promise**



Note: Cathode used in Leyden Jar is NMC622; for others, it's not specified.

Source: QuantumScape, Faraday Institute, SES, company websites, and Bernstein analysis

COST IMPLICATIONS FOR ANODE ADVANCEMENTS

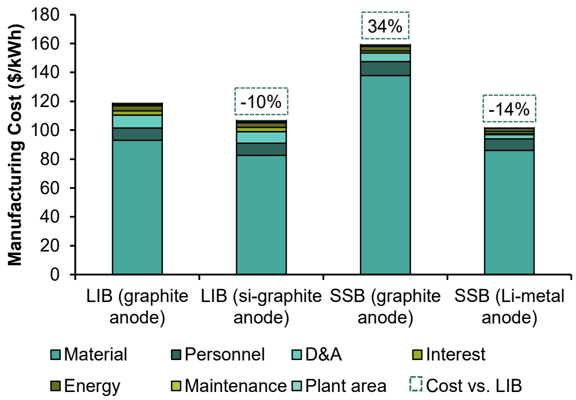
Cathode manufacturing is costly. Besides low flammability and high energy density, the potential for lower production costs is a key benefit of SSBs. One of the costliest parts of LiB manufacturing is electrode manufacturing. To make the electrodes, a slurry of active material is cast onto metal foils (both cathode and anode), which must then be slowly dried, pressed, and vacuum dried. The electrodes are then cut and stacked (~100 stacks in an EV battery) or wound. The battery is then formed (charged and discharged once), following which gases generated in the process are removed, and then the battery is sealed.

This multi-step manufacturing process means cathodes account for a large part (40%) of the manufacturing costs, excluding components, R&D, and sales costs, while cell assembly accounts for 20% and cell finishing 40%.[44] Tesla plans to reduce this by 18% by moving to a two-step process from a four-step process. Removing one electrode, as with a Li-metal SSB, therefore reduces manufacturing costs significantly compared to LiBs. Furthermore, formation and testing costs are also reduced in SSBs. However, a key challenge of SSBs is making the process of inserting the solid electrolyte compatible with today's cell manufacturing processes without significantly increasing manufacturing costs.

[44] As estimated by Sila Nanotechnologies.

SSB Li-metal cost advantage. Research published in *Energy Technology* shows Li-metal SSBs have a potential cost advantage at scale. Using Monte Carlo simulations at a production level of 6GWh researchers show Li-metal SSBs have a 14% cost advantage over LiBs with a graphite anode. Although material costs are slightly higher for this type of battery, processing costs are the lowest among the battery types. Sulfide-based SSBs (graphite anode) are shown to be 34% more expensive than traditional LiBs due to 48% higher material costs but offset by lower processing costs. This type of battery has the disadvantage of higher cathode manufacturing costs for both electrodes. Interestingly, adding silicon to LiB anodes decreases costs by 10%, almost as much as Li-metal LiBs, almost purely due to lower anode costs (-37%) (see Exhibit 152 and Exhibit 153).

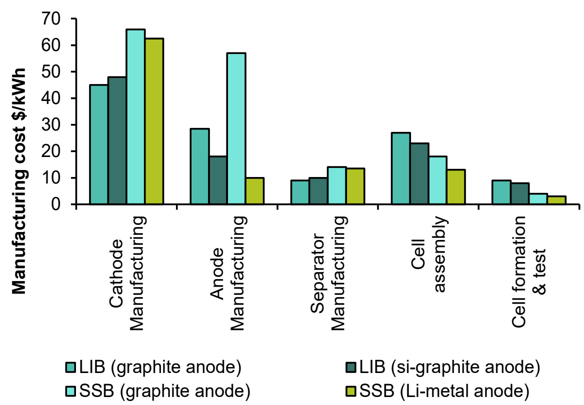
EXHIBIT 152: **SSB with Li-metal anode has a 14% cost benefit, while SSB graphite could be 34% more expensive**



Note: Scenarios are based on NMC811 cathode and a production output of 6GWh/year.

Source: "Solid versus Liquid—A Bottom-Up Calculation Model to Analyze the Manufacturing Cost of Future High-Energy Batteries" by Joscha Schnell, Heiko Knörzer, Anna Julia Imbsweiler, and Gunther Reinhart published in Energy Technology January 2020, and Bernstein analysis

EXHIBIT 153: **Li-metal SSB's cost advantage lies in anode, cell assembly, formation, and test**



Note: Scenarios are based on NMC811 cathode and a production output of 6GWh/year.

Source: "Solid versus Liquid—A Bottom-Up Calculation Model to Analyze the Manufacturing Cost of Future High-Energy Batteries" by Joscha Schnell, Heiko Knörzer, Anna Julia Imbsweiler, and Gunther Reinhart published in Energy Technology January 2020, and Bernstein analysis

SSB players estimate further cost reductions. SES estimates that at a scale of 30GWh, it can achieve an 18% net cell cost reduction versus LiBs. QuantumScape estimates its technology has a 17% cost benefit to LiBs; however, it doesn't specify at what scale or assumed LiB cost today. Solid Power has an extremely ambitious cost reduction target of 40% from US$142/kWh today for LiBs to US$85/kWh by 2027 at a scale of 10GWh. The company claims cost improvements come from supply chain development, purchasing scales, and targeted vertical integration. Furthermore, current LiBs share the same Cathode Active Materials (CAM) as their high-silicon and Li-metal cells. As they progress to next-gen CAM, costs are expected to decrease further as the CAM reduces from ~US$35/kWh to ~US$3/kWh.

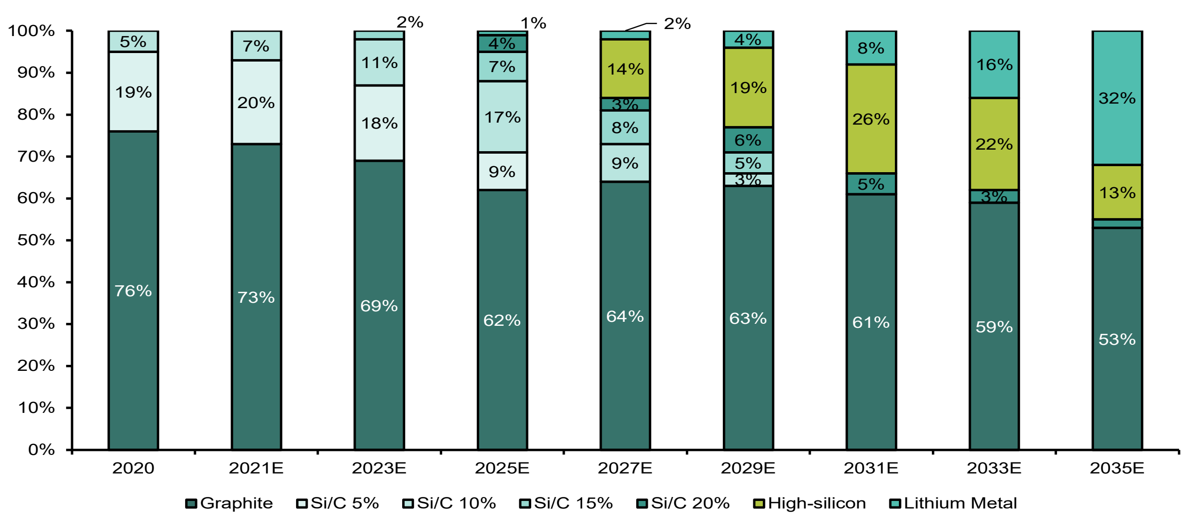
OUTLOOK FOR ADOPTION

The benefits of high-silicon anodes and Li-metal SSBs are clear — higher energy density, lower cost/kWh, and faster charge times, and more stability in the case of SSBs. However, at present, these technologies are only at prototyping or testing stage; for instance, at QuantumScape, commercialization is not expected until 2025-28. Many uncertainties remain about the ability to scale these technologies with previous technical challenges such as dendrite formation due to lithium plating and micro-cracking of, e.g., ceramic separators. The progress on certain criteria such as cycle life, particularly for high-silicon anodes, also needs to be proven.

We expect the challenges will be surmounted in the long run as capital markets seem very willing to supply growth capex, with ~US$3.2bn in capex being raised for just two projects, SES and QuantumScape. However, the first plants are ~2x more capital intensive than benchmark cathode material plants (US$60/kWh versus US$28/kWh). Thus, adoption will likely follow, with Li-metal the best contender, given its high energy density and lower cost potential. However, the road to get there will be bumpy.

Li-metal SSBs will likely take a decade to ramp. BNEF estimates Li-metal SSBs will not ramp up until the 2030s, reaching a 32% share by 2035. High-silicon anodes will ramp more quickly, taking a 26% share by 2031 but losing share to Li-metal from then on. Graphite will remain a dominant technology, particularly for applications where cycle life is important, and it is a well-understood and scaled manufacturing process that will likely take a 53% share of anodes by 2035 (see Exhibit 154). BNEF estimates this increased use in high-energy-density anodes, as well as the use of high-voltage cathodes, will result in weighted average pack-level energy density increasing from ~170Wh/kg to ~300Wh/kg.

EXHIBIT 154: **BNEF expects Li-metal anodes could account for nearly one-third of battery anodes by 2035; high silicon will take ~10%**



Note: High-silicon refers to anodes using 50% or more silicon.

Source: BNEF data and estimates, and Bernstein analysis

HOW WILL CATHODE MANUFACTURERS EMBRACE ANODE DEVELOPMENTS?

Anode developments are broadly agnostic to cathode types. Solid Power has shown its SSB technology works with multiple platforms, and QuantumScape recently confirmed its anode technology works with LFP cathode chemistries. Umicore and BASF have both been developing cathode materials for customers for use in SSBs.

Cathode manufacturers will aim to be at the forefront of anode developments. Advancements in energy densities and improvements in battery technology are clearly in their interests, as they expediate EV adoption. We, therefore, expect them to be at the forefront of developments in this space, despite not currently producing anode material. Umicore, for example, disclosed in 2021 its investments as part of Solid Power's US$187mn pre-SPAC raise, showing its commitment to developments in anode technology and SSBs. It also includes composite anodes in the long-term research pipeline. We imagine others in our coverage will also develop silicon anodes in the long run. However, in the short term, they may opt to make strategic investments similar to Umicore's.

INVESTMENT IMPLICATIONS

Advancements in anode technology and future developments of SSBs are supportive of our covered cathode manufacturers Umicore and BASF. Both are largely cathode agnostic and their deployment will precipitate the ramp up in EV adoption and, thus, cathode demand. We rate BASF Outperform with a target price of €112 and Umicore Market-Perform with a target price of €53.

EV CHARGING: ANOTHER STRING TO OIL MAJORS RENEWABLES BOW

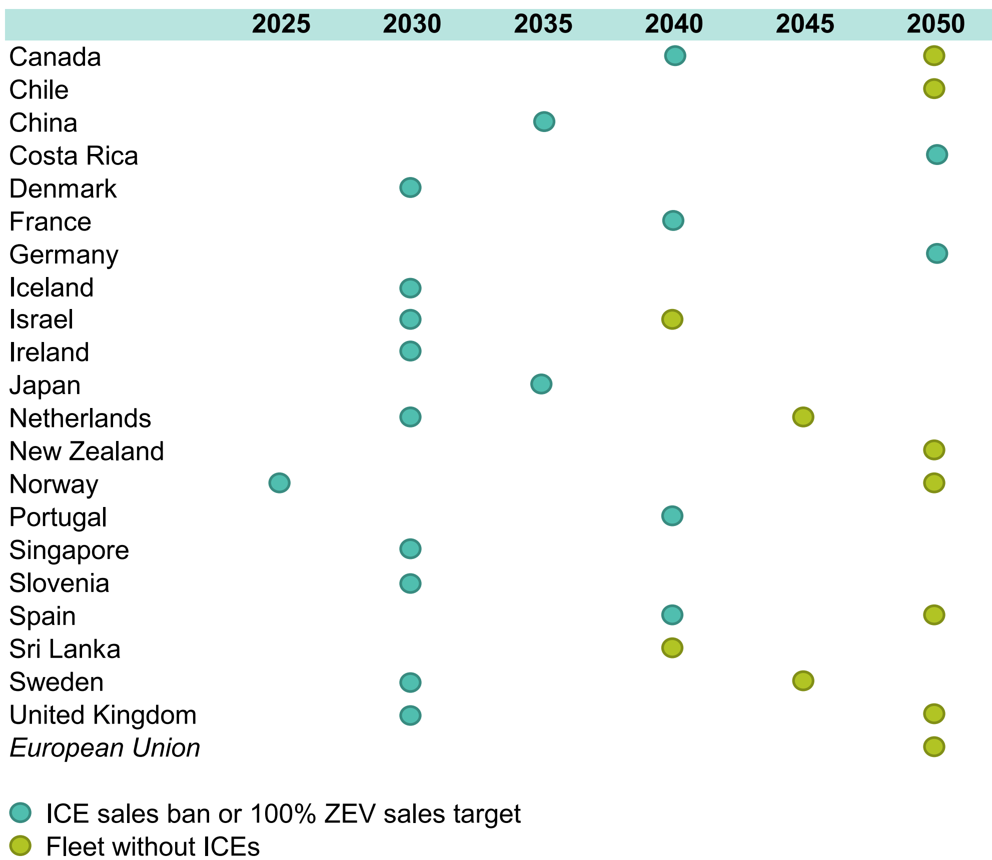
OVERVIEW

- **Serving the growing EV fleet offers another attractive growth market for European Integrated Energy companies, with today's global fleet with just 0.5% penetration set to grow to 36% by 2040.** This translates to 12.2 trillion km travelled by BEVs globally by 2040 (excluding 2Ws), from just 143 billion km in 2020 (128 billion km in 2019). Today, just 15% of this distance (22 billion km) is driven in Europe, but Europe's share grows to 23% in 2025 (175 billion km) and to 19% (2.4 trillion km) by 2040.
- **To support this, Europe's current fleet of 286,000 public chargers will have to grow to 4.5 million by 2030** or to as much as 7.346 million in some scenarios. Just 4% of these are fast chargers, despite ~14% assumed for fast chargers globally.
- **Government policy clearly supports this Electric Revolution, such as the Green Deal's AFID target ratio of 0.1 public charger per EV, or announcements in the recent Fit for 55 package.** Atypical for the Oil Majors, EV charger infrastructure rollout also has public backing, ranking among the most important factors for EV adoption across consumer surveys carried out by a variety of industries.
- **Oil Majors will likely be a big part of the power supply needed for public charging in Europe, growing from 3.7GWh (1.7GWh public, 0.8GWh fast) in 2020 to 257.5GWh (126.5GWh public, 62.0GWh fast) in 2040.** This is US$0.9bn of revenue today (49% fast) growing to US$62.4bn (53% fast) with gross margin potential in 2040 of US$58.3bn (53% fast).
- **EBITDA from public charging should thus grow from -US$14mn today, and reach breakeven in 2026 and then US$46bn by 2040.** Overall, public charging breaks even first in 2026, while fast charging breaks even in 2027. The latter's share of EBITDA grows from 35% to 54% in 2040, with capex required of US$0.8bn in 2020 growing to US$12.0bn in 2040.
- **Such a revenue model should benefit from other opportunities** including network membership fees, lower costs from station batteries, and opportunities in home and fleet charging, not to mention EV lubricant sales and cross-selling high-margin convenience to this new forecourt footfall. Finally, it can also capture the climate-conscious customer with certified renewable EV power offers, complementing current carbon-neutral fuel sales.

EV PENETRATION IS ONE-WAY TRAFFIC

The key driver behind the growth in the EV charging market is the uptake of EVs, and policy momentum is behind this, with countries across the world setting targets to end the sale of ICE vehicles and even remove ICE vehicles from their national vehicle fleets. And this momentum is only accelerating — in July, 2021, Europe's Fit for 55 announced measures to tackle rising emissions in road transport by requiring average emissions of new cars to come down by 55% from 2030 and 100% from 2035 compared to 2021 levels. As a result, all new cars registered as of 2035 will be zero-emission. However, to ensure that drivers are able to charge or fuel their vehicles at a reliable network across Europe, the Alternative Fuels Infrastructure Regulation will require an expansion of charging capacity in line with zero-emission car sales, and to install charging and fueling points at regular intervals on major highways: every 60km for electric charging and every 150km for hydrogen refueling (see Exhibit 155).

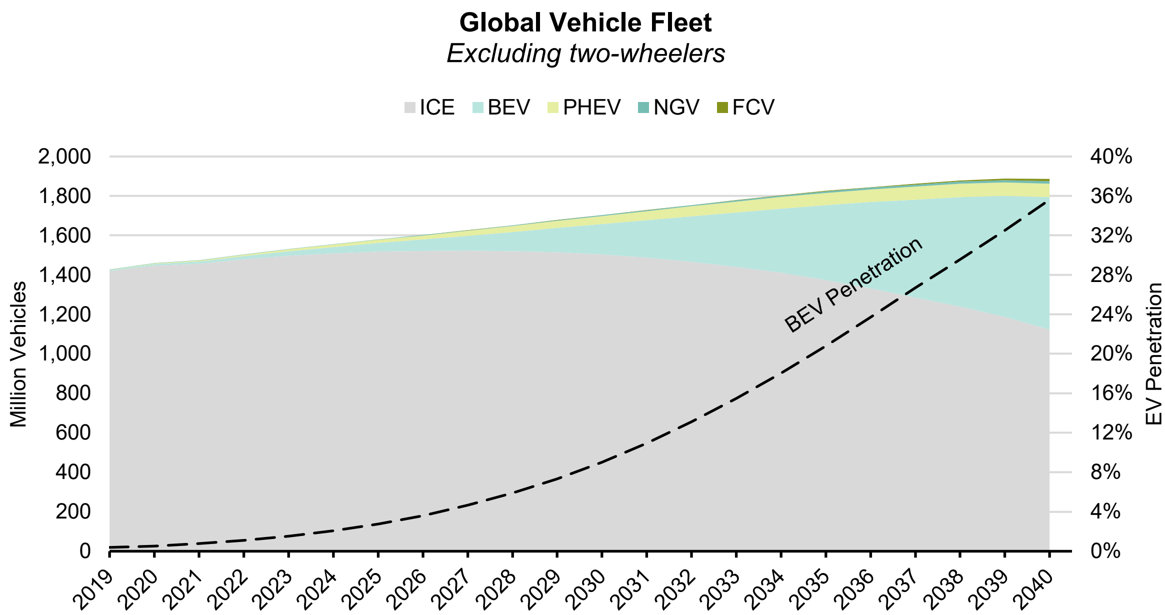
EXHIBIT 155: **Momentum is building for the uptake of EVs**



Source: IEA and Bernstein analysis

Despite today's global fleet of 1.5 billion ICE vehicles growing just 5% before it begins to decline in 2027, the global fleet of EVs, which today represents just 8 million vehicles will grow 11% in that time, and the majority of the gap will be filled by battery electric vehicles (BEVs). As a result, the penetration of BEVs will grow from just 0.5% in 2020 (~8 million vehicles globally) to 22.9% in 2030 (~154 million vehicles) and then 35.6% by 2040 (~672 million vehicles). This inevitably presents a huge market opportunity for the charging of EVs (see Exhibit 156).

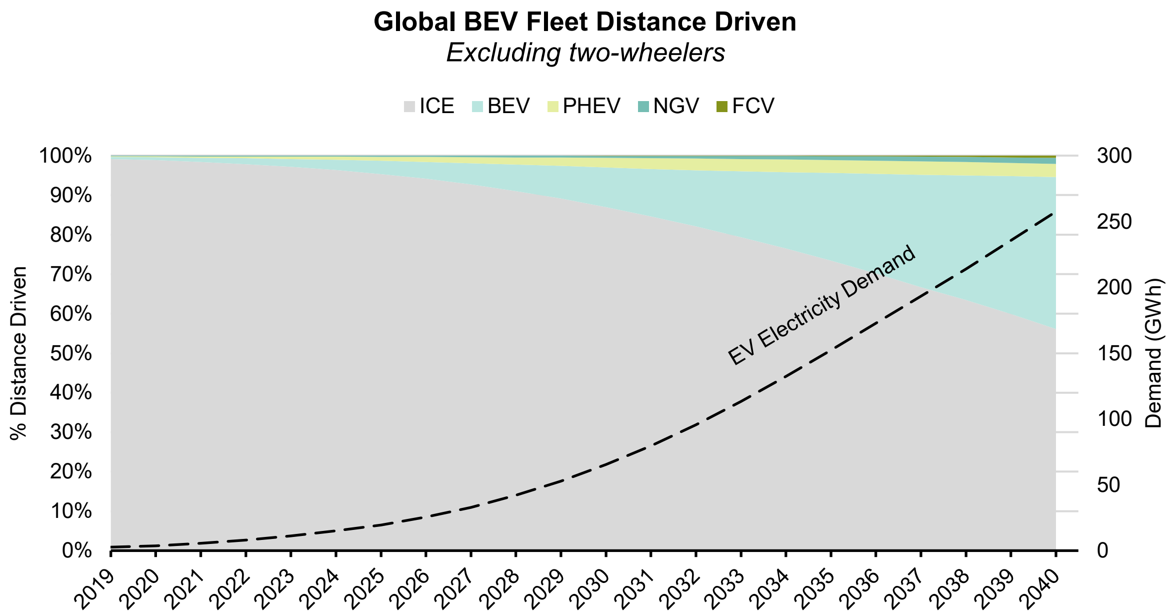
EXHIBIT 156: **Global BEV penetration is low today but rises to 36% by 2040**



Source: BNEF estimates (all years) and Bernstein analysis

We can translate such trends into distance travelled by EVs globally, which today represents just 0.8% of the 19 trillion km travelled on the roads each year, and initially grows more slowly than fleet penetration, reaching just 10.0% by 2030 (there are early advantages to using BEVs for shorter-distance inter-city journeys, including the lack of range-related issues, the relative efficiency advantages of EVs in slow-moving/stop-start traffic, and low-emission rules within city centers). However, by 2040 BEVs will travel 38.4% of the 32 trillion km travelled (see Exhibit 157).

EXHIBIT 157: **BEVs share of distance travelled rises from ~1% in 2020 to ~38% in 2040, driving a 24% CAGR increase in required electricity demand over the period**



Source: BNEF estimates (all years — distance driven), and Bernstein estimates (all data — electricity demand) and analysis

Combined with efficiency improvements in EVs (we see efficiencies improving from 6.1km/kWh today to 9.4km/kWh by 2040), we can determine electricity requirements for BEV charging, which grows at a 24% CAGR from 3.8TWh in 2020 to 258TWh in 2040.

EV CHARGING BUSINESS MODELS

Depending on the use-case, a variety of types of EV chargers may be used, which are generally categorized according to the power of the charger (i.e., the speed at which it charges a battery of a given size). Family homes, some workplaces, and company fleets are able to rely on slow charging (3-7kW) as charging time is not a constraint. Fleet charging tends to use medium-power chargers, with fleets of large-battery CVs and buses needing to be charged overnight, thus normal AC chargers (11-22kW) or AC fast chargers (43kW) may be used.

Public "on-the-go" charging is generally split into slow public and fast public charging. Charging at street-sides and carparks, as well as some workplaces and company fleets can rely on a range of chargers from slow (3-7kW) charging all the way to AC fast chargers (43kW). Fast charging is used at fuel stations and charging hubs — these may have normal (11-22kW) and AC fast chargers (43kW). However, they generally focus on fast on-the-go charging, in the form of 50kW DC fast chargers or 100-350kW DC ultrafast chargers.

It is these last two categories of public charging that are the priority focus of the Integrated Energy Majors, whose first goal is to leverage their customer networks and existing forecourts to provide such fast charging (see Exhibit 158 and Exhibit 159).

EXHIBIT 158: **European Integrated Energy Majors are primarily involved in public charging**

		Home Homes, workplaces, company fleets	**Public Slow** Streets, carparks, workplaces, company fleets	**Fleet** Commercial vehicle fleets and night charging at bus depots	**Public Fast** Fuel stations and charging hubs
Slow	3-7 kW AC	●	●		
Normal	11-22 kW AC		●	●	●
AC Fast	43 kW AC		●	●	●
Fast	50 kW DC				●
Ultrafast	100-350 kW DC				●

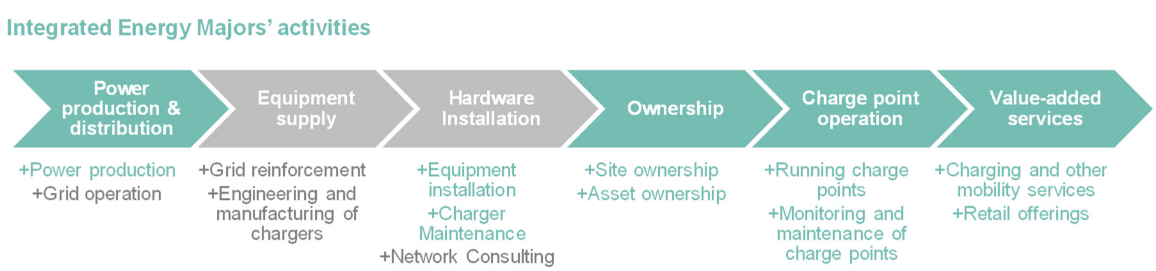
Main areas of interest for the Oil Majors

Source: Bernstein analysis

EV CHARGING VALUE CHAIN

The Integrated Energy Majors are able to participate across most of the EV charging value chain, which runs from production and distribution of the power required to charge the EVs, to supply and installation of the equipment, to ownership and operation of the chargers, charging stations and charging networks, to provision of additional services to EV drivers.

EXHIBIT 159: **Integrated Energy Majors are able to operate across most of the public EV charging value chain**



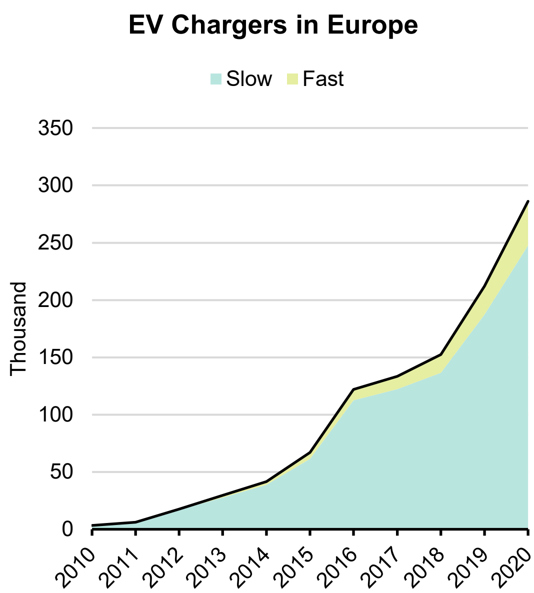
Source: BCG and Bernstein analysis

EV CHARGING NETWORKS

Global public charging networks have grown at a 78% CAGR over 2010-20, with 1.3 million chargers available globally as of 2020, of which 0.8 million were in China and 0.3 million were in Europe. The European charger network has also grown slightly slower than the global trend, at a 54% CAGR over 2010-20. However, going forward, the outlook for the European charging networks is for faster growth, with the IEA's stated policies scenario (STEPS) suggesting a CAGR of 33% to 2030 in Europe compared to 29% globally; in its sustainable development scenario (SDS), the European public charging network grows at a 38% CAGR to 2030 compared to 35% globally (see Exhibit 160 and Exhibit 161).

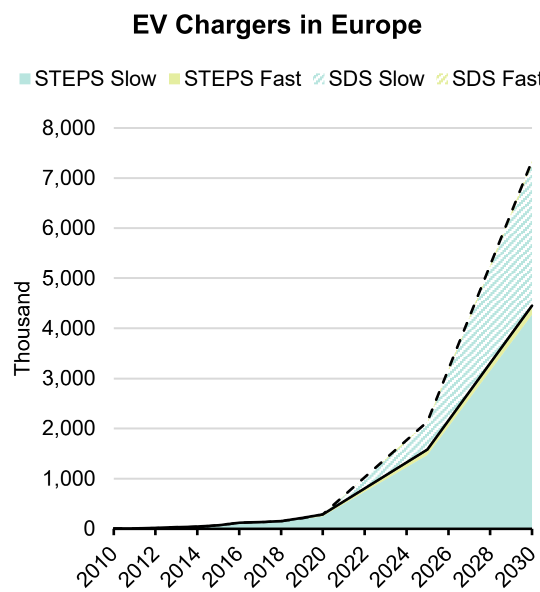
Within Europe, the number of fast chargers is lower than in the rest of the world. As of 2020, just 13% of the 286,000 public chargers in Europe were fast chargers, compared to 29% of the global fleet. This will likely fall further looking out to 2030, when just 4% of the 4.46 million chargers in Europe will be fast chargers, compared to 14% of the 16.09 million available globally.

EXHIBIT 160: **The number of EV chargers in Europe grew at a 54% CAGR from 2010 to 2020...**



Source: IEA and Bernstein analysis

EXHIBIT 161: **...and is expected to grow at a 33% CAGR to 2030 in the IEA STEPS, or 38% in the SDS**



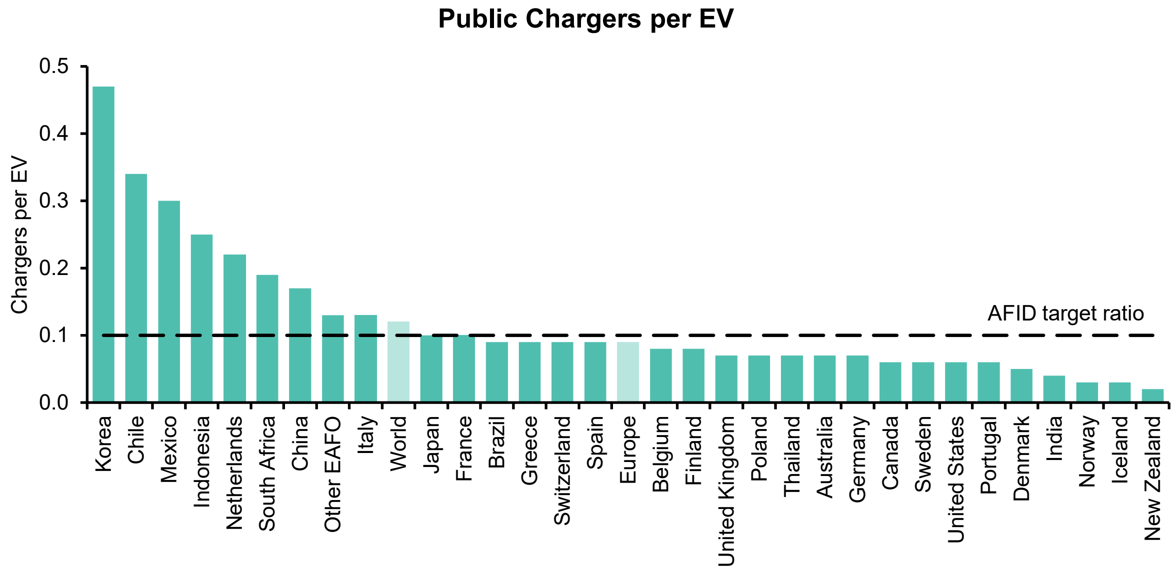
Source: IEA data and estimates (2021+) and Bernstein analysis

POLICY SUPPORT AND NATIONAL TARGETS

In addition to banning ICE vehicles sales and aiming to eliminate ICEs from the fleet of vehicles in Europe, there are a variety of policies and targets that support the rollout of EV charging. The EU Green Deal targets 1 million charging points by 2025, a number we are set to exceed (1.58 million chargers in the EU + UK, compared to the 286,000 chargers today of which 33,000 are in the UK).

The AFID set a target with the EU of deploying one public charger per 10 EVs by 2020 (an AFID ratio of 0.1). As a whole, the EU didn't quite achieve this target, with a ratio of 0.09, although globally the ratio is 0.12. Within the EU, the Netherlands (0.22) and Italy (0.13) did exceed the target, while France achieved a ratio of exactly 0.1. The lowest AFID ratios tend to belong to countries with higher EV penetration, such as Norway (0.03), Iceland (0.03), and Denmark (0.05) — that is, EV adoption outpacing the growth of the charger network. These countries are all sparsely populated, with most EV owners living in houses with private parking and being able to use private home charging (see Exhibit 162).

EXHIBIT 162: **Ratio of public chargers to EVs in Europe is slightly below AFID target ratio of 0.1**



Source: IEA and Bernstein analysis

A number of individual European countries have their own policies and incentives to support the rollout of EV charging infrastructure (see Exhibit 163).

EXHIBIT 163: **EV charging incentives in major European countries**

Belgium	+ 13.5% corporate tax deduction on investments in charging infrastructure + €75 office parking space tax in Brussels waived if charging units are fitted
Denmark	+ Commercial EV charging is tax exempt, meaning companies are entitled to an electricity tax rebate of ~1 DKK/kWh
Finland	+ €4.8M public investment in public charging in Helsinki in the past three years, and €5.5M budget has been allocated for 2020-21 + Subsidy for up to 35% of charging investments by corporates
France	+ €300 tax credit for private residential EV charger, subsidy for purchase and installation costs of charging points of 40% for businesses, 50% for apartment blocks, 40% (capped at €2,160) for municipalities
Germany	+ Subsidies for public charging points: up to €3,000 for up to 22kW, up to €12,000 for up to 100kW DC, up to €30,000 for greater than 100 kW DC + Grid connections subsidized up to €5,000 for low voltage and €50,000 for medium voltage connections
Italy	+ Tax deduction of 50% on a total amount up to €3,000 on purchase and installation of chargers spread over ten annual instalments. Valid until end of 2021.
Spain	+ Subsidies of 30-40% of purchase and installation costs up to €100,000 for individuals and companies through the MOVES II program
Sweden	+ Grant of up to 50% of public and private parking stations available through the Klimatklivet program + Up to 50% or SEK 10,000 for purchase and installation of home chargers through the Charge at Home program
Netherlands	+ Individuals can request the installation (for free) of a public charge point near their residence or place of work
UK	+ Grants for up to 75% or £350 of purchase and installation of a single home EV charger or up to 40 chargers at workplaces + Businesses that install charging infrastructure can access tax benefits through a 100% first-year allowance for expenditure on EV charging equipment

Source: Wallbox and Bernstein analysis

In July, 2021, the EU announced its Fit for 55 package, including a number of policies and targets for EV charging:

- EU member states are required to install 1kW of charging capacity per registered EV, which is expected to result in 1 million charge points by 2025, 3.5 million by 2030, 11.4 million by 2040, and 16.3 million by 2050.
- Across the TEN-T network of major European highways, at least 300kW of charging capacity will be required every 60km by 2025, and 600kW by 2030, with a broader category of European highways expected to reach these targets by 2030 and 2035, respectively (see Exhibit 164).

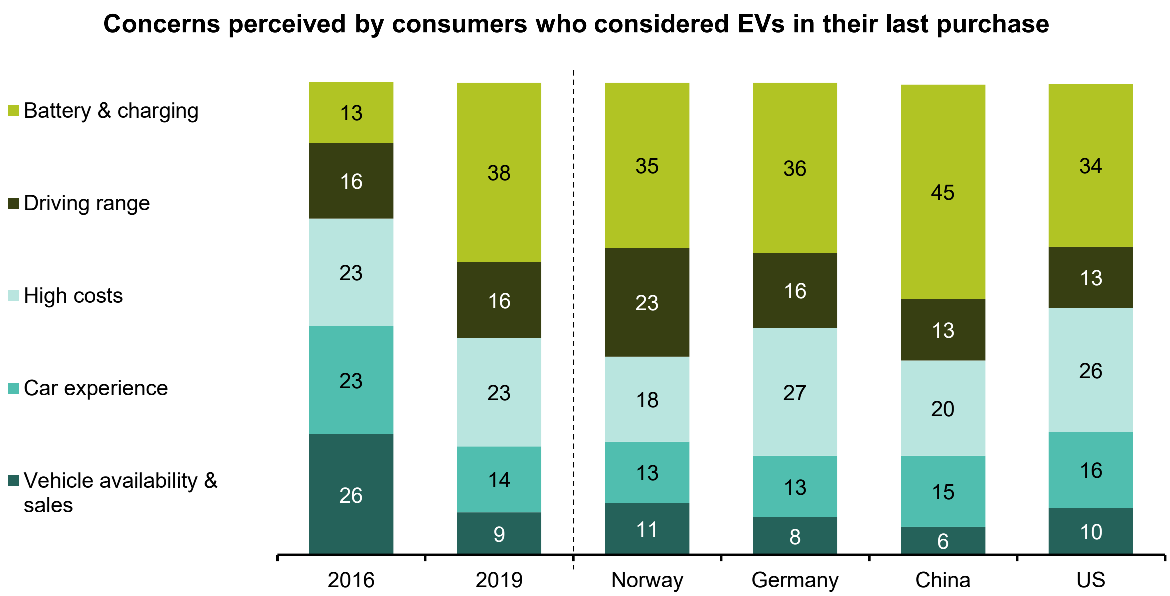
EXHIBIT 164: **Electric and hydrogen refueling infrastructure proposals**

Source: European Commission

PUBLIC SUPPORT

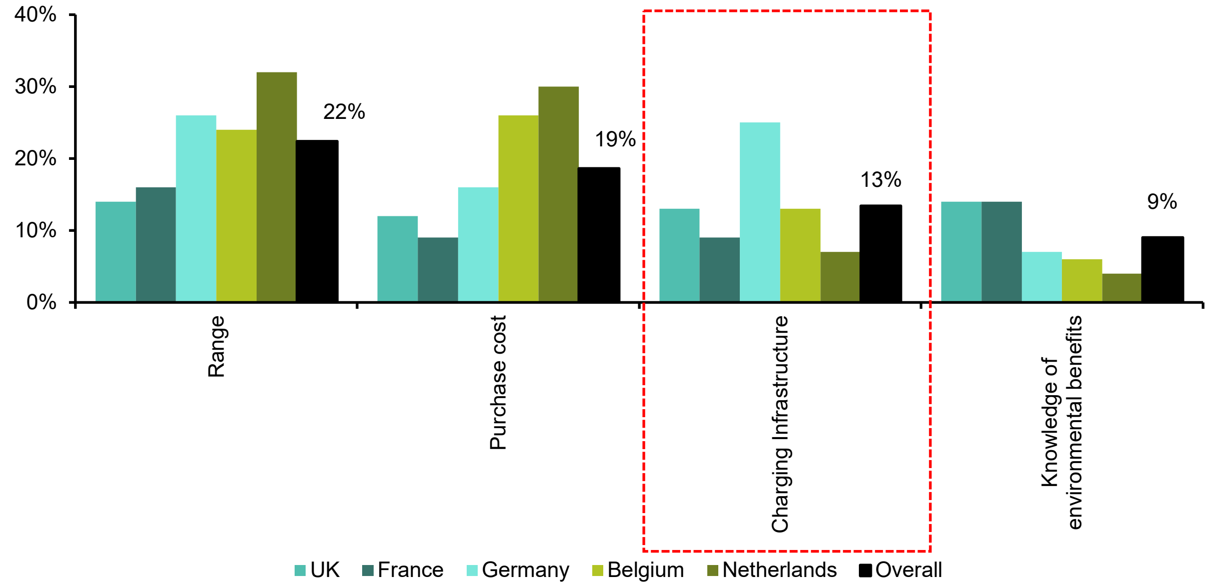
Support for charging infrastructure is not just policy driven, but is coming from the general public as well, with charging availability voted consistently across surveys as among the most significant barriers to EV adoption (see Exhibit 165 to Exhibit 167).

EXHIBIT 165: **With EV prices declining and vehicles improving, charging has become the top barrier to adoption**



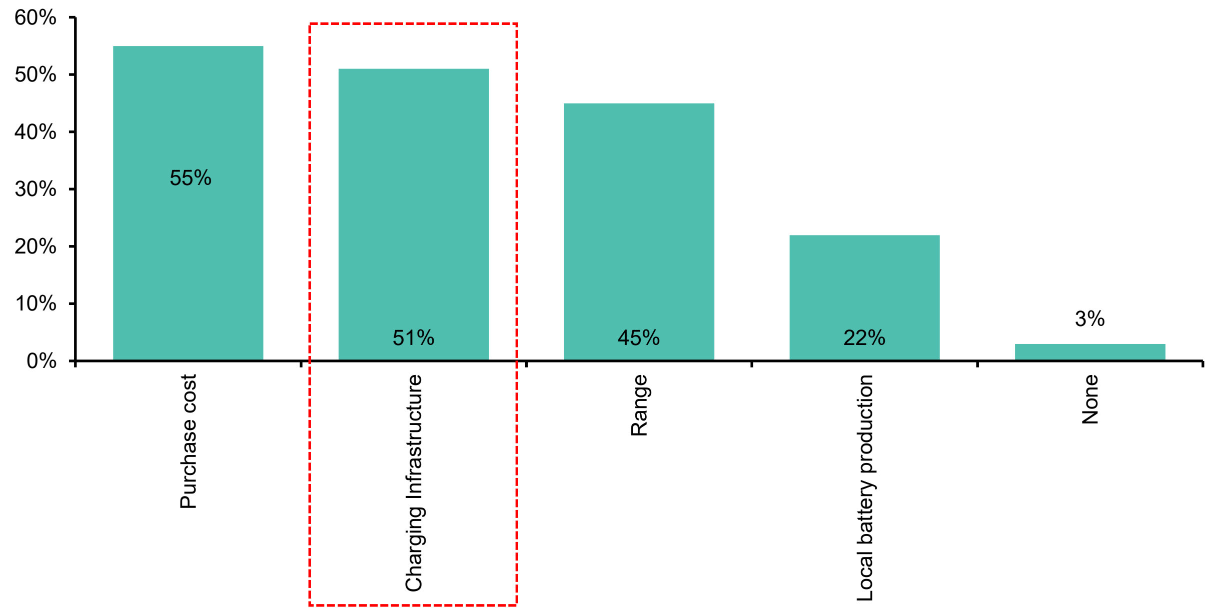
Source: McKinsey and Bernstein analysis

EXHIBIT 166: **Percentage of drivers saying the most important driver for mass EV adoption would be charging infrastructure**



Source: NewMotion and Bernstein analysis

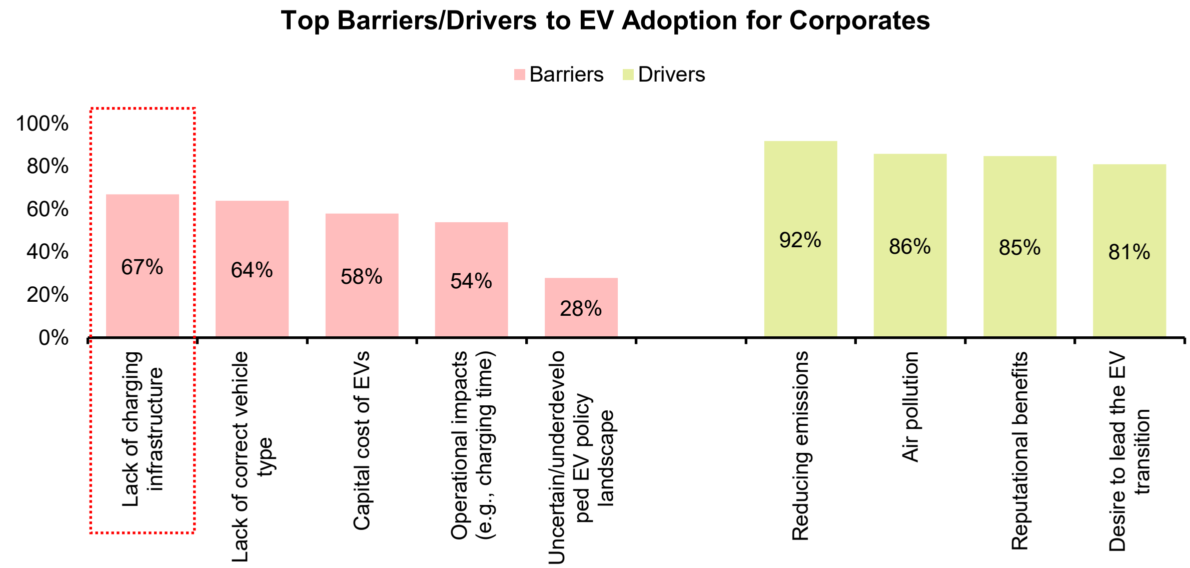
EXHIBIT 167: **Factors influencing the point at which emissions-free cars will overtake the sale of ICE cars**



Source: Transport & Environment and Bernstein analysis

The Climate Group's EV100 initiative is a group of 110 companies involved in the EV value chain across 80 markets, representing 169,000 EVs and 2,100 charging sites. These companies see similar barriers to the general public (see Exhibit 168), with a lack of charging infrastructure, EV costs, and operational impacts (the specific example given is charging time, although range could be seen in a similar vein) among the most important barriers to adoption. In contrast to the general public, however, the corporate sector suffers from a lack of commercial EVs. Drivers for EV adoption by corporates are also similar to those of the general public, led by a desire to reduce emissions and air pollution.

EXHIBIT 168: **Fleet owners' view of barriers to EV adoption roughly mirror public views**

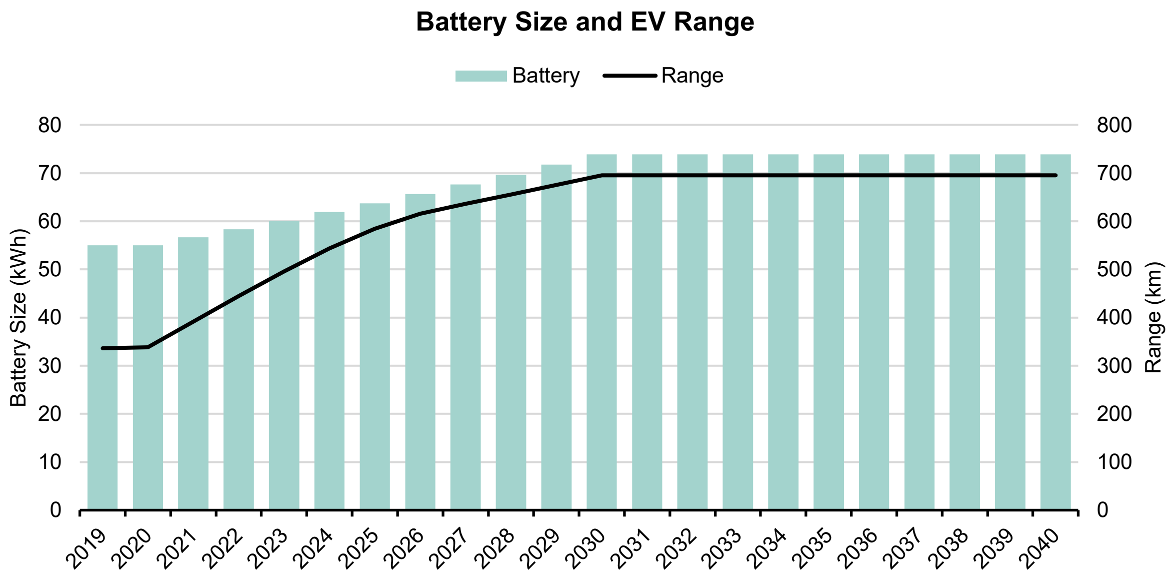


Source: The Climate Group and Bernstein analysis

EARNINGS POTENTIAL OF EV CHARGING

We assume that battery sizes grow 3% each year to 2030 before flattening, while EV efficiency grows 12% in 2021 and 2% less each subsequent year, leading to average EV ranges doubling from 338km in 2020 to 696km in 2030 (see Exhibit 169).

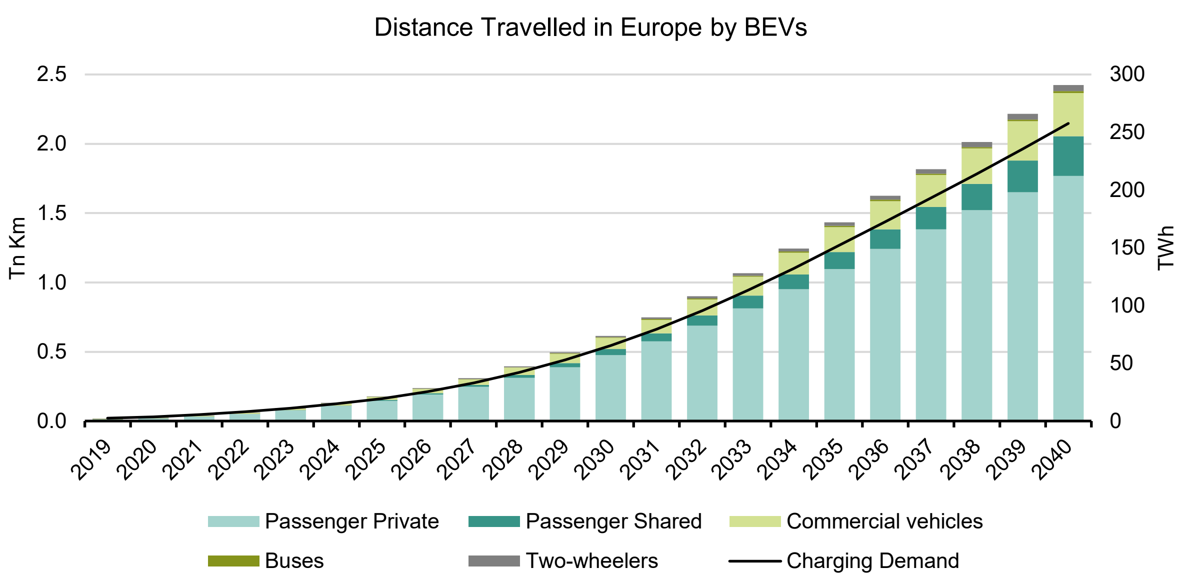
EXHIBIT 169: **We assume battery sizes grow 3% each year to 2030 before flattening; thus, average EV ranges double from 338km in 2020 to 696km in 2030**



Source: IEA, and Bernstein estimates (2021+) and analysis

As these are average ranges/battery capacities, we further assume that passenger cars have ranges/battery capacities equal to the average, while CVs have double the range, buses 1.5x the range, and 2Ws a quarter of the range.

EXHIBIT 170: **Total distance travelled by a BEV increases from 16 billion km in 2019 to 2.42 trillion km by 2040, in which time electricity demand attributable to EV charging grows from 2.7TWh/year to 258.5TWh/year**

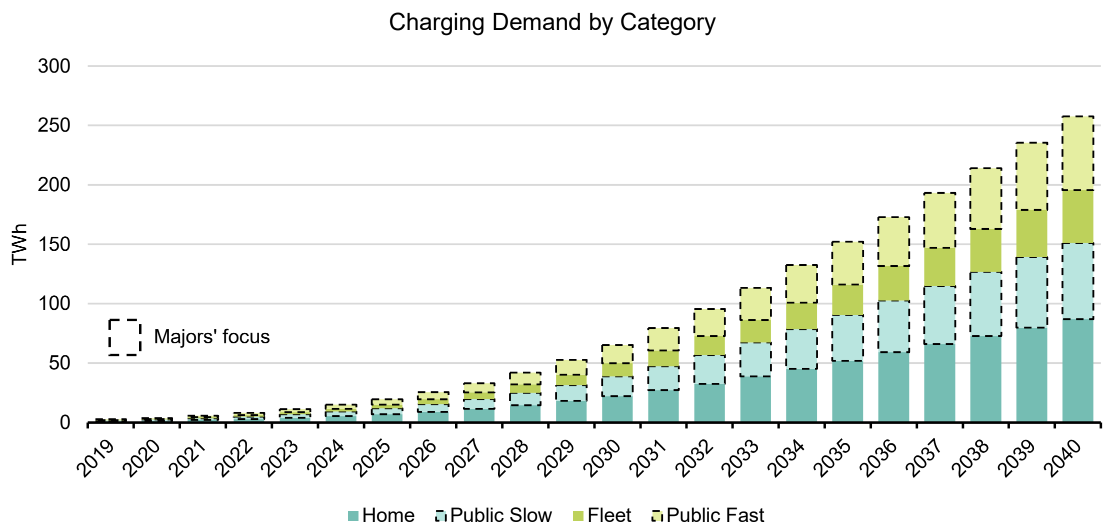


Source: BNEF, and Bernstein estimates (all years) and analysis

We then use the following assumptions for charging preferences to determine the demand for each category, in GWh/year (see Exhibit 171):

- **Private passenger vehicles** are charged 40% at home, 30% at slow public chargers, 20% at fast public chargers, and 10% using fleet chargers.
- **Shared passenger vehicles**, which include digital-hailing, taxis, car-sharing, and autonomous vehicles operated in a shared fleet use all charging types equally.
- **Commercial vehicles** are charged equally at fleet chargers and at public fast chargers.
- **Buses** are exclusively charged using fleet charging at bus depots.
- **2Ws** are charged 85% at home, 10% using slow public chargers, and 5% using fast public chargers.

EXHIBIT 171: **Total power demand for public charging rises from 1.7TWh/year in 2020 to 126.5TWh/year in 2040**



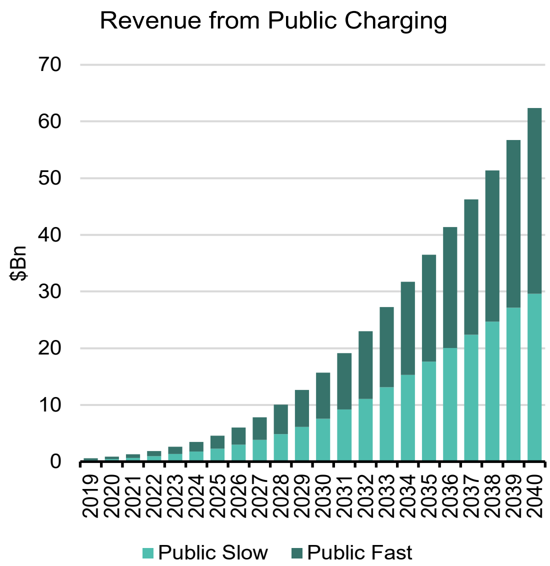
Source: Bernstein estimates (all years) and analysis

We assume this power is sold at US$0.58/kWh through slow chargers and select the upside case on pricing US$0.94/kWh through fast chargers, i.e., Ionity's latest pricing inclusive of VAT, which we deduct below, and carry this flat through to 2040. We assume power is purchased at wholesale levels, using US$27/MWh in 2021, US$30 in 2022, US$31 in 2023, and US$32 in 2024 (the forward curve), and then carry US$32/MWh forward.

The result is a gross margin of US$848mn in 2020 (51% slow charging and 49% fast charging), rising to US$59.4bn in 2040 (47% slow charging and 53% fast charging).

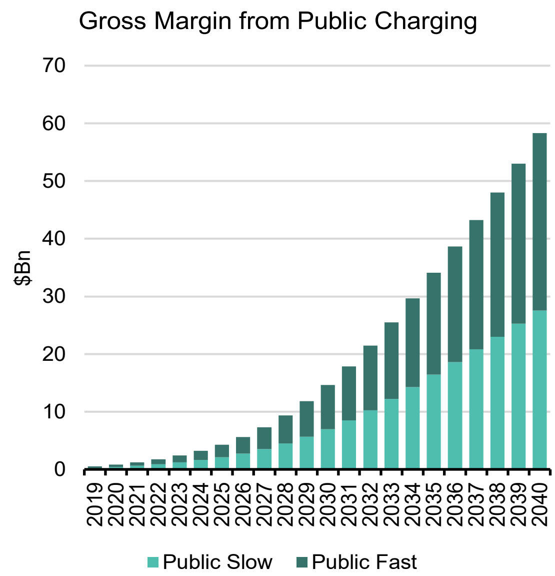
Many network operators also charge a subscription fee, an additional revenue line. However, we do not model this, as in most cases the fee is compensated for by lower unit charging costs.

EXHIBIT 172: **Revenue reaches US$62bn by 2040...**



Source: Bernstein estimates (all years) and analysis

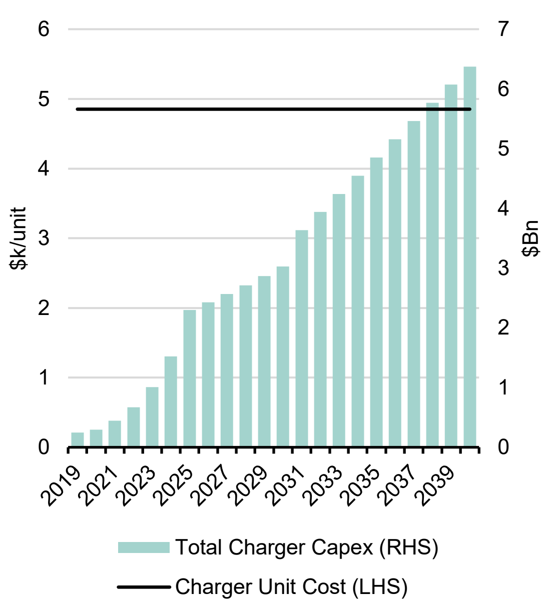
EXHIBIT 173: **...with gross margin of US$58bn**



Source: Bernstein estimates (all years) and analysis

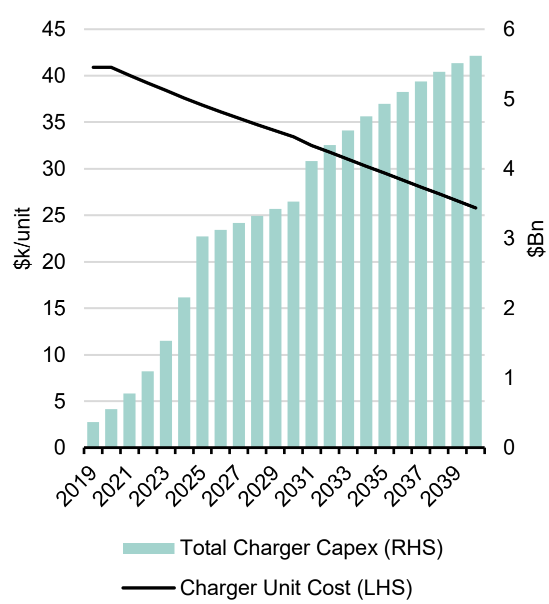
Based on Transport & Environment estimates, we assume the cost of public slow chargers with an average power of 13kW stays flat at US$4,900 currently, while the cost of fast chargers with an average power of 54kW falls from US$40,900 currently to US$36,800 in 2025 and US$33,400 in 2030, before falling linearly to US$25,500 in 2040.

EXHIBIT 174: **Slow charger costs and total European capex**



Source: Transport & Environment estimates (2019-30), and Bernstein estimates (2031+) and analysis

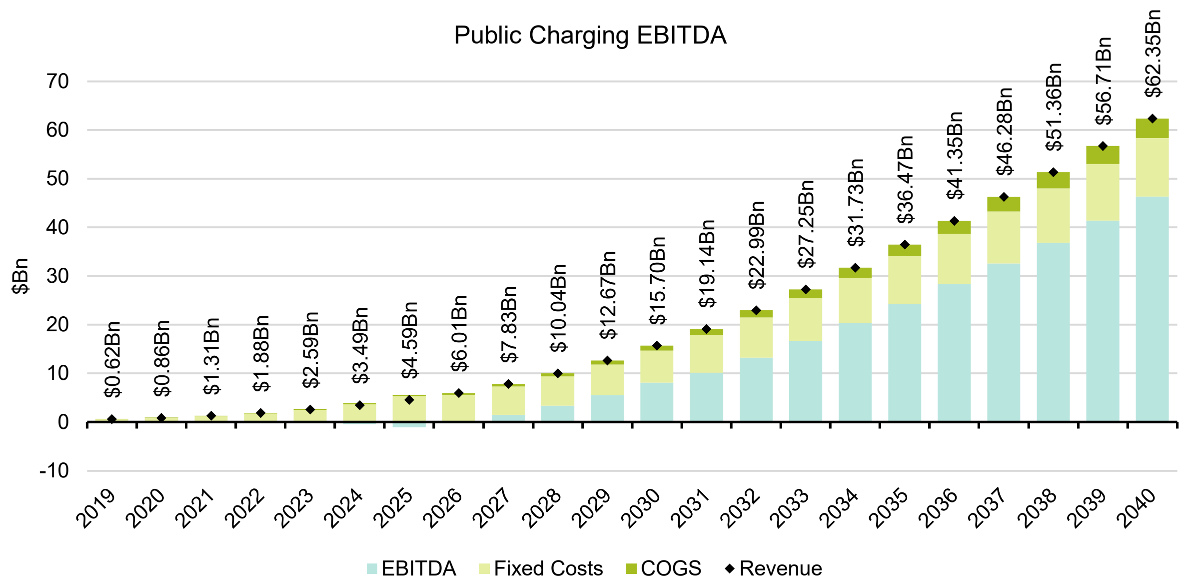
EXHIBIT 175: **Fast charger costs and total European capex**



Source: Transport & Environment estimates (2019-30), and Bernstein estimates (2031+) and analysis

This allows us to calculate an estimate of total EBITDA potential in Europe for public EV charging (see Exhibit 176).

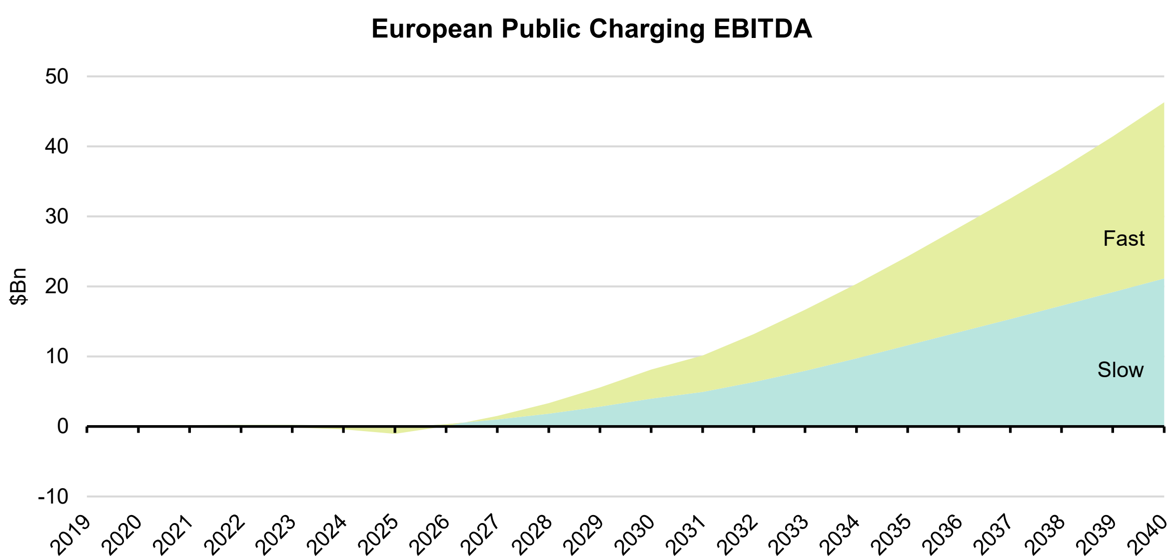
EXHIBIT 176: **EBITDA from public charging in Europe should reach US$46bn by 2040 from -US$14mn today**



Source: BNEF, Transport & Environment, IEA, and Bernstein estimates (all years) and analysis

Dividing it again by type, we see that the current high costs of fast chargers mean that the EV charging market will be loss-making until 2026, while fast charging first becomes profitable a year later in 2027 (see Exhibit 177).

EXHIBIT 177: **EBITDA from public charging in Europe by charging type**



Source: BNEF, Transport & Environment, IEA, and Bernstein estimates (all years) and analysis

ADDITIONAL OPPORTUNITIES

There are several ways that the same network operators we have discussed can generate additional earnings, including:

Charging station batteries

Earlier this year, Shell announced the trial of a battery-powered ultrafast 175kW charging station at a Dutch filling station. Compared to a charger that is directly grid-linked, this has two main advantages:

- The battery will be optimized to charge at off-peak times when power is the cheapest, thus reducing the cost to Shell of the electricity sold.

- High-powered chargers, particularly when clustered at a filling station (or in the future, a fast-charge hub), cause significant strain on the grid. Powering the chargers from a battery reduces this strain by both allowing a lower power to be drawn from the grid and boosting this with the battery, or removing the peaks and troughs in power requirements as cars are connected and disconnected by allowing the battery to be slowly charged over time.

- Additionally, the battery can act as a "virtual power plant," supplying power back to the grid when the charger is not in use and demands on the grid are at their highest, as well as assisting with frequency regulation, similar to V2G technology.

Memberships

Many charging networks charge a membership fee to allow drivers to use their network. This generates additional revenues. However, most networks that require membership also have lower selling prices. Moreover, EVs represent a number of other opportunities aside from public charging networks.

Home/Fleet charging

The market we look at in the earlier sections of this chapter considers only public charging, the demand for which we estimate will be 126.5TWh/year by 2040. However, there will also be 86.8TWh/year of demand for home charging and 44.3TWh/year for fleet charging, combined to 51% of the total EV charging market.

The Integrated Energy Majors and utilities alike will benefit from this, as they install home and fleet chargers, and even offer services to manage the charging of larger fleets, such as trucks, vans, and buses charging at depots, as well as fleets of taxis and even private vehicles charging at workplaces.

Moreover, the increase in domestic power demand from EV charging will benefit some Majors that are growing their retail power markets, as well as the utilities that are already in this market.

EV fluids and lubricants

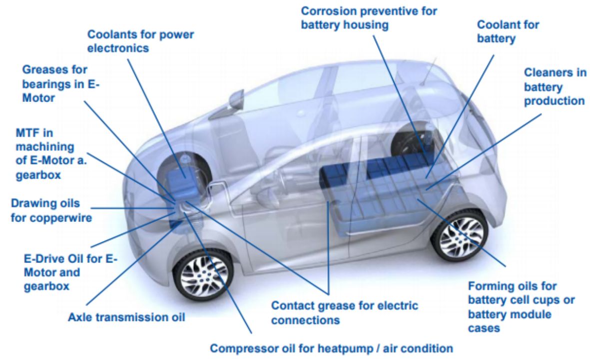
Shell, BP, TOTAL, and Repsol have all introduced ranges of oil-based fluids for EVs, which help with the lubrication of motors and transmissions, and with thermal management of the battery and motor, as well as inverters and fast chargers (see Exhibit 178 and Exhibit 179).

EXHIBIT 178: **Aside from engine oil, EVs require more fluids than ICEs**

Powertrain applications	ICE	EV
Engine oil	✓	✗
Transmission oil	✓	✓
Greases	✓	✓
Specialty greases	✓	↑
Lubricants for Auxiliary systems	✓	↑
Cooling & functional liquids	✓	↑

Source: Bernstein analysis

EXHIBIT 179: **Oils, lubricants, and greases are used throughout the vehicle, not just in the powertrain**

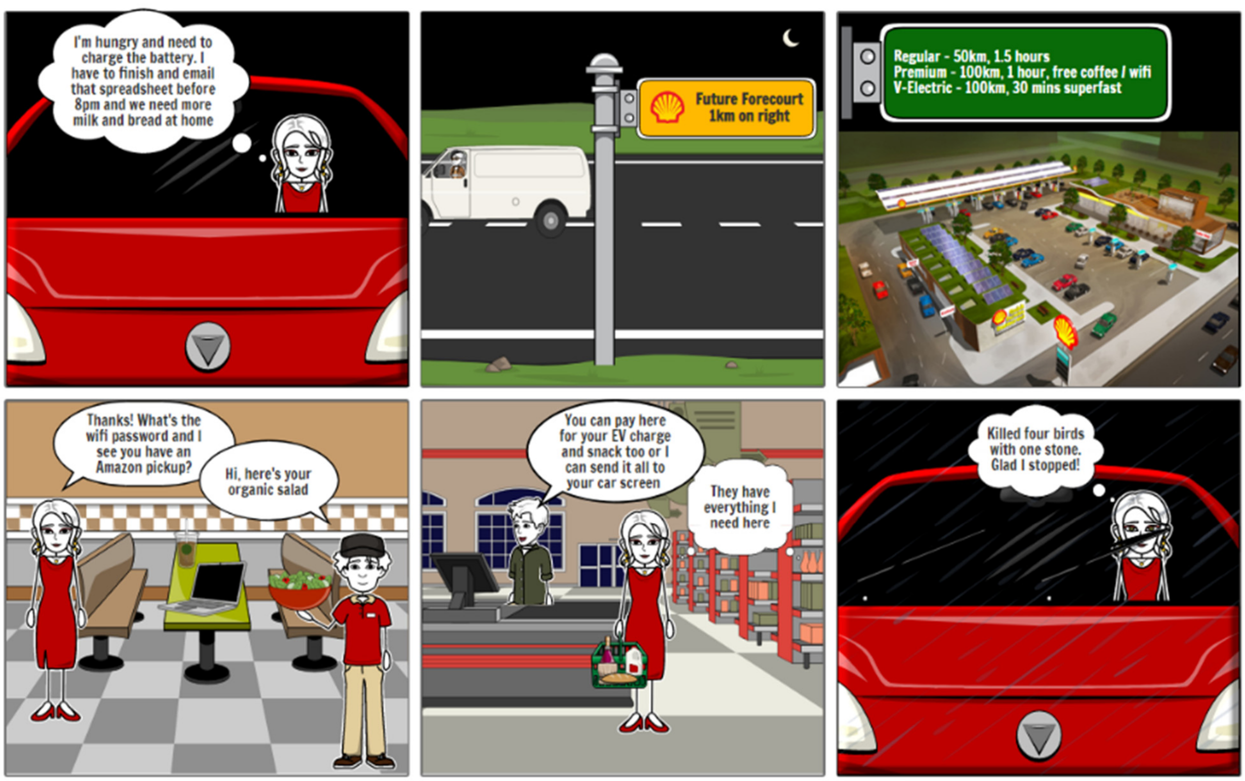


Source: BP

Retail

Rather than a threat to the Majors' forecourts, the Electric Revolution will be an opportunity to bring customers into the Majors' retail sites, where they will spend more time (even with a 350kW charger, today's 55kWh average battery would take ~10 minutes to charge, versus around five minutes to fill an ICE car) and, therefore, more time to pick up convenience (see Exhibit 180).

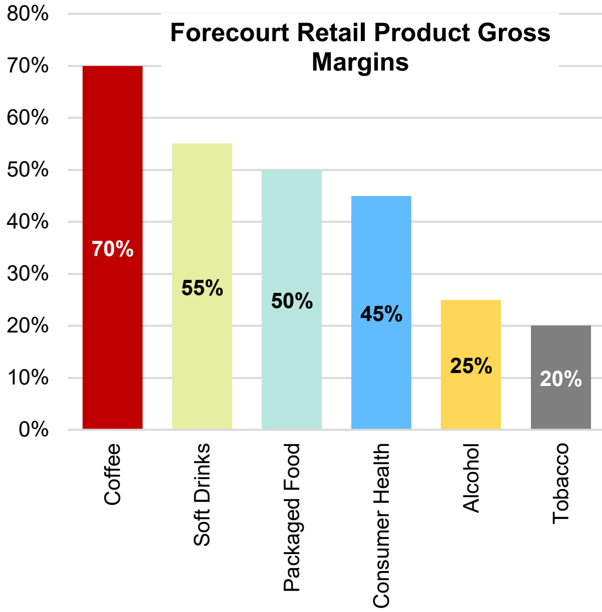
EXHIBIT 180: **How we think forecourt retailing will look in the future**



Source: Bernstein analysis

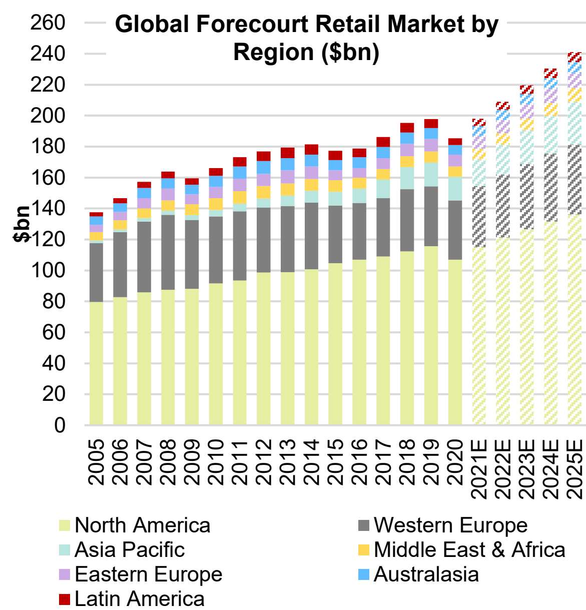
The Majors' retail offerings are their highest-margin businesses (see Exhibit 181), and are globally a US$200bn market growing at ~5% per year (see Exhibit 182).

EXHIBIT 181: **Forecourt retail is the Majors highest-margin business**



Source: Bernstein estimates (all data) and analysis

EXHIBIT 182: **Western Europe is 20% of the growing forecourt retail market**



Source: Euromonitor data and estimates, and Bernstein analysis

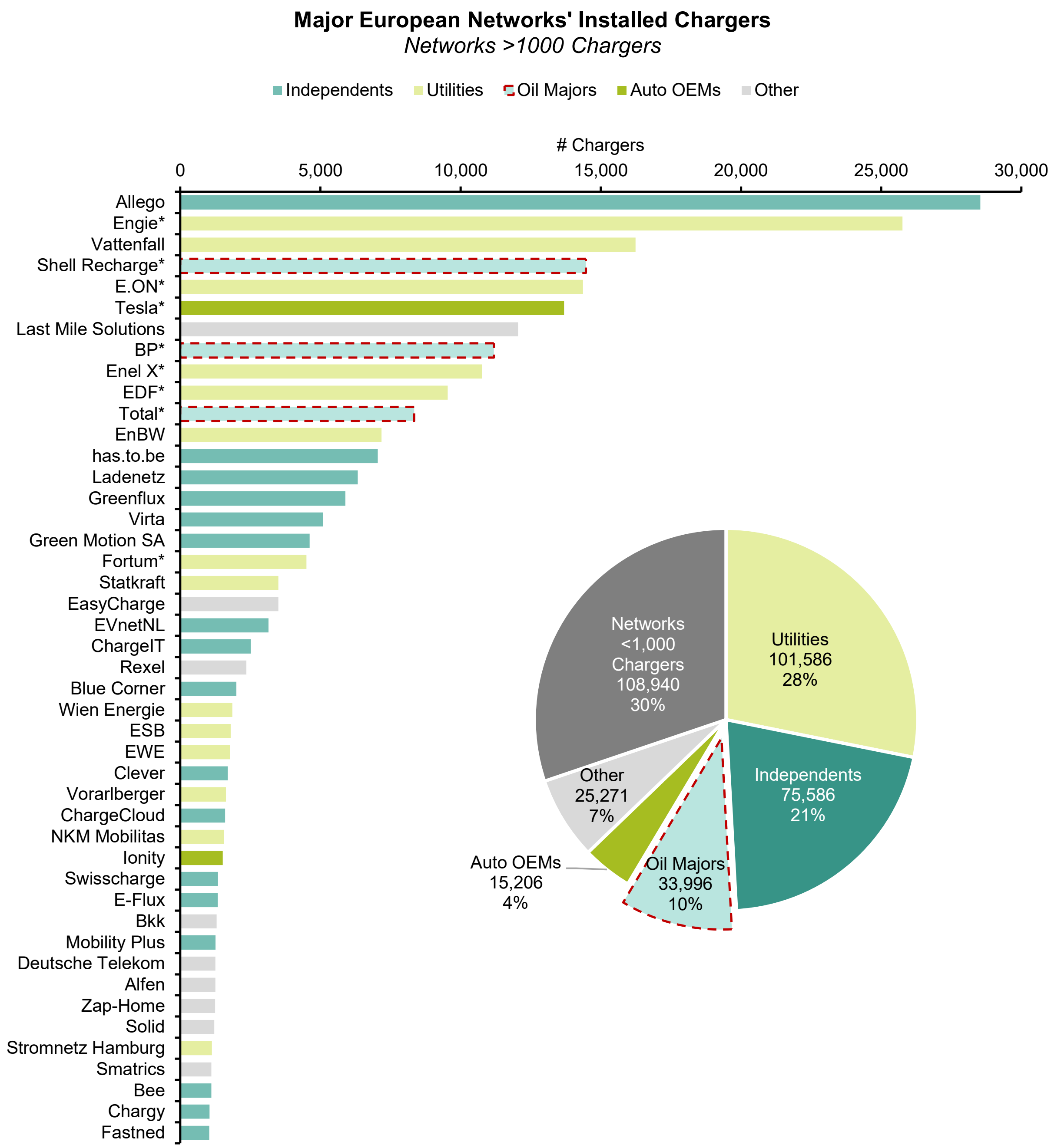
Corporate partnerships

We have seen an increasing number of corporate partnerships in renewables, such as BP's agreement to supply Amazon with power for its data centers and distribution hubs, and we are seeing this in EV charging too. TOTAL recently signed an agreement with Uber to provide its drivers in France with access to its charging network, while BP has a similar partnership in the UK with Uber to provide charging points, starting with a fast-charging hub in London.

HOW TO PLAY THE EV CHARGING THEME

Investible opportunities exist across the EV charging value chain. There are listed specialist charger manufacturers and charge point operators. However, it is the Utilities and Oil Majors that dominate, as both operate across most (or all) of the value chain and hold dominant shares of the European public charging market (see Exhibit 183 and Exhibit 184).

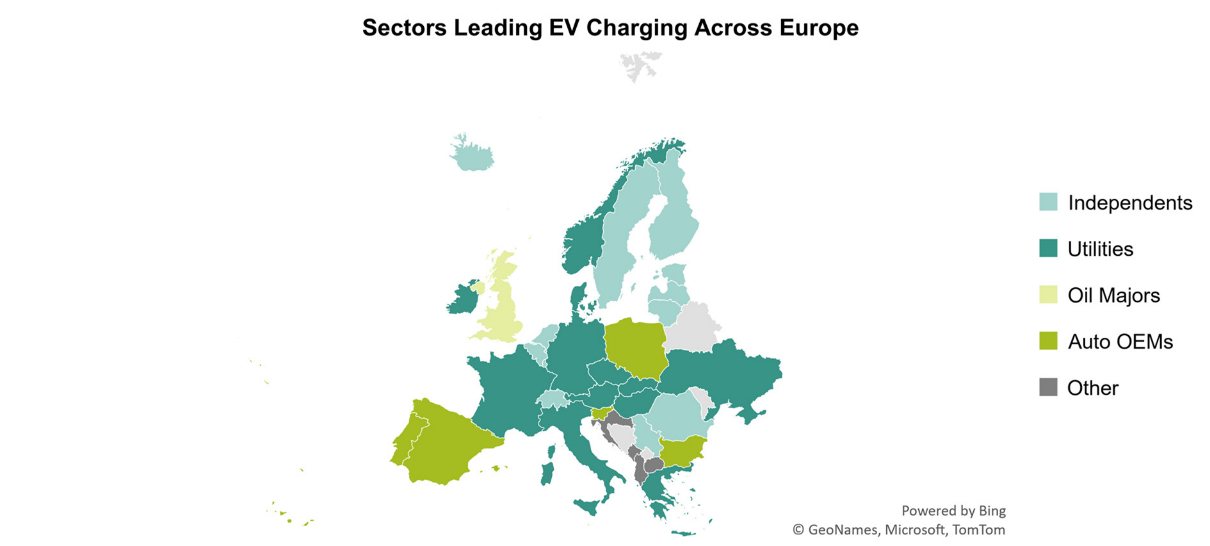
EXHIBIT 183: **Oil Major networks represent 10% of public chargers in Europe, with Shell #4, BP #8, and TOTAL #11**



* Covered by Bernstein

Source: BNEF and Bernstein analysis

EXHIBIT 184: **Utilities have the leading market share in most countries across Europe, with BP #1 in the UK**



Note: Oil Majors is BP in the UK; auto OEMs is Tesla; and other is Deutsche Telekom.

Source: BNEF and Bernstein analysis

BP

With BP Pulse (formerly BP Chargemaster), BP is the leading public charging provider in the UK with over 11,000 charge points and more in China. By 2030, the company aims to install 16,000 chargers in the UK (out of 70,000 globally), selling 30x more energy than its charger network does today. BP Pulse is opening the first EV charging-only hub in the UK later in 2021, with 24 ultrafast charging points.

BP has a partnership with Uber in the UK to charge its rapidly growing EV fleet, and in June opened the first fleet rapid-charging hub (ten 50kW chargers with 12 more being added) in London, which will be accessible to Uber and other fleet customers, with another under construction (see Exhibit 187).

In China, BP will likely grow from the current 1,500 charge points to 35,000 charge points by 2030 (50% of BP's charger network), which is expected to generate earnings the size of its current UK retail business. Also, the company's BP Xiaoju — a JV with Didi — is the leading ride-hailing app in the country, with 550 million users and 1 million EVs.

BP has also launched Aral Pulse, its network of ultrafast 350kW chargers in Germany, which operates 100 charging points at 25 filling stations as of the end of February, 2021 which it expects to increase fivefold by the end of the year (see Exhibit 186). BP also has a partnership with VW to develop an ultrafast charging network in Germany.

BP is also leveraging the Castrol brand, with its new brand Catron ON, to enter the EV lubricants market. This includes transmission fluids that improve lifespan and efficiency (hence range), coolants that enable faster charging, and greases that improve efficiency (see Exhibit 185).

EXHIBIT 185: **Castrol's line of EV products**

Source: BP

EXHIBIT 186: **350kW Aral charger in Germany**

Source: BP

EXHIBIT 187: **BPs EV-only ultrafast charging hub is set to open in the UK later in 2021**

Source: BP

Shell

Shell is aiming for 500,000 charge points by 2025 and 2,500,000 by 2030, and operates four EV charging brands:

- **Shell Recharge** has 108 fast and ultrafast chargers (50kW and 150kW+) in the UK at Shell forecourts and aims for 200 by the end of 2021 and 5,000 by 2025 (see Exhibit 188). Through Shell Recharge, the company is also aiming to convert a central London fuel station into an EV charging hub with ten 175kW charging points in 2021-22 (see Exhibit 190).

- **NewMotion** operates across the EV charging value chain, from installing both home and public chargers to operating its own network of >10,000 charge points (including >270 in the UK), as well as providing customers access to a broader network of 200,000 chargers across 35 European countries including 4,000 in the UK. NewMotion also provides smart charging services as well as fleet, workplace, and carpark charging.

- **Ubitricity** is an on-street charging provider focused on retrofitting existing lampposts and bollards with charging equipment, which Shell announced in early 2021 it would be acquiring (see Exhibit 189). Ubitricity operates almost 3,700 public charging points in the UK, with more in Germany and France, and has installed over 1,500 fleet charging points. Through Ubitricity, Shell is also venturing into V2G technology.

- **Greenlots** is an EV charging technology company, which develops charging network management software, manages charging networks and individual charging stations, and provides turnkey EV charging solutions.

Shell has also introduced a range of EV fluids similar to BP, including Shell E-Transmission Fluid, Shell E-Thermal Fluid, and Shell E-Grease.

EXHIBIT 188: **Shell Recharge network in the UK**

Source: Shell

EXHIBIT 189: **Ubitricity's lamppost chargers**

Source: Ubitricity

EXHIBIT 190: **Shell Recharge's concept EV charging hub in London**

Source: Shell

TotalEnergies

TotalEnergies (TOTAL) installs, maintains, and manages charging points for customers (individuals, businesses, and local governments) as well as operating a network of its own public chargers.

TotalEnergies own operated network consists of 15,000 charge points in France, the Netherlands, and Belgium. It has recently acquired Blue Point London with 1,600 on-street charge points and Charging Solutions with 2,000 (non-public) business charge points in Germany. It has also installed 6,500 local authority-owned public charge points in France.

TotalEnergies is targeting 25,000 charge points operated by 2025 and 70,000 by 2030.

Aside from EV charging, it also has a line of EV fluids.

ENI

ENI has an agreement between its retail business, Eni gas e luce, and Be Charge to install co-branded charging stations in Italy, powered by ENI-supplied energy, with discounts available for Eni gas e luce customers. Be Charge has more than 3,000 charging points (22-300kW) in Italy with more than 35,000 under construction.

Repsol

Repsol currently has 300 public charging points in Spain, 1,000 private chargers, as well as a 50% stake in Ibil, an EV charging technology company. Repsol also has a line of EV fluids including lubricants, coolants, and brake fluids.

Galp

Galp aims to expand its network to 10,000 charging points in Iberia by 2025, from 51 today.

Other ways to play

Aside from the Majors, the utilities represent a key investment opportunity in the EV charging theme, both as network owners/operators but also given the increase in power demand expected as a result of EV charging. There are also investible pureplay charge point operators as well as pureplay charging equipment manufacturers.

EXHIBIT 191: **Exposure to the EV charging theme**

Company	Ticker	Market cap ($M)	Currency	Share Price	Coverage	Target Price	Upside
Oil Majors							
BP	BP/.LN	83,833	GBp	302.40	Clint	540.00	79%
Shell	RDSB.LN	154,830	GBp	1,436.80	Clint	2400.00	67%
TotalEnergies	TTE.FP	117,174	EUR	37.89	Clint	44.00	16%
Utilities							
Enel	ENEL.IM	92,841	EUR	7.80	Becker	-	-
EDF	EDF.FP	40,868	EUR	11.05	Becker	-	-
E.ON	EOAN.GR	34,121	EUR	11.03	Venkateswaran	-	-
Engie	ENGI.FP	34,135	EUR	11.97	Becker	-	-
Charging Equipment/Technology							
Nuvve	NVVE.US	193	USD	10.37	N/C	N/A	N/A
Zaptec	ZAP.NO	358	NOK	42.30	N/C	N/A	N/A
Signet EV	260870.KS	299	KRW	63,000.00	N/C	N/A	N/A
Electreon Wireless	ELWS.IT	493	ILs	16,400.00	N/C	N/A	N/A
Compleo	C0M.GY	433	EUR	94.80	N/C	N/A	N/A
Charge Point Operators							
Fastned	FAST.NA	1,176	EUR	59.40	N/C	N/A	N/A
ChargePoint	CHPT.US	6,669	USD	21.77	N/C	N/A	N/A
Evgo	EVGO.US	2,394	USD	9.05	N/C	N/A	N/A
Blink	BLNK.US	1,285	USD	30.48	N/C	N/A	N/A

Note: Data as of August 16, 2021

Source: Bloomberg and Bernstein analysis

INVESTMENT IMPLICATIONS

Out of 1 million global retail fuel stations, European Oil Majors account for a 9% market share but hold the best locations after multi-decade nodal optimization. In many countries, two-thirds to four-fifths of miles travelled are on the busier multi-lane roads and motor/freeways, where you find these retail assets. Co-locating EV fast chargers with fuel pumps at such sites offers new revenue streams, while driving greater footfall through their high-margin convenience stores. The latter 15-20% ROCE businesses are already mispriced inside the Integrateds, leaving successful EV customer capture as pure upside. Our analysis today sizes just the public charging opportunity and we put that as a ~US$50bn EBITDA accretive prize by 2040. Marketing already constitutes 14-17% of earnings for our top picks — BP, Shell, and Repsol — and long-term earnings will be boosted by EV fast charging sales. Fleet charging and at-home charging will follow through as well, together with EV lubricant sales. Combined, serving the EV revolution is a growth market the fast-pivoting European Oil Majors will dominate in our view.

INDIA ELECTRIC VEHICLES: POWERING THE ELECTRIC REVOLUTION THROUGH POLICY PUSH

OVERVIEW

The Indian government is pushing for the commencement of an EV revolution. Hence, apart from the efforts to stimulate demand, it is also formulating policies to help develop a local manufacturing ecosystem. In this chapter, we discuss the likely scale-up of EV battery manufacturing and reassess the broader impact of an EV scale-up on imports.

Background: To promote manufacturing, a Production-Linked Incentive (PLI) scheme was announced by the government, covering various sectors. For advanced cell chemistry (ACC), US$2.4bn of incentives have been allocated for five years. The scheme approved in May 2021 targets to set up local battery manufacturing capacity of 50GWh per year, with 25/60% domestic value addition by years two and five, respectively. Each selected manufacturer for ACC battery storage must commit to a minimum of 5GWh per year plant and incur mandatory investment of INR2.25bn/GWh.

Key insights into the likely impact on the EV industry:

- We expect domestic ACC battery production to start in CY2024 and get fully commissioned by CY2027. We estimate for manufacturers, the scheme would imply a benefit of ~18% on revenues on a base case.

- Of the several applications of ACC batteries, the primary use case is for EVs. At 3kWh battery capacity per electric 2W (or 30kWh for cars), the target battery manufacturing capacity is sufficient to power 16.7 million 2Ws or 1.7 million electric PVs per year, which is broadly in line with current annual domestic demand for these end markets.

- While battery manufacturers may be concerned about the demand scale-up to fully utilize the incentives, we see that as less of a challenge. Our base case EV adoption scenario assumes a gradual increase in EV sales mix across auto end markets over the next decade, with 60% and 25% of domestic 2W and PV sales, respectively, by 2030. Accordingly, we estimate annual EV sales to be 20 million by 2030, with EV stock of 70 million across all auto end markets. The implied battery demand to service this market would be 64GWh per year by 2027 and 144GWh per year by 2030, suggesting offtake may be less of a challenge for PLI-backed battery manufacturing capacity.

- In terms of the impact on India, we note the localization of battery manufacturing should help drive a net saving of US$2.6bn p.a. of imports (reduction in crude imports, offset by increase in imports of battery/components) from CY2030, even if we assume all the raw materials (metals) are imported. On a cumulative basis, we expect net saving of US$7bn on imports over CY2024-CY2030.

In summary, we believe we are nearing the commencement of a phase of rapid acceleration in EV volumes, with new entrants and launches from incumbents likely accelerating. Demand-side incentives as well as disincentives for ICE business models (emissions regulation, etc.) along with creation of a local component ecosystem, especially for batteries, will help tilt the annual sale mix toward EVs by the end this decade. Along with this, we see opportunities for investments becoming more visible to public markets.

DRIVING EV ADOPTION

EV adoption in India is still in early stages, with less than 1% of vehicles being BEVs. There are several reasons for the low EV buildout in India, including the lack of serious players in the market and no local EV cell capacities. As always, India did not plan in advance and is only now reacting slowly to the need for pushing an EV ecosystem. While taxes on EVs have been reduced and there are some limited incentive schemes in place, there is now a push to develop a local EV cell manufacturing capacity in India. There are incentives under the newly launched PLI scheme, the details of which were released recently. We present a perspective on the impact of this scheme on the EV industry.

PLI SCHEME FOR ACC BATTERY

In November 2020, the government of India announced an additional budget of US$20bn for a PLI scheme, spread across 10 sectors to boost local manufacturing. The automobile sector was a key beneficiary, with aggregate allocation of ~US$10bn, including US$2.4bn for ACC battery storage system (Lithium-ion (Li-ion) cells and other related technologies). Over the past few months, the government has been gradually approving the PLI scheme as per the approved allocation announced in 2020. The PLI scheme for ACC battery storage was notified earlier in May 2021. In the following sections, we present our views on the likely impact of this policy on the Indian automobile sector and EV adoption.

Key highlights of the PLI scheme for ACC battery storage

The PLI Scheme of INR181bn (US$2.4bn) for ACC battery storage targets to achieve domestic manufacturing capacity of 50GWh per year of regular ACC battery plant (likely those based on LiB cells) and 5GWh of niche ACC facility (new technology). This scheme is expected to benefit multiple sectors, given new/existing use cases of ACC batteries in EVs, consumer electronics, advanced electricity grids, solar rooftops, etc.

The said manufacturing facility of 55GWh needs to be commissioned within two years once the government selects companies for ACC battery manufacturing through competitive bidding. The target incentive (US$2.4bn) would then be offered for the following five years, subject to meeting the below conditions:

- Each selected manufacturer for ACC battery storage must commit to a minimum of 5GWh plant and incur mandatory investment of INR2.25bn/GWh.

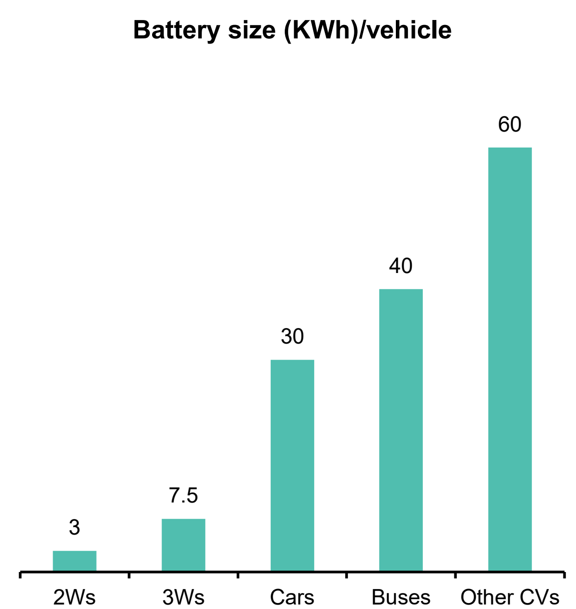
- To boost local manufacturing versus direct cell imports by battery assemblers, the minimum limit for domestic value addition is set at 25/60% by the end of the second and fifth years, respectively.

The government estimates this scheme could promote direct investments of around INR450bn in ACC battery storage manufacturing projects over the next two to seven years.

VOLUMES PLI-BASED CAPACITY CAN SUPPORT

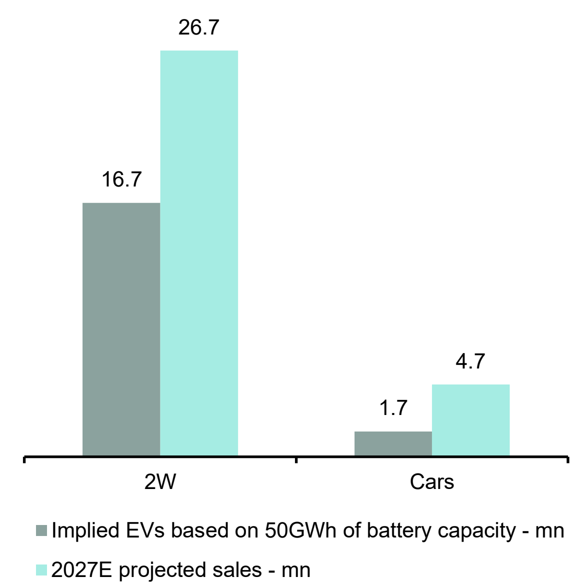
While ACC batteries could have multiple applications, the majority of the demand in India is estimated to emerge from EV sales. Assuming a battery capacity of 3.0kWh per electric 2W, battery manufacturing capacity of 50GWh is sufficient to power 16.7 million 2Ws annually in India (if the entire capacity is diverted to this end market). In terms of 2027 estimated total domestic 2W sales of 26.7 million, 50GWh of battery manufacturing capacity can power 60% of the 2W market opportunity. Similar analysis on battery demand from electric cars gives equivalent figures of 1.7 million electric cars, which is 35% of new vehicle sales in 2027E (see Exhibit 192 and Exhibit 193). As such, the target battery manufacturing capacity appears sufficient, as adding more capacity will be easier once it gets rolling.

EXHIBIT 192: **Battery size per vehicle based on end use**



Source: Society of Indian Automobile Manufacturers (SIAM) and Bernstein analysis

EXHIBIT 193: **Implied EVs fulfilled by 50GWh battery capacity versus 2027E sales**

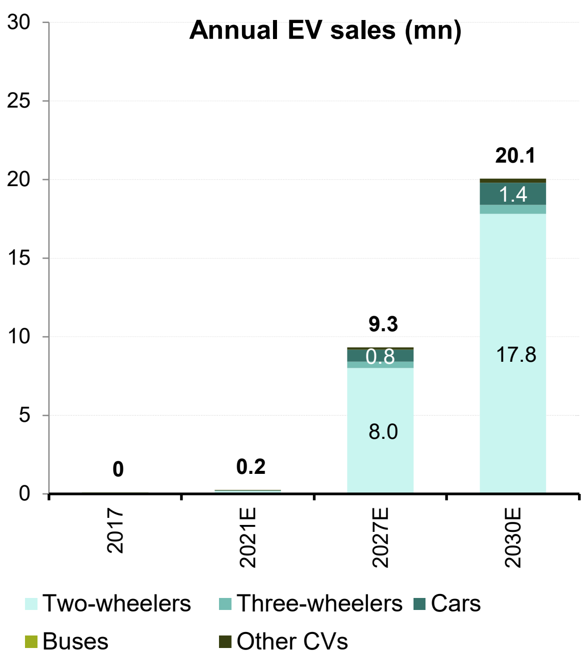


Source: SIAM, and Bernstein estimates and analysis

ACC battery demand from automobile sector — over 70 million automobile stock to be EVs by 2030

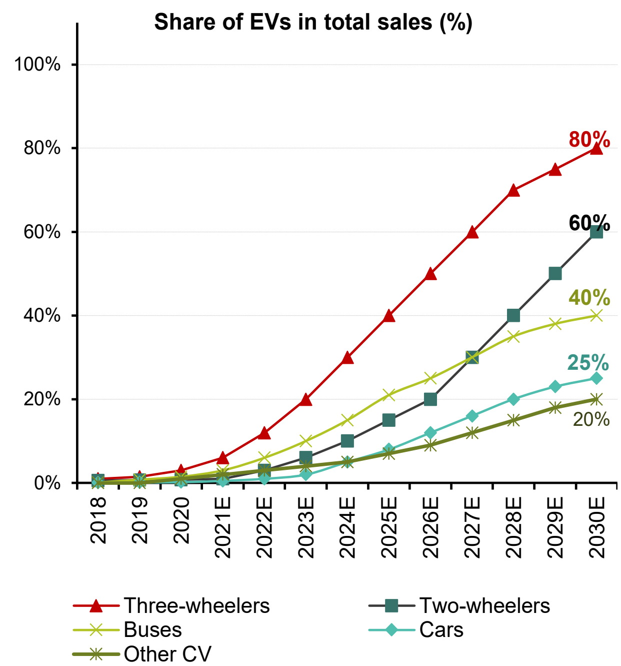
To estimate the overall ACC battery capacity required to fulfill domestic demand from the automobile sector, we look at our long-term forecast of EV sales in India (across end markets) and map it with per vehicle average battery pack. In our base case scenario, we assume 60% of all 2Ws and 25% of all cars sold in 2030 (FY2031) will be EVs (BEV + PHEV) (see Exhibit 195). For three-wheelers (3Ws) and buses, it is 80% and 40%, respectively, while 20% of all other CV sales is expected to be EVs by 2030E. Based on our assumptions, we estimate around 9.3 million annual automotive vehicle sales in 2027E to be electric (using ACC battery), which would increase to ~20 million by 2030E (see Exhibit 194).

EXHIBIT 194: **We expect annual EV sales (based on ACC) in India to expand to 9.3 million units by 2027**



Source: Society of Manufacturers of Electric Vehicles (SMEV), and Bernstein estimates and analysis

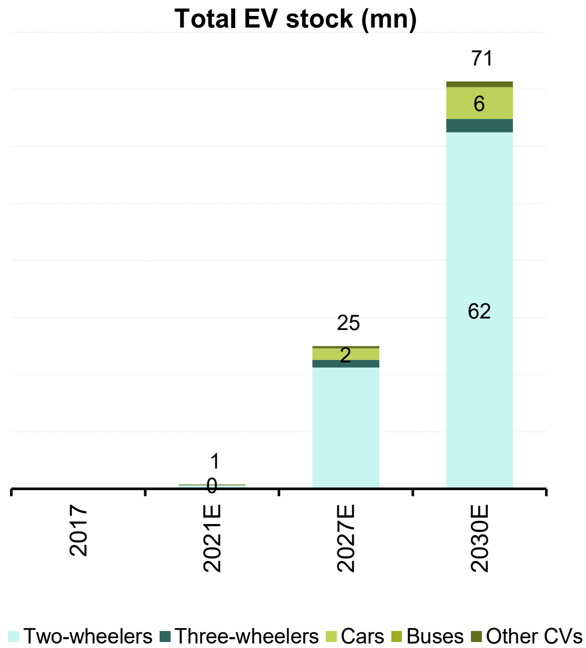
EXHIBIT 195: **EV penetration in India to increase to 60% of annual sales for 2W and 25% for cars by FY2031**



Source: SMEV, and Bernstein estimates and analysis

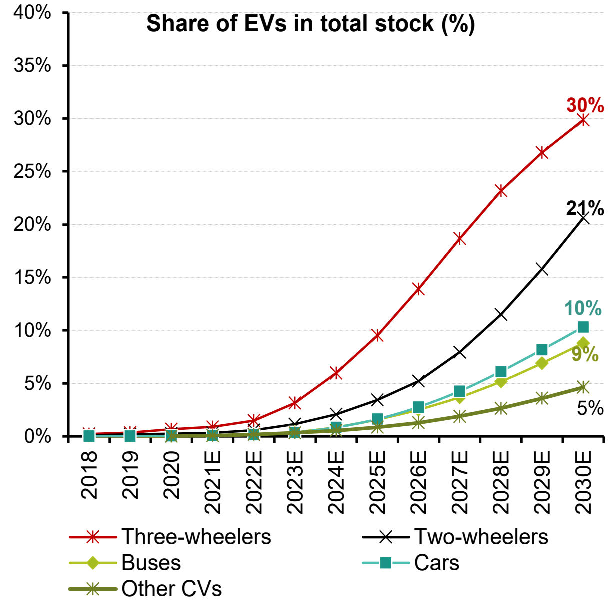
The overall EV stock in the country is expected to increase to 25 million vehicles in 2027 and to 70 million by 2030, from less than 1 million EVs as of 2020. Part of ACC battery demand will also likely come from battery replacement of these vehicles every few years. The 3W segment is estimated to have the highest share of EV stock at 30%, followed by 21% for 2W and 10% for cars by 2030 (see Exhibit 196 and Exhibit 197).

EXHIBIT 196: **EV stock in India to increase to 70 million by 2030**



Source: SMEV, and Bernstein estimates and analysis

EXHIBIT 197: **21% of 2W stock and 10% of car stock in India to be EVs in 2030**



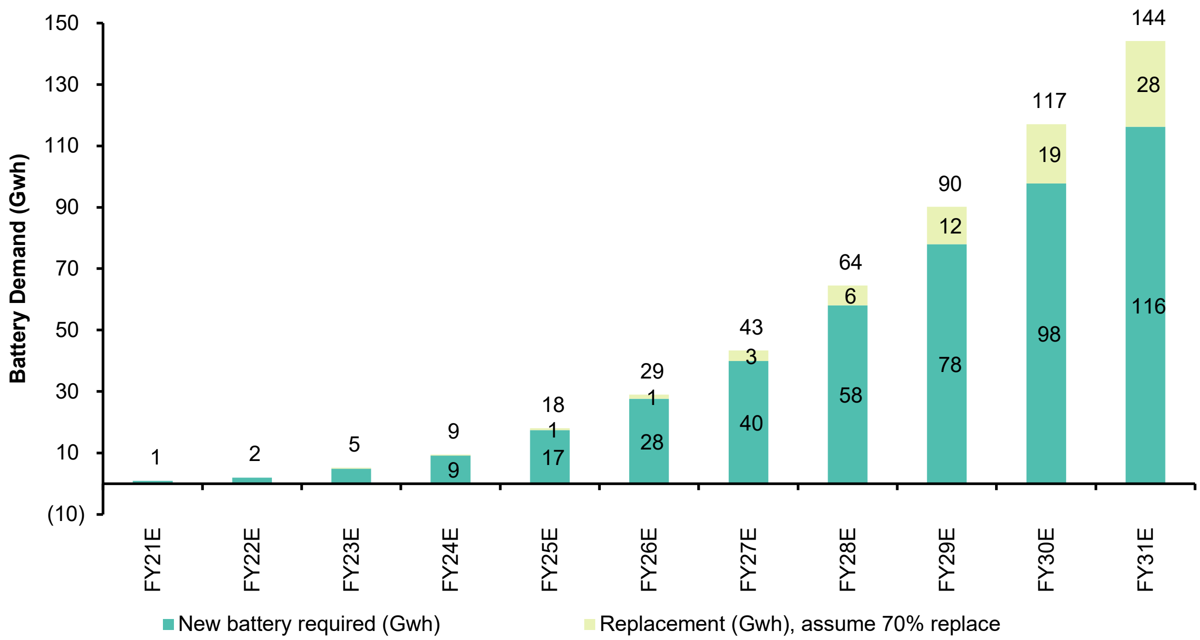
Source: SMEV, and Bernstein estimates and analysis

We estimate battery demand from automobile stock to be 55GWh by 2027

Based on our assumption for EV adoption and four-year battery replacement cycle, our estimates point to a battery requirement of 64GWh battery capacity by 2027 (FY2028), which includes 58GWh from new demand and 6GWh from replacement demand (see Exhibit 198).

The planned capacity for domestic ACC battery manufacturing is broadly in line with our estimate of battery demand from the automobile sector. In India, the bulk of the demand for batteries will likely emerge from 2Ws, with 50% contribution in new vehicle sales by 2030.

EXHIBIT 198: **India EV ACC battery demand estimates — new versus replacement**



Source: Bernstein estimates and analysis

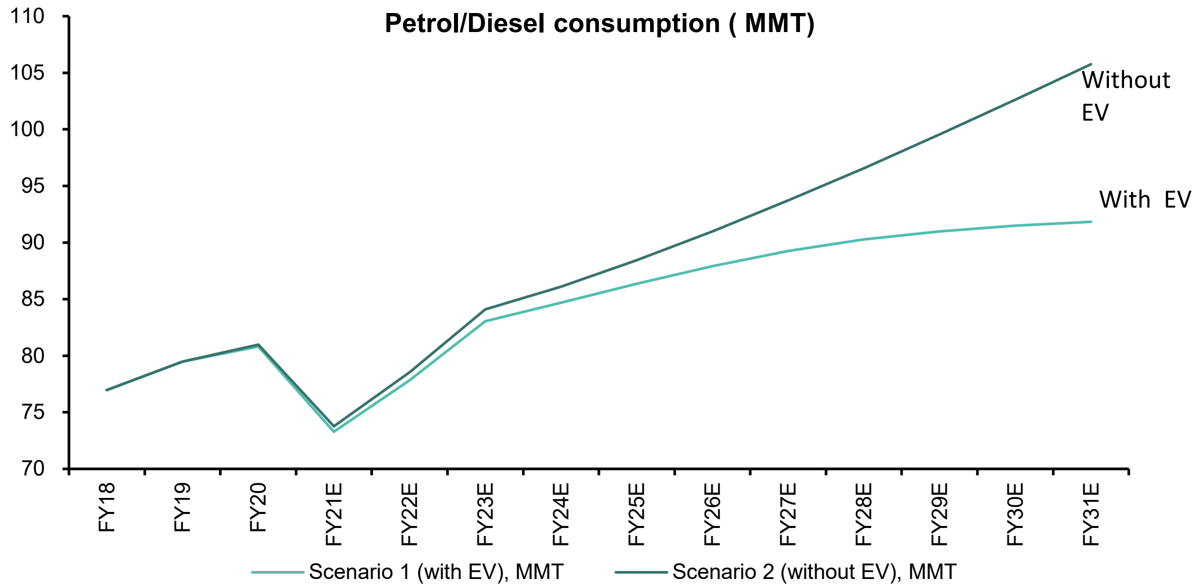
IMPACT ON IMPORTS

One of the common discussion points on EV has been the net impact on imports — savings in fuel bills versus import of battery cells. Once local manufacturing of battery cells commences, the equation would shift toward net saving in imports (inclusive of battery cells). We expect the PLI scheme to help start local cell manufacturing from CY2024 onward.

We estimate US$7bn saving in fuel import bill in 2030, cumulative benefit of US$24bn over CY2024-CY2030E

In our base case assumption for EV adoption, we estimate oil consumption by the transport sector to increase only marginally to 90MMT by CY2030E from the current 80MMT p.a. requirement, ensuring saving on fuel imports. In the absence of EVs, oil consumption would increase to 106MMT by 2030 (see Exhibit 199).

EXHIBIT 199: **Saving in petrol/diesel consumption owing to increase in sales of EVs**



Note: FY2021 consumption assumes lower demand because of Covid-19.

Source: Petroleum Planning & Analysis Cell (PPAC), and Bernstein estimates and analysis

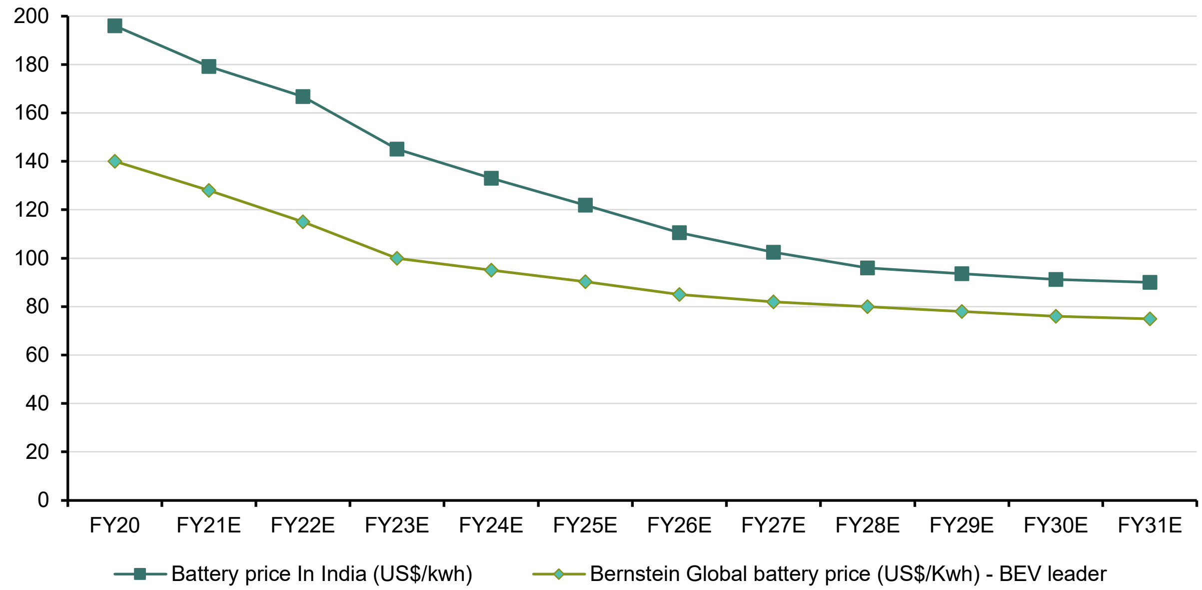
The potential saving from EV adoption could help cut down the fuel import bill by US$3-US$7bn p.a. by CY2027 and CY2030, respectively. The calculation is done assuming crude price at US$70/barrel.

Offsetting impact from import of battery cells and other raw materials

Part of this saving, however, would be offset by the import of raw material for ACC battery cell manufacturing in India, given limited reserves in the country. In addition, some vendors may continue to import battery packs/cells, as battery manufacturing capacity ramp may continue to lag demand growth. To get a perspective on this, we look at the landed battery price in India and other considerations in the following sections.

The domestic battery price in India is expected to remain at a premium versus global prices because of import transportation expense, taxes (10% custom duty on imports), and lower operating leverage for domestic manufacturing. The current battery price is ~US$180/kWh, compared to the global price of leading manufacturers at ~US$130/kWh. This implies a premium of 40%, which is expected to gradually reduce to 20% from FY2028 onward (see Exhibit 200).

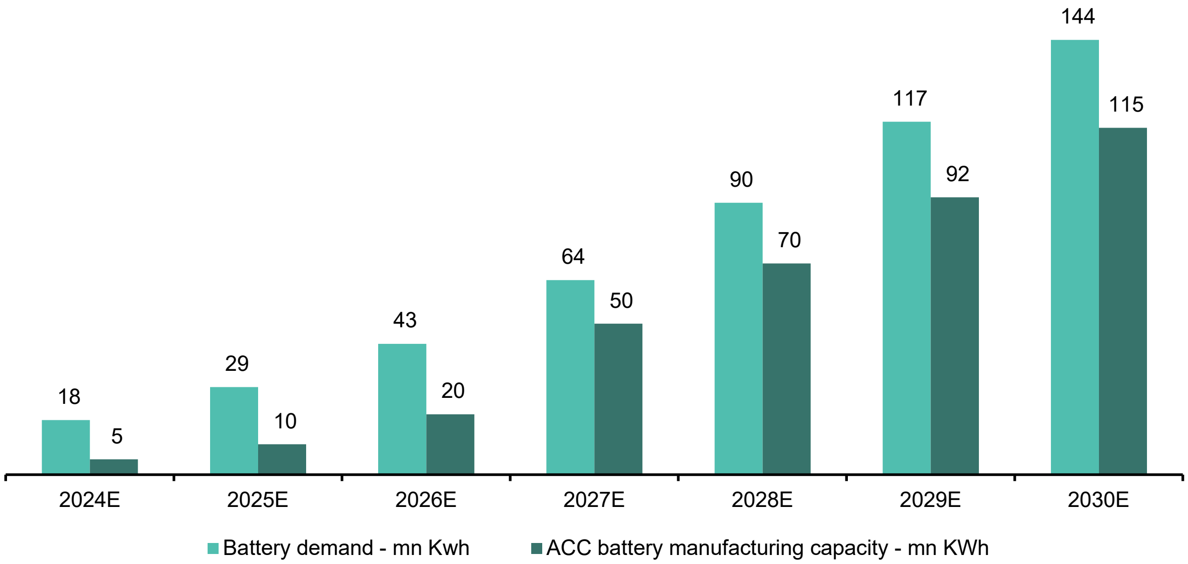
EXHIBIT 200: **Battery price projection**



Source: Industry data, and Bernstein estimates and analysis

While the PLI scheme should help ramp up domestic cell manufacturing, we expect some gap with demand to remain (see Exhibit 201). This would be fulfilled through direct import of battery cells, which would then be locally assembled. Normally, cells account for ~70% of the cost of a final battery pack, while the rest is related to value addition from assembling (including BMS). As such, we estimate total import value of around US$235mn toward cell imports in 2021, which would expand to US$1.8bn by 2030.

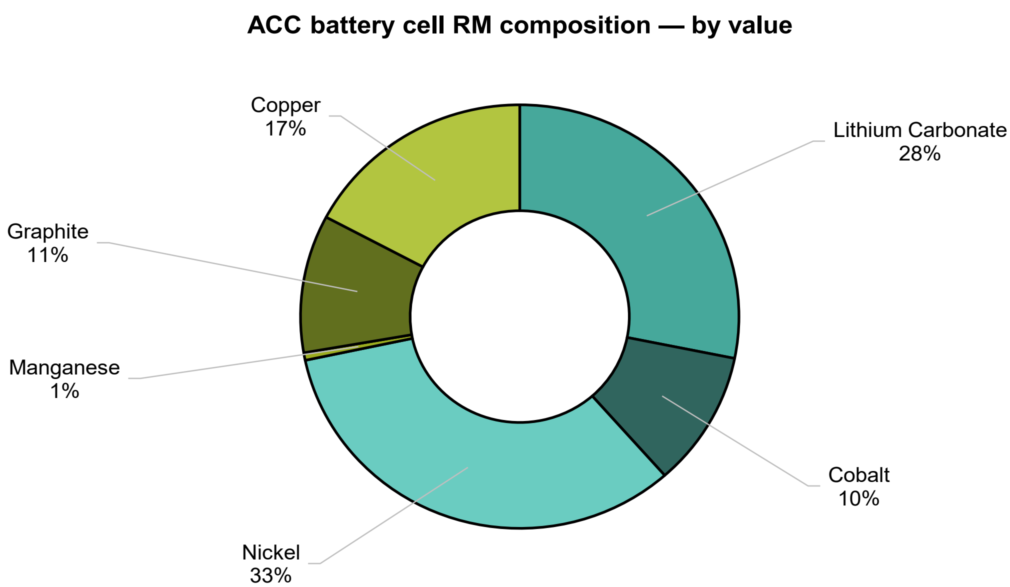
EXHIBIT 201: **Domestic battery manufacturing capacity is likely to lag EV demand over the next decade**



Source: Government of India, and Bernstein estimates and analysis

Further, there are limited known reserves for ACC battery raw material in India. In the worst case, we assume 100% of raw material required for cell manufacturing is imported. At current metal cost of ~US$30/kWh for LiB, ~80% of the cost is related to procurement of lithium, nickel, and copper (see Exhibit 202). Given elevated commodity prices now, we expect the raw material cost to gradually come down to US$22/kWh by 2030.

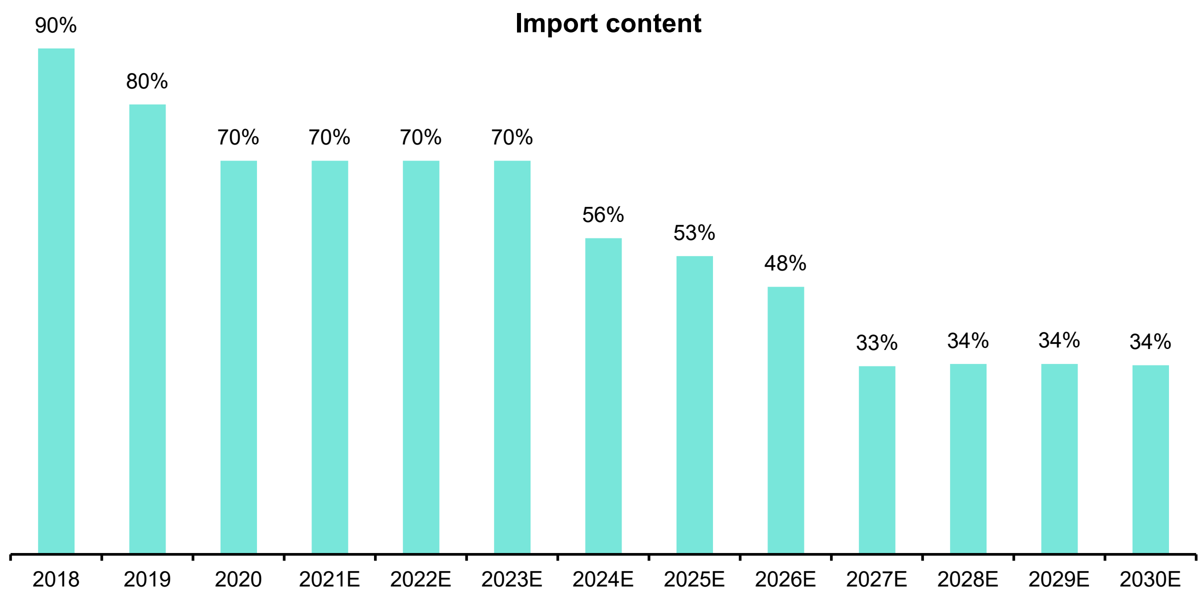
EXHIBIT 202: **Lithium, nickel, and copper are the key metals, together accounting for ~80% of cost of metals used**



Source: Bernstein analysis

We expect domestic cell manufacturing to start production only from 2024. Till then, EV battery cells will likely continue to be imported for assembling battery packs locally. As such, the share of imports (including cell as well as raw material cost) is expected to remain at 70% until 2023 and gradually decline to 34% by 2030 (see Exhibit 203).

EXHIBIT 203: **Mix of imports in overall battery costs in India, assuming indigenization push, led by PLI**

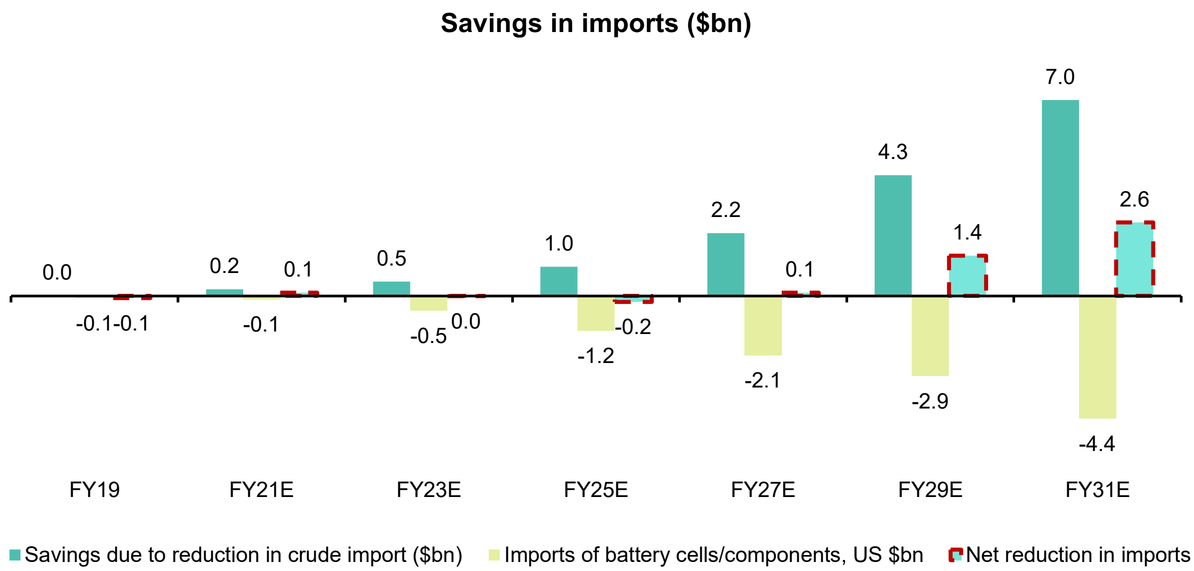


Source: SMEV, and Bernstein estimates and analysis

Net saving in import bill of US$7bn over CY2024-CY2030

Adjusting for these two impacts on net imports in our base scenario of EV adoption, we expect a saving of US$2.6bn in import bills in CY2030. On a cumulative basis, we estimate net savings of US$6.8bn over CY2024-CY2030 (see Exhibit 204).

EXHIBIT 204: **India: Reduction in imports due to EV adoption**



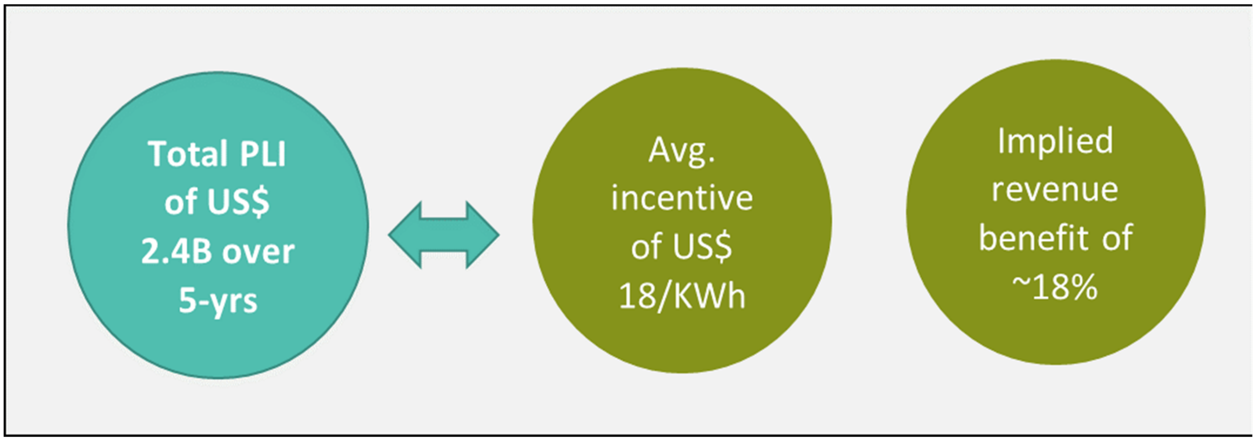
Source: SMEV, and Bernstein estimates and analysis

QUANTIFYING BENEFIT OF PLI SCHEME FOR MANUFACTURERS

The government is yet to announce the mechanism of incentive sharing with manufacturers. While one way could be to link it with actual production volume, there could be several other possibilities: (1) revenue-based incentive, (2) higher incentive per unit production in initial years, which gradually reduce over time, or (3) fixed incentive every year for five years, based on target final capacity. In our view, this would be linked to estimated domestic production over the five-year period starting from CY2024 and a fixed incentive value per unit production over five years.

As per our estimate for domestic production capacity ramp, a total of 135GWh of ACC battery is expected to be locally produced over CY2024-CY2028E. This implies an average incentive of US$17.8/kWh. This, in our view, is a good amount to compensate for any potential loss from lower plant profitability in initial years. As a percentage of revenue, the PLI incentive is estimated to be ~18% of cumulative revenue of all manufacturers over CY2024-CY2028E (see Exhibit 205).

EXHIBIT 205: **Impact of PLI on battery manufacturers**



Source: Government of India, and Bernstein estimates and analysis

The actual production volume for ACC battery storage and average realization may be different from our estimate. We have done a sensitivity analysis to assess the revenue impact of the PLI scheme under different scenarios (see Exhibit 206).

EXHIBIT 206: **Sensitivity of revenue contribution from PLI versus production volume and average realization**

PLI as % of revenue		Cumulative production (GWh) over CY24-28				
		120	130	135	140	150
Average Realisation (US$ per KWh)	90	22%	21%	20%	19%	18%
	100	20%	18%	18%	17%	16%
	110	18%	17%	16%	16%	15%
	120	17%	15%	15%	14%	13%
	130	15%	14%	14%	13%	12%
	140	14%	13%	13%	12%	11%

Source: Government of India, and Bernstein estimates (all data) and analysis

Risk of weak domestic demand remains a challenge, but likely manageable

Our base case domestic EV battery demand assumes a certain level of EV penetration, which may not materialize if other controlling factors such as product availability, charging infrastructure, and cost convergence are not favorable. For manufacturers putting up ACC battery capacity, this could be a key concern. We believe there will be some form of forward contract with OEMs to get a comfort on certain offtake, or OEMs themselves taking a lead to invest in this area. Global OEMs with supplies in other markets might be better placed as part of the ACC battery production could be diverted for the export market. Further, the benefit from PLI is good enough to compensate for any potential loss because of higher manufacturing costs in India versus global leaders. In summary, we believe the PLI scheme is a good step toward indigenization of ACC battery manufacturing for the EV transition.

DRIVING BUILD-UP OF PUBLIC CHARGING NETWORK

There is no official data on the progress of a charging network in the country, given disintegrated and subscale efforts from multiple players across different cities (see Exhibit 207). Management commentary of key players, however, suggests there is a network of around 1,000 public charging stations in India. As this is spread across India, the density of charging stations is not sufficient to have a reliable charging network. In comparison, China had ~500,000 public charging stations as of December 2019, which probably justifies ~5% of PV sales in the country being BEVs (including PHEVs).

EXHIBIT 207: **Limited EV charging network in India**

Company	Public charging station installed	Expansion plan
EESL - JV of PSUs	~207 stations across India	500 stations in FY21
Tata Power	170 stations across India	Target of 700 by FY21
Rajasthan Electronics	NA	Contracted Okaya Power to supply, install and commission 4,244 stations
Power Grid Corporation	~15 stations	NA
NTPC	~100 stations	NA
Ather Energy	53 2W charging station in Bengaluru and Chennai	Target of 500/6500 by CY21 and CY24 respectively
PlugNgo	3 fast charging station in Delhi	NA
Magento Power	NA	10K stations for electric 2W in Maharashtra

Source: State governments and Bernstein analysis

Most current operators of EV charging stations in India have independent mobile applications to unlock, charge, and digitally pay at their respective stations. We visited one such charging station of EESL in Delhi in 2020. While the process is simple, most users would need to be trained once to get used to accessing the public charging station.

In the long run, we believe a single mobile application to locate and access charging stations of different service providers will be beneficial for consumers. A few aggregators have already started work in this direction and are expected to gradually onboard different charging operators on their platforms (see Exhibit 208 and Exhibit 209).

EXHIBIT 208: **Charging station by EESL in Delhi...**

Source: Bernstein photo

EXHIBIT 209: **...which can be used through QR code**

Source: Bernstein photo

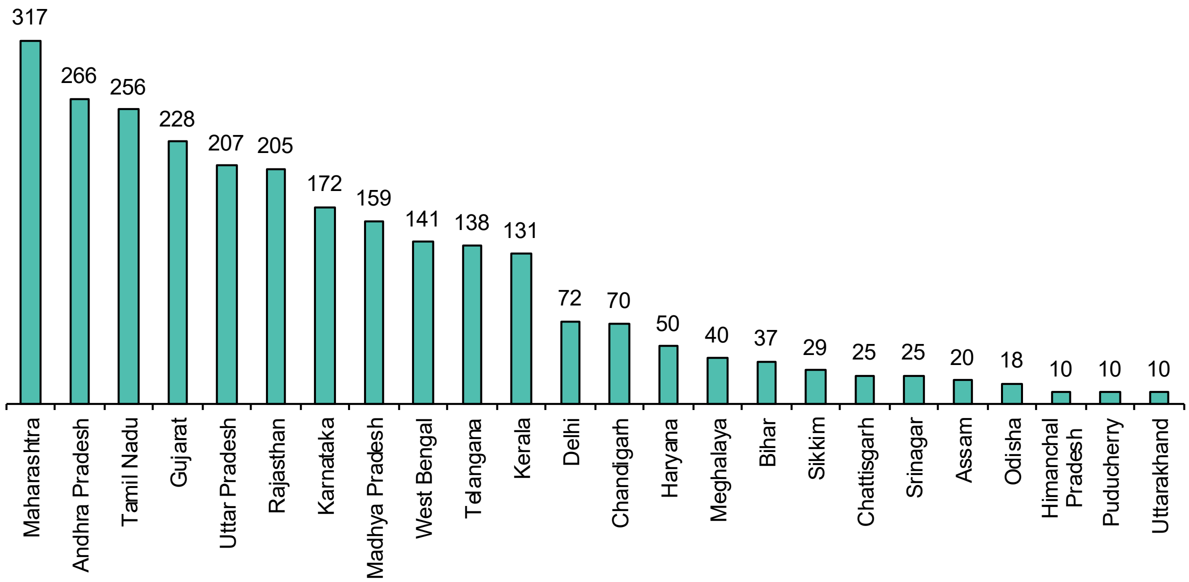
POLICY FRAMEWORK FOR EV CHARGING INFRASTRUCTURE

To help create an EV charging infrastructure in India, government policies have been supportive both in the form of financial assistance and favorable tax rates for equipment manufacturers.

Capital subsidy under the central FAME scheme

The Faster Adoption and Manufacturing of Hybrid and EV (FAME) scheme, which is currently in the second phase, has been allotted INR10bn (~US$135mn) for charging infrastructure over a three-year period, starting April 2019. The scheme provides affordable funding and capital subsidy (up to 70%) for setting up charging stations for orders allotted by the Department of Heavy Industries (DHI). In January 2020, the department sanctioned 2,636 EV charging stations in 62 cities (one station per 4km*4km grid) across 24 states/union territories (UTs) (see Exhibit 210). Also, DHI issued a proposal (in October 2020) to build another 1,500+ charging stations on major highways across the country.

EXHIBIT 210: **Government sanctioned 2,636 charging stations to be built in 62 cities across 24 states/UT under the FAME II scheme**



Source: DHI and Bernstein analysis

Most state EV policies include separate incentives for creating charging infrastructure

Most Indian states have notified or issued a draft EV policy to promote EV adoption and support buildout of the EV ecosystem. In addition to offering cash subsidy for purchase of EVs, these states offer capital subsidy and other incentives for building charging infrastructure in their states. From our analysis, we note there are 12 such states with a draft/approved EV policy, and the cash subsidy for charging stations is normally around 25% of the cost for the first few hundred stations in the state. While not many states have announced a timeline, the policy wording of a few suggests there would be at least one charging station in a radius of 3km (see Exhibit 211).

EXHIBIT 211: **Highlights of state EV policy to promote building EV charging infrastructure**

States	Incentive for charging Infrastructure	Targets	Policy status
Andhra Pradesh	25% capital subsidy for first few stations	100K charging station by 2024	Approved
Bihar	25% capital subsidy for first 250 stations	Fast charging at interval of 50km on highways	Draft
Delhi	Capital subsidy for cost of chargers and installation expenses to selected operators	Public charging g facility within 3km from any place in Delhi	Approved
Karnataka	25% capital subsidy for first few charging and swapping stations	NA	Approved
Kerala	25% capital subsidy for first few charging and swapping stations	One station per 3km*3km grid	Approved
Madhya Pradesh	25% capital subsidy on charging equipment/machinery	NA	Approved
Maharashtra	25% capital subsidy for first 250 stations	NA	Approved
Punjab	Upto 50% capital subsidy for first 1000station	NA	Draft
Tamil Nadu	NA	One station per 3km*3km grid in major cities	Draft
Telangana	Favourable power tariff	Charging/swapping station every 50km within state	Approved
Uttar Pradesh	25% capital subsidy for first 100 stations	200K fast charging station by 2024	Approved
Uttarakhand	NA	NA	Approved

Source: State governments and Bernstein analysis

Delicensing public charging stations encourages private participation

In December 2018, a policy for charging infrastructure was released, which delicensed the setting up of public charging infrastructure and allowed the setting up of private charging infrastructure. The policy also highlighted the charging infrastructure standards — fast charging is based on international standards, while slow/moderate charging needs to follow Bharat EV charger specifications (see Exhibit 212).

The key highlights of the policy notification (with amendments issued in October 2019) are:

- **Delicensing public charging stations:** Setting up of charging stations has been announced as a delicensed business activity (provided it meets technical standards prescribed by the government). Power distribution companies (discoms) are supposed to give priority to connection requests from any person seeking to set up a public charging station. This will lead to fast ramp-up of the charging infrastructure in the country.

- **Timeline and coverage:** The policy will first be rolled out in megacities (with 4 million+ population), i.e., Mumbai, Delhi, Bengaluru, Hyderabad, Ahmedabad, Chennai, Kolkata, Surat, and Pune. The timeline for the first phase is three years. In the second phase (third to fifth year), other big cities and state capitals will be covered.

- **Location of charging stations:** In all megacities/large cities, there will be at least one charging station in a 3*3km grid and one station every 25km on both sides of the highway for short-range EVs. For long-range EVs, there will be a fast charging station at every 100km on both sides of highways, along with separate stations at bus depots, transport hubs, etc. Priority will be given to existing retail outlets of oil marketing companies (OMCs) for setting up the charging stations. The recent orders sanctioned for charging stations by DHI broadly follow this framework.

EXHIBIT 212: **Standards for setting up public charging stations**

Charger Type	Charger Connecters	Min. wattage	Rated Output Voltage (V)	No. of Connector guns	Vehicle category
Fast	Combined Charging System	50 kW	200-750 or higher	1 CG	4W
	CHArge de Move (CHAdeMO)	50 kW	200-500 or higher	1 CG	4W
	Type-2 AC	22 kW	380-415	1 CG	4W, 3W, 2W
Slow/Moderate	Bharat DC-001	15 kW	48	1 CG	4W, 3W, 2W
	Bharat DC-001	15 kW	> 72	1 CG	4W
	Bharat AC-001	10 kW	230	3 CG of 3.3 kW each	4W, 3W, 2W

Source: Ministry of Power and Bernstein analysis

- **Power tariff for charging infrastructure:** Power tariffs for charging stations are to be fixed by the appropriate commission in accordance with the Tariff Policy. Service charges for providing a charging facility would be subject to a certain ceiling if the station was set up using any form of government incentive.

- **Minimum requirements:** (1) An exclusive transformer for the charging station, (2) stations to facilitate charging for vehicles in any combination of one or more charger as per specified configuration, and (3) tie up with a network service provider to facilitate online booking of charging slots by EV owners. No minimum requirement for stations meant for captive use/by companies.

- **Implementation of policy:** State discoms will be the main agents for implementation of the policy. They will finalize the cities and highways to be taken up and eventually award the order (through DHI) for installation and O&M of these stations.

Delinking battery from EV to create opportunity in battery swapping

One of the major challenges for EV adoption has been the slightly higher upfront cost, which is especially true for price-sensitive consumers in the 2W/3W segment. In order to address this concern, the government issued a notification in August 2020 to allow sale of electric 2Ws/3Ws without a battery. Charged batteries could be separately rented at a nominal recurring monthly charge, which is in some way similar to fuel expenses incurred by ICE vehicle owners.

The broad intent of this policy is to ensure price parity of EVs with existing comparable ICE vehicles and encourage consumers to switch to EVs. Different models for battery rental programs are being worked out, with the ultimate objective of ensuring the operating cost of EVs is lower than that of conventional ICE vehicles. We believe this would create new opportunities in battery swapping stations once the battery pack is standardized across OEMs. Sun Mobility and a few other start-ups are currently working to build business around "Energy as-a-Service," which includes the owning and leasing of a battery, providing charging service through a network of battery swap stations, etc. The Taiwanese company Gogoro has been successful in deploying a swapping-based business model.

INVESTMENT IMPLICATIONS

We believe policy push and increasing affordability will lead to a sharp increase in EV demand in India. Local manufacturing of battery cells in India will be an additional benefit, assuming the PLI scheme garners sufficient demand from battery cell manufacturers. While we believe there will be sufficient demand by the time these capacities are rolled out, we believe OEM collaborations for offtake may be required to justify capacity addition. We remain positive on the prospects of EV adoption over the next decade. Our current picks are, however, not based on potential winners in the EV regime, but will eventually be the case in a few years. For now, Maruti, Mahindra, and Bajaj Auto are the key Outperform ideas.

AUTOMATION AND ESG: CHINA'S CARBON NEUTRALITY ON ROBOTICS, SERVO MOTION, LASER, AND VISION

OVERVIEW

- Climate change, an important ESG theme, will have a material and positive impact on automation demand in the coming decade. In 2020, China promised to hit a CO2 emission peak by 2030 and achieve carbon neutrality by 2060. Almost immediately, the power and transportation industries acted by sharply increasing investment in renewables and EVs. In this chapter, we go through the detailed production processes and automation needs for EV battery and solar panel production and, based on that, we quantify the impact on key automation technologies — robotics, laser, vision, and servo motion — and automation players in China.

- By our estimate, the demand for these products from the renewables and EV industries will increase at a 19-22% CAGR over 2020-25, and account for 9-16% of the respective industry total in 2025 (see Exhibit 214 and Exhibit 215). Among the automation players, Estun is a top beneficiary of increased investment in battery and solar panel production. In our earnings model (the base case), the two verticals will contribute 24% of the company's robot shipment and 12% of total revenue in 2025. In an optimistic scenario in which Estun's market share in the two verticals increases faster, there could be an additional RMB900mn contribution, raising our 2025 top-line forecast by a further 12% (see Exhibit 213).

- Inovance's servo business will also likely see a strong uplift, with the battery industry continuing to drive robust growth and accounting for 18-20% of its servo segment revenue in 2025 (see Exhibit 248 and Exhibit 249). Furthermore, our analysis shows that in laser (see Exhibit 250) and vision (see Exhibit 251), battery and solar opportunities will be substantial for Chinese players such as Hikrobot (a subsidiary of Hikvision) and OPT (not covered), and the China business of IPG, Cognex, and Keyence. Hikrobot will likely additionally benefit from incremental AGV demand, for which the opportunity from battery and solar in 2025 is about 3.4x Hikrobot's AGV shipment in 2020 (see Exhibit 252).

CARBON NEUTRALITY TO DRIVE AUTOMATION DEMAND

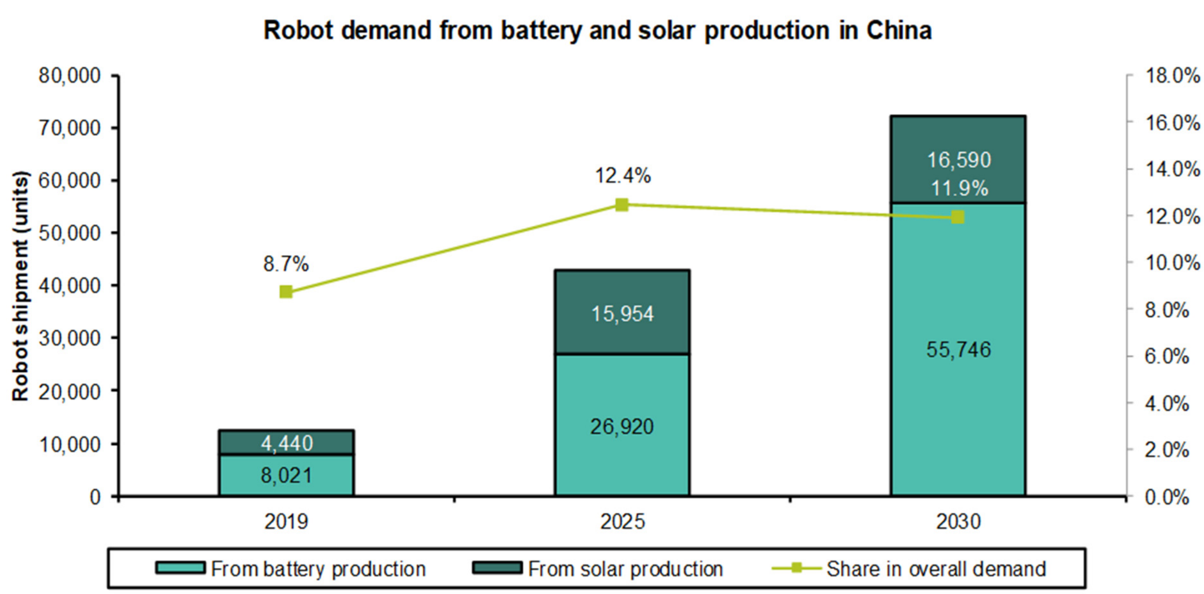
As introduced earlier, our estimation on demand of robotics, laser ,vision, and servo motion from EV battery and solar panel production are summarized in Exhibit 213 to Exhibit 215.

EXHIBIT 213: **Estun: Revenue impact from solar panel and battery production — modeled versus optimistic scenarios**

Estun: Revenue impact from solar & battery production								
Scenario	Robot market share in solar production		Robot market share in battery production		Robot segment revenue from solar & battery (RMBmn)	Servo market share in solar & battery	Automation components segment revenue from solar & battery (RMBmn)	Estun total revenue (RMBmn)
	2020	2025	2020	2025	2025	2025	2025	2025
Modelled	18-20%	20%	3-5%	10%	769	3%	122	8,952
Optimistic		30%		20%	1,380	10%	407	9,848

Source: MIR Databank, company reports, and Bernstein estimates (2025) and analysis

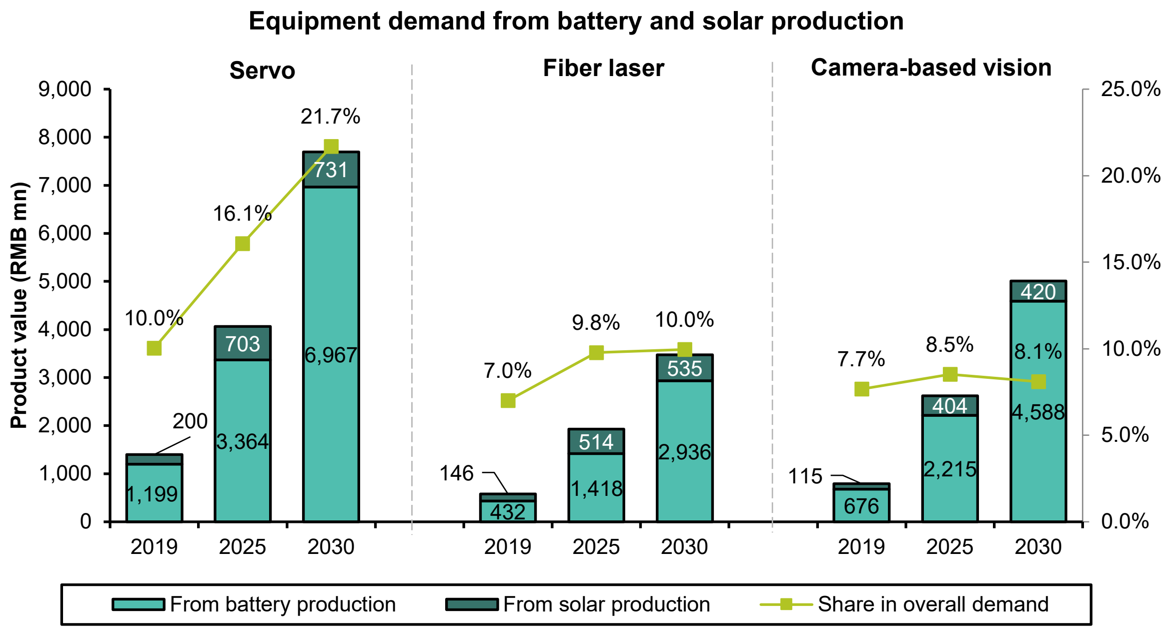
EXHIBIT 214: **Robot demand from battery and solar panel production in China will likely increase in absolute level as well as in relative importance**



Note: Product share is defined as the ratio of robot demand in battery and solar industry, and total robot demand.

Source: MIR Databank, Statista, CPIA, Bernstein Memory & EV Battery team, Bernstein Asian Renewables, Power and Coal team, and Bernstein estimates (2025+) and analysis

EXHIBIT 215: **Battery and solar production will also meaningfully drive the growth of servo motor, fiber laser, and machine vision demand in the coming decade**



Note: Product share is defined as the ratio of product demand in battery and solar industry, and total product demand.

Source: MIR Databank, Annual Report on Chinese Laser Industry, China Machine Vision Union (CMVU), Statista, Bernstein Memory & EV Battery team, CPIA, Bernstein Asian Renewables, Power and Coal team, and Bernstein estimates (2025+) and analysis

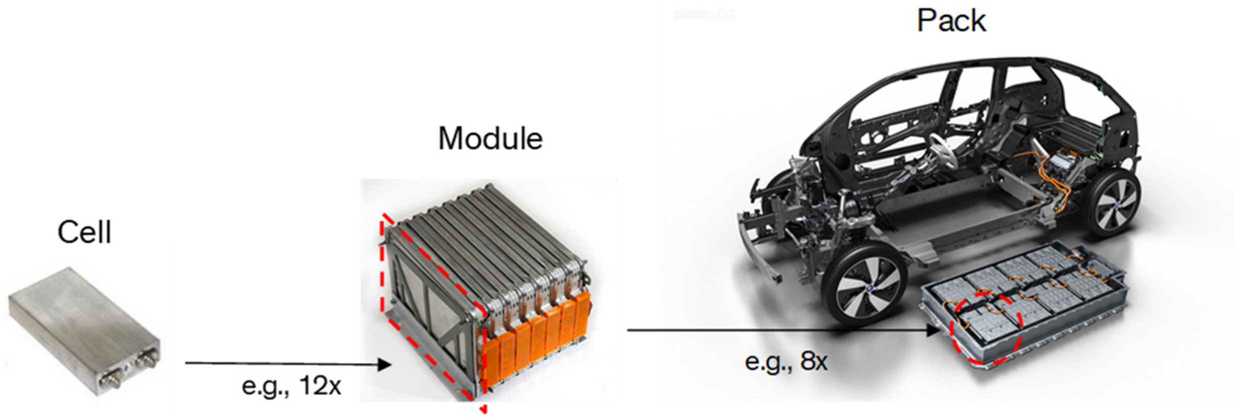
BATTERY

We first explain the battery production processes (see Exhibit 217 to Exhibit 219) and then detail the equipment type, investment breakdown, and where respective automation technologies are used (see Exhibit 220 to Exhibit 222).

PRODUCTION PROCESSES

Battery is the energy source in an EV. An EV needs many cells to power it. In the most common setup, engineers connect cells into a "module" and then assemble a few modules into a "pack" (see Exhibit 216). Typically, there is one battery pack per car.

EXHIBIT 216: **EV battery cell, module, and pack**



Source: Wikimedia Commons and Bernstein analysis

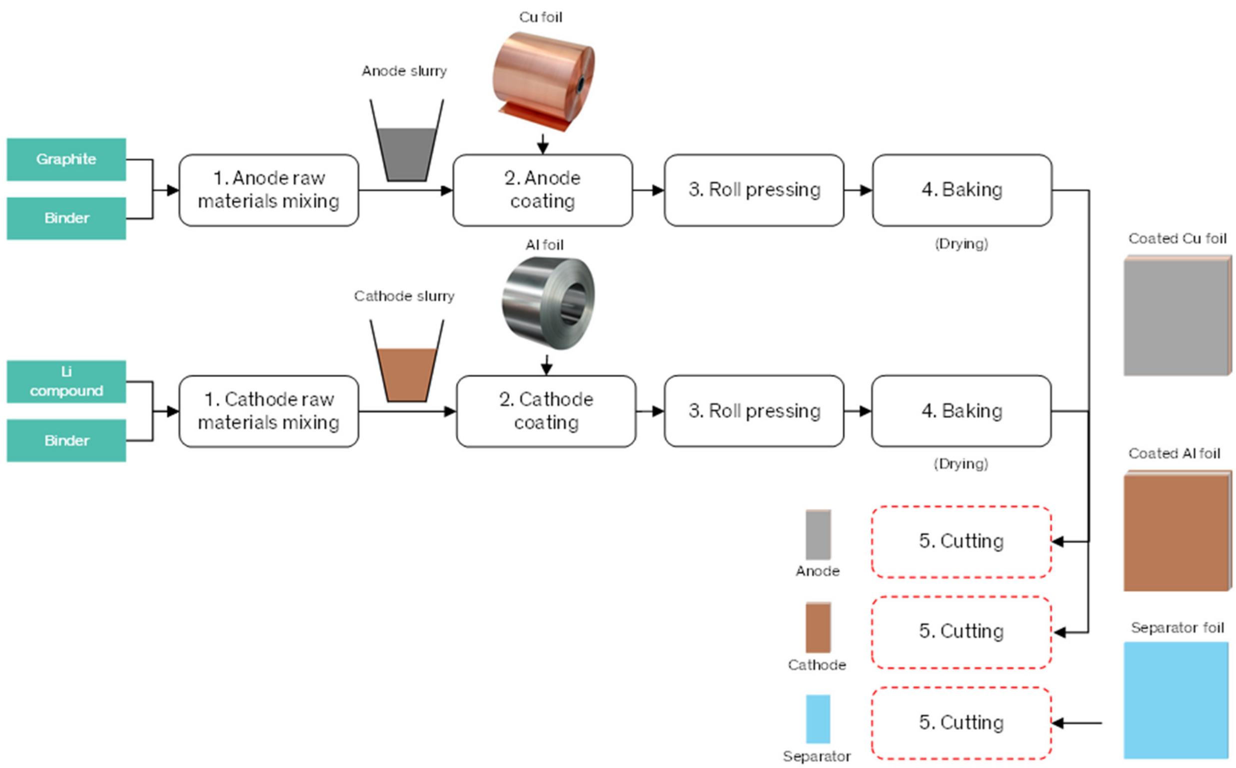
The manufacturing processes of a battery can be mainly divided into three parts: cell front-end processes, cell middle processes, and cell back-end processes and module/pack processes. In Exhibit 217 to Exhibit 219, red boxes/dashed outlines indicate the use of laser equipment.

Cell front-end processes

Front-end processes fabricate electrodes and the separator for a cell (see Exhibit 217) and account for about 50% of equipment capex.

- **Step 1: raw materials mixing.** Electrode active material (i.e., Li compound for the cathode and graphite for the anode), binder, and solvent are mixed and stirred together to form a homogeneous slurry.
- **Step 2: coating.** The two types of slurry formed in step 1 are evenly coated on Cu (i.e., copper) foil for anode and Al (i.e., aluminum) foil for cathode, respectively.
- **Step 3: roll pressing.** The coated foils are passed through a pair of rolls that press against each other to ensure the coating materials make good contact with the foils.
- **Step 4: baking.** The coated foils are dried.
- **Step 5: cutting.** The coated foils, together with the separator, are cut into small slices suitable for a single cell. A mechanical cutting machine was once the mainstream in cutting, but now laser cutting is becoming increasingly popular.

EXHIBIT 217: **Cell front-end processes**



Note: Processes outlined in dashed boxes involve lasers.

Source: Wikimedia Commons and Bernstein analysis

Cell middle processes

The output of the cell middle processes, which account for about 30% of equipment capex, is a "raw" cell before activation and testing (see Exhibit 218).

- **Step 6: winding.** Cathode, anode, and separator are wound into a "flat" roll.
- **Step 7: cell case welding.** Five pieces of metal sheet are welded together to form a cuboid-shaped case without a lid. The lid has a complex structure (with two holes and two terminals) and is processed in later steps.
- **Step 8: tab welding.** Two thin metal trips (tabs) are welded (using laser or ultrasonic) to the cathode and anode, respectively.
- **Step 9: terminal welding.** The two tabs are welded (using laser or ultrasonic) to the positive terminal and negative terminal, respectively.
- **Step 10: assembly.** The roll is inserted into the case and the lid is placed onto the case.
- **Step 11: pressure relief vent welding.** A laser welds a thin Al sheet with the edges of one hole on the lid. This process requires a high-quality laser source and strict operation — the weld must be strong and form a perfect seal.

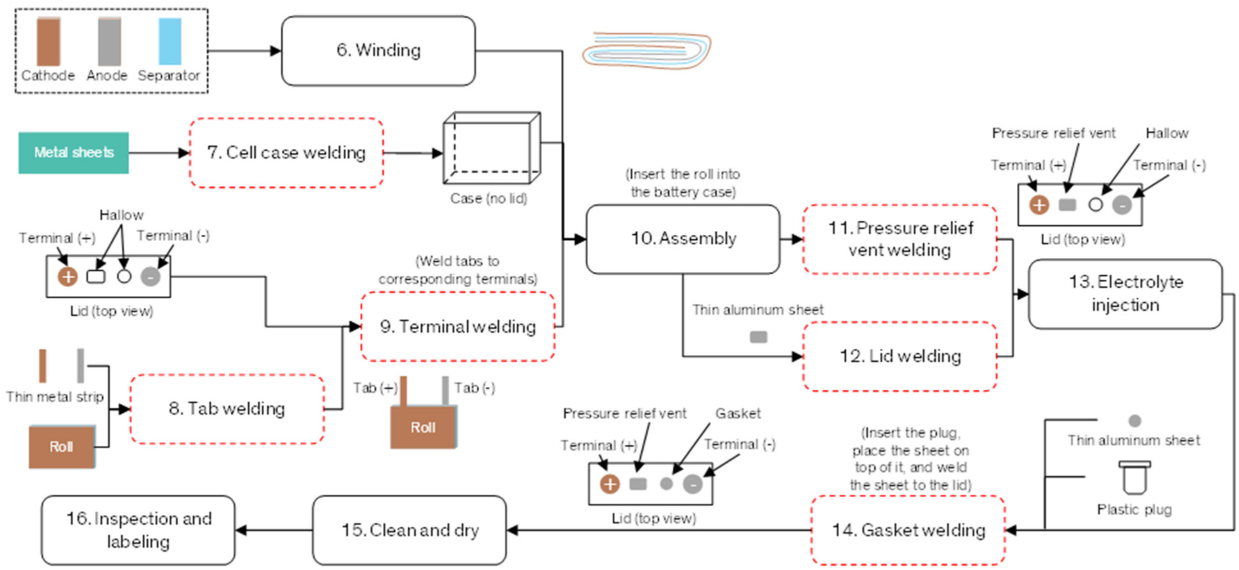
- **Step 12: lid welding.** The lid and the non-lidded case are welded together with a laser.

- **Step 13: electrolyte injection.** Electrolyte is injected into the case through the hole reserved for the gasket.

- **Step 14: gasket welding.** A plastic/rubber plug is inserted into the remaining hole, a thin Al sheet is placed on top of the plug, and the sheet is welded (using laser) to the lid.

- **Steps 15 and 16: cleaning, drying, inspection, and labeling.** Every cell will go through an appearance check and be marked with unique codes for tracking.

EXHIBIT 218: **Cell middle processes**



Note: Processes outlined in dashed boxes involve lasers. Some manufacturers also cut the "tabs" out of the electrode slits (step 5). In that case, step 8 is omitted.

Source: Bernstein analysis

Cell back-end and module/pack processes

Cell back-end processes include all types of testing and activation for the cell. When cells are ready, they are packaged into modules and then packed in the module/pack processes (see Exhibit 219). These processes account for around 20% of equipment capex.

- **Step 17: formation.** The cell is charged and discharged repeatedly with a small current to activate it.

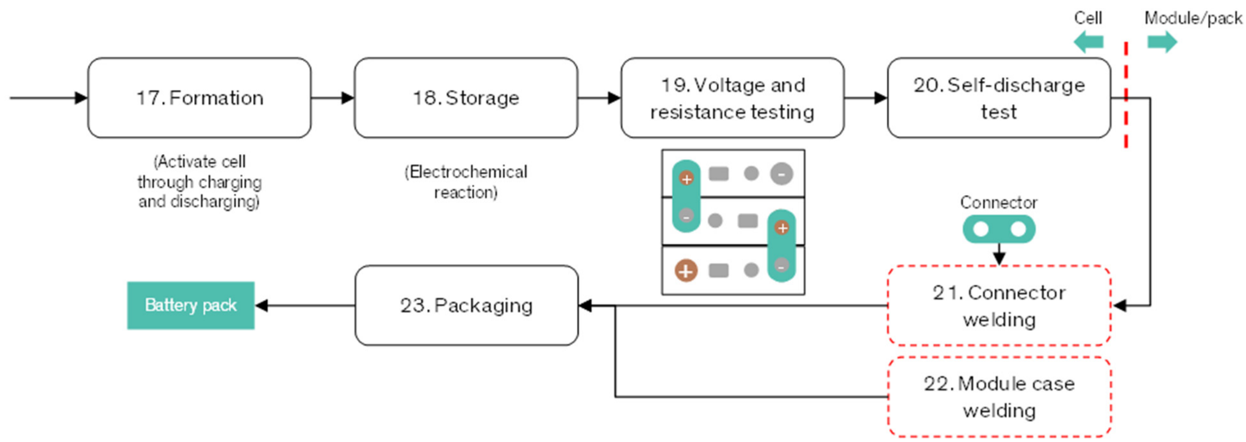
- **Step 18: storage.** Typically, the cell is stored in a high-temperature room (e.g., 50-60°C). During storage, certain electrochemical reactions take place inside the cell, leading to changes of a set of parameters such as voltage, resistance, and capacity.

- **Step 19: voltage and resistance testing.** Cells with voltage and resistance deviating far from nominal values will be screened out and disposed of.

- **Step 20: Self-discharge test.** Self-discharge is an unfavorable characteristic — the higher the self-discharge rate, the lower energy one can get from the battery. The purpose of this step is to identify and discard cells with a high self-discharge rate.

- That's a wrap for cell manufacturing. To turn cells into a usable pack, manufacturers connect the cells in serial and parallel configuration (**step 21**, using laser to weld connectors), put the cells into a module case (**step 22**, laser welding), and package the modules into a pack (**step 23**).

EXHIBIT 219: **Cell back-end and module/pack processes**



Note: Processes outlined in dashed lines involve lasers.

Source: Bernstein analysis

EQUIPMENT AND INVESTMENT

In China, battery equipment capex is ~RMB280mn per GWh of capacity. The cell front, middle, and back-end and module/pack processes account for approximately 50%, 30%, and 20% of total equipment investment (see Exhibit 221), respectively. In developed markets, the total capex is US$100-US$150mn per GWh. Assuming ~60% of capex being equipment investment, it is about twice the equipment value in China.

The complex manufacturing process requires many types of specialized equipment (e.g., for coating, winding, and injection). As part of these subsystems, automation technologies are important for material handling (robots and AGV); material processing (laser for cutting, welding, and marking); and quality control, tracking, and inspection (vision). Based on our analysis, 1GWh battery capacity will need, on average, 39 fiber lasers, 137 industrial robots, 40 AGVs, 2,634 servos, and 451 camera-based vision systems (see Exhibit 220). These account for 2.6%, 5.9%, 4.3%, 6.1%, and 4.0% of total equipment investment, respectively (see Exhibit 221).

EV battery manufacturing requires lasers with various specs (see Exhibit 222) and has a much higher stability requirement than general manufacturing because imperfect welds may result in leakage, which is a serious safety issue. Therefore, IPG's lasers have very high market share in EV battery production.

EXHIBIT 220: **Quantity of equipment and automation devices used in 1GWh capacity battery production**

Process	Equipment	Equipment quantity per GWh capacity	Number of automation devices used per GWh capacity				
			Laser source	Industrial robot	AGV	Servo	Camera-based vision
Battery cell front-end processes	Mixing machine	16	-	16	16	48	-
	Coating machine	18	-	18	-	234	72
	Rolling machine	10	-	-	-	80	40
	Striping machine	6	-	-	-	42	24
	Tab forming machine	2	2	-	-	10	8
	Electrode slitting machine	6	6	6	-	96	24
Battery cell middle processes	Cell winding machine	19	-	-	19	1,520	76
	Shell insertion machine	6	-	6	-	24	24
	Tab welding machine	2	2	-	-	10	8
	Injection machine	13	13	13	-	130	-
	Top cover/cell case laser welding machine	14	14	28	-	210	56
Battery cell back-end processes and module/pack processes	Drying oven	16	-	16	-	192	-
	Formation system	240	-	-	-	-	-
	Grading system	30	-	30	-	-	-
	Module assembly line	2	2	-	-	10	-
	Inspection equipment	115	-	-	-	-	115
	Pack assembly line	2	-	4	-	28	4
Others	AGV	5	-	-	5	-	-
Total			**39**	**137**	**40**	**2,634**	**451**

Source: Contemporary Amperex Technology (CATL), Schneider Electric, Feasibility Study on the Construction of ZR's Lithium Battery Assemble Line, and Bernstein estimates (number of automation devices used per GWh capacity) and analysis

EXHIBIT 221: **Equipment and automation device investment in 1GWh capacity battery production**

Unit: RMB thousand	Investment per GWh capacity	Investment in automation devices per GWh capacity				
		Laser source	Industrial robot	AGV	Servo	Camera-based vision
Front-end processes equipment	137,342	1,480	4,800	4,800	3,315	4,200
Middle processes equipment	86,958	5,365	5,640	5,700	12,311	4,100
Accessory equipment	6,443	-	-	-	-	-
Back-end processes and module/pack processes equipment	41,930	370	6,000	-	1,495	2,975
Production supporting equipment	5,317	-	-	1,500	-	-
Office equipment	1,177	-	-	-	-	-
Total	279,167	7,215	16,440	12,000	17,121	11,275
% as of total investment	100%	2.6%	5.9%	4.3%	6.1%	4.0%

Source: CATL, Schneider Electric, Feasibility Study on the Construction of ZR's Lithium Battery Assemble Line, and Bernstein estimates (number of automation devices used per GWh capacity) and analysis

EXHIBIT 222: **Common types of fiber lasers used in battery production**

Step	Process	Fiber laser source used
5	Anode cutting	100-200W pulsed 1-6kW CW
	Cathode cutting	
	Separator cutting	
7	Cell case welding	2-6kW CW
12	Lid welding	
8	Tab welding	100-300W pulsed 500W-1kW CW
9	Terminal welding	100-300W pulsed 500W-6kW CW
11	Pressure relief vent welding	500W-6kW CW
14	Gasket welding	500W-1kW CW
21	Connector welding	4-6kW CW
22	Module case welding	6kW+

Source: IPG presentation, industry interviews, and Bernstein analysis

Vision in battery production

In battery production, about 25% of camera-based vision is used as the last step before pack assembly to inspect for module defects. This is somewhat "independent of" the production flow and can be augmented by human verification (see Exhibit 220). The rest is mostly integrated inline vision, which tolerates much lower error rates.

In addition to camera-based vision, there is also intensive use of non-camera vision (mostly laser sensing) throughout the process.[45] Unfortunately, we cannot reliably quantify its value in the system, although we know it is as big as — if not bigger than — camera-based vision. We use Keyence product examples to provide a qualitative description.

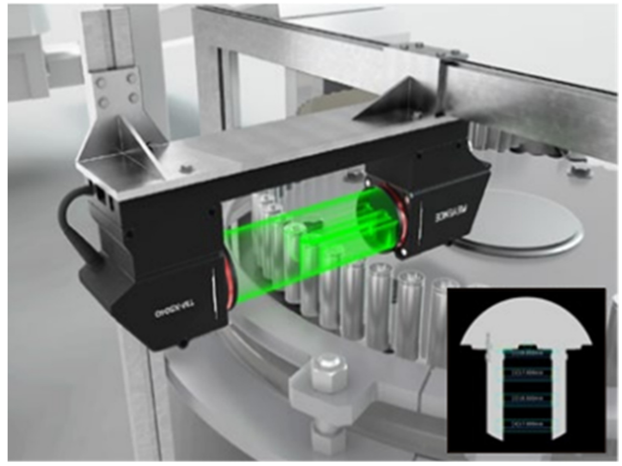
In battery manufacturing, Keyence provides solutions to deal with precision inspection and measurement needs. High-precision laser confocal sensors can perform non-contact measurement of wet or dry electrode coating thickness (see Exhibit 223). These sensors are perfect for transparent or mirror surfaces and cost RMB40,000-RMB70,000 per unit.[46] Keyence's latest silhouette measurement sensors are used for high-speed, complex feature measurements of battery parts (see Exhibit 224). 3D vision using structured light or laser interference is used for the precision inspection of weld quality and others (see Exhibit 225). Many more laser detection sensors are used for positioning and inspection throughout the processes in both battery and solar production (see Exhibit 226 and Exhibit 227).

[45] See detailed discussion of the two vision segments in The "TAM"inator: Sizing markets, fears, and dreams - 10%+ for 10+, the long-term vision for industrial vision (Keyence, Cognex).
[46] See Mirror, mirror, on the wall, who is the fairest of them all? - Automation new products of the year.

EXHIBIT 223: **Battery production: electrode coating thickness**

Source: Keyence

EXHIBIT 224: **Battery production: multi-point measurement of battery outer diameter**

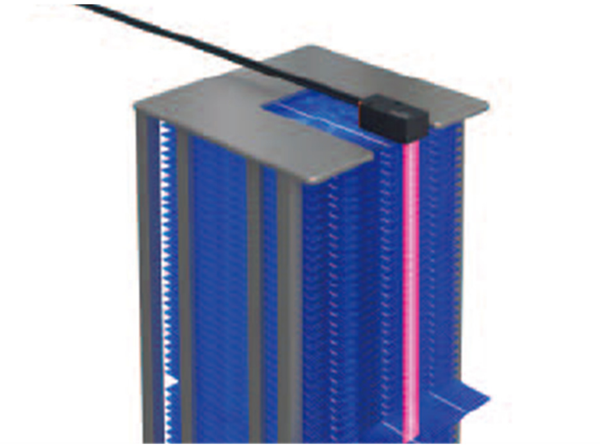


Source: Keyence

EXHIBIT 225: **Battery production: post encapsulation welding inspection**

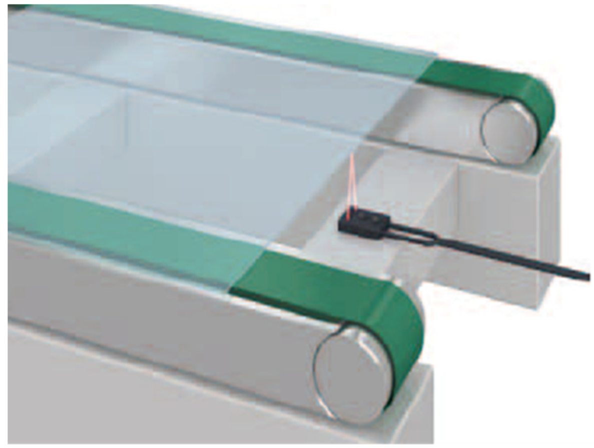
Source: Keyence

EXHIBIT 226: **Solar production: checking for protrusions inside cassettes**



Source: Keyence

EXHIBIT 227: **Solar production: positioning before glass bonding**



Source: Keyence

SOLAR

In this section, we discuss the manufacturing process of solar cells and modules (see Exhibit 228) and then detail the equipment type, investment breakdown, and where respective automation technologies are used (see Exhibit 229 to Exhibit 237).

Our discussion focuses on "Passivated Emitter and Rear Contact" (PERC) solar cells, the most common type used today. Compared to conventional solar cells, PERC cells are modified with an extra layer on the rear side of the cell that increases energy output by 6-12%.

PRODUCTION PROCESSES

The solar panel production processes are summarized in Exhibit 228.

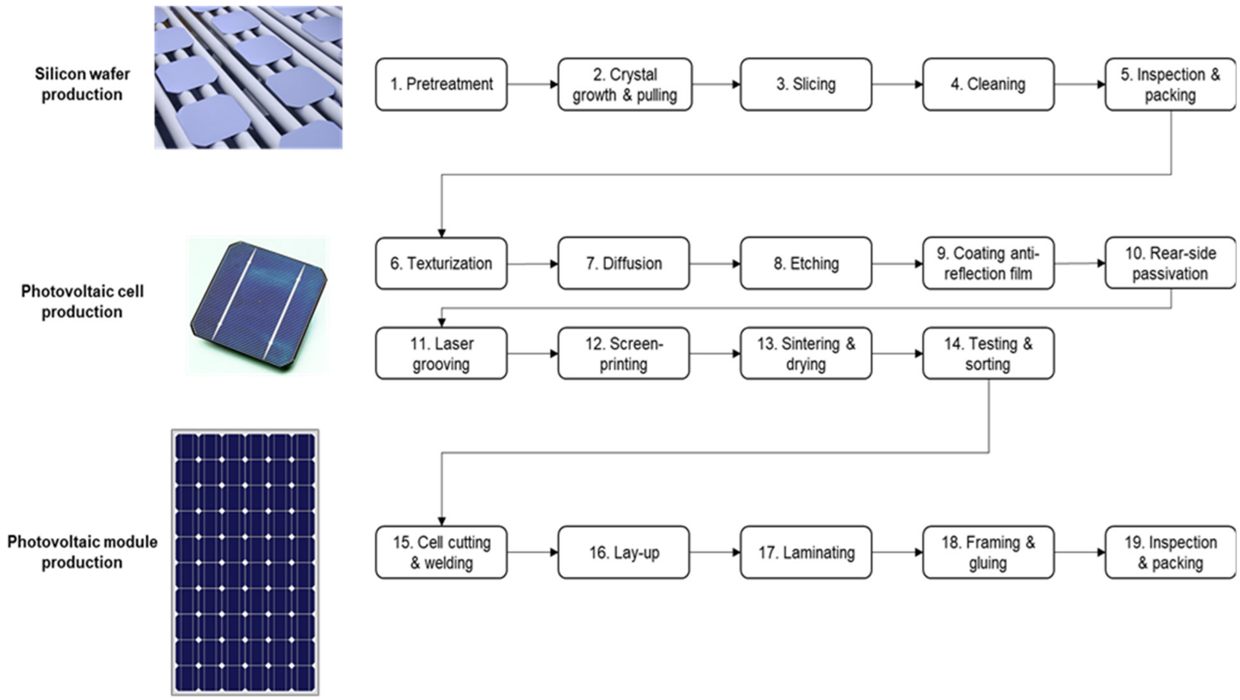
Silicon wafer production

The function of this process is to fabricate pure silicon wafer. These processes account for ~36% of total equipment investment.

- **Step 1: pretreatment.** To wash and clean raw silicon materials.
- **Step 2: crystal growth and pulling.** To melt the raw materials in a monocrystalline silicon furnace and pull the silicon ingots.
- **Step 3: slicing.** The block is sliced at once into many wafers with a wire-saw.
- **Step 4: cleaning.** This step removes trace metals, residues, and particles on the sliced silicon wafers.

- **Step 5: inspection and packing.** Both camera-based and non-camera-based vision can be used to detect cracks, chips, and fragments.

EXHIBIT 228: **Solar panel production processes**



Source: Wikimedia Commons and Bernstein analysis

Photovoltaic cell production

The following processes are used to convert a wafer into a solar cell, which is capable of converting solar power into electricity. These processes account for ~54% of total equipment investment.

- **Step 6: texturization.** Texturization is to fabricate microstructures on the silicon surface. These structures are able to reduce the front reflection and this increases short circuit current and, therefore, efficiency.

- **Step 7: diffusion.** Diffusion is a high-temperature thermal process in which silicon wafers are doped with extrinsic elements such as boron or phosphorous. In addition, laser can be introduced to generate localized doping. In such cases, a pulsed laser is directed at the silicon wafer, allowing boron/phosphorous atoms in the gas to diffuse into the localized molten sections of the silicon wafer.

- **Step 8: etching**. To remove the doped wafer edge and phosphosilicate glass layer by etching.

- **Step 9: coating anti-reflection film.** Coating anti-reflection film reduces reflection and increases light absorption of solar cells and, thus, increases efficiency. The thin layer of anti-reflective film is typically fabricated by Plasma Enhanced Chemical Vapor Deposition (PECVD).

- **Step 10: rear-side passivation.** This dielectric passivation layer on the rear side contributes to the increase of efficiency by increasing the solar cell's ability to capture light, reflecting specific wavelengths of light and reducing electron recombination.

- **Step 11: laser grooving.** This step uses laser ablation to create contact openings in the rear passivation layer. Various laser sources ranging from nanosecond lasers to ultra-short pulse lasers are possible, depending on customer requirements.

- **Step 12: Screen printing.** This step is for fabricating electrodes on both front-side and rear-side via screen printing.

- **Step 13: sintering and drying.** This step is to sinter and dry the electrodes fabricated in the previous step.

- **Step 14: testing and sorting.** This step is to test the solar cells and sort them based on efficiency.

Photovoltaic module production

The following processes are to integrate solar cells to a matrix-like structure, i.e., a module. These processes account for 9% of total equipment investment.

- **Step 15: cell cutting and soldering.** To laser cut solar cells into multiple pieces, e.g., two to four, and then interconnect the cell pieces, 20 pieces, into cell strings by series soldering.

- **Step 16: lay-up.** To position multiple cell strings, six, on glass with a layer of encapsulant material between cells and the glass.

- **Step 17: laminating.** After the cells are put together, a cover made from highly durable, polymer-based material is added on the rear side. This multilayer sandwich structure is laminated into one single unit thanks to the polymerization of the encapsulating material.

- **Step 18: framing and gluing.** This step is to trim the surplus material of encapsulant and back sheet that is left around the glass after the lamination process and then the frame is applied around the PV module.

- **Step 19: inspection and packing.** Once the module is ready, testing is carried out to ensure the module performs as expected. The measurement is done by a sun simulator that is able to produce some specific light conditions that measure the power of the module.

EQUIPMENT AND INVESTMENT

We estimate equipment capex to be RMB666mn per GW of solar production capacity in China. The equipment capex in silicon wafer, photovoltaic cell, and photovoltaic module production is 36%, 54%, and 9%, respectively (see Exhibit 232). Based on our analysis, 1GW solar production capacity brings extra demand of 32 lasers, 189 robots, eight AGVs, 2,374 servos, and 191 camera-based vision systems (see Exhibit 229 to Exhibit 231), accounting for 0.9%, 3.4%, 0.4%, 1.2%, and 0.7% of total equipment capex, respectively.

Solar cell/module production uses pulsed lasers for localized processing within a confined zone, i.e., laser doping, laser grooving, and laser scribing; green nanosecond pulsed lasers are especially useful (see Exhibit 233). Solid-state lasers are most commonly used for PV-related processes, but IPG's fiber green pulsed fiber lasers (GLPN series) have demonstrated superior performance and are taking market-share.

Several types of robots are used in solar manufacturing (see Exhibit 234): light payload (payload ≤20 kg) six-axis robots are mainly used in the lay-up process (see Exhibit 235); heavy payload (payload >20 kg) six-axis robots are used to carry cargo such as wafer carriers (see Exhibit 236); SCARA/Delta robots are used in wafer transfer and in packing (see Exhibit 237). Estun has over a 90% robot market share in the lay-up process, and it has recently won robot orders in the other two key processes, i.e., wafer carrier handling and packing. We believe this will continue to drive growth and share gain for the company.

EXHIBIT 229: **Quantity of equipment and automation devices used in solar panel production (1): silicon wafer**

Equipment		Unit price (RMB thousand)	Equipment quantity per GW	Number of automation devices per GW capacity				
				Laser source	Industrial robot	AGV	Servo	Camera-based vision
Raw material cleaning equipment		47	40.7	-	-	-	488	-
Mono-crystal	Monocrystalline silicon furnace	1,339	107	-	-	-	533	-
	Other crystal pulling equipment	829	1.3	-	-	-	6.7	-
Machining	Double blades shearing	800	2.7	-	-	-	13.3	-
	Multi blades shearing	1,450	1.6	-	-	-	8.0	-
	Squaring & cropping	1,300	4.3	-	-	-	21.3	-
	Double side grinder	1,500	5.9	-	-	-	29.3	-
	Automation	30,000	0.13	-	-	-	0.7	-
	Other machining equipment	244	2.4	-	-	-	-	-
Slicing	Slicing machine	1,780	24.0	-	-	-	120	-
	Sorting machine	1,500	6.4	-	-	-	32.0	12.8
	Wafer cleaning equipment	900	6.4	-	6.4	-	-	-
	Slicing automation	28,000	0.13	-	0.27	-	0.67	-
	Gluing automation	10,000	0.13	-	0.27	-	-	-
	Packing automation	10,000	0.13	-	0.27	-	0.67	-
	Other slicing equipment	307	5.5	-	10.9	-	-	-
Graphite processing		600	0.87	-	-	-	4.3	-
Inspection		-	Several	-	-	-	-	1.0
Auxiliary		-	Several	-	-	-	-	-
Work fixture		-	Several	-	-	2.0	-	-
Office and others		-	Several	-	-	-	-	-
Total				-	**18.1**	**2.0**	**1,258**	**13.8**

Source: LONGi, HCFA Technology Co., Ltd. (HCFA), and Bernstein estimates (number of automation devices used per GW capacity) and analysis

EXHIBIT 230: **Quantity of equipment and automation devices used in solar panel production (2): photovoltaic cell**

Equipment		Unit price (RMB thousand)	Equipment quantity per GW	Number of automation devices per GW capacity				
				Laser source	Industrial robot	AGV	Servo	Camera-based vision
Processing	Texturization	3,500	4.8	-	-	-	24.0	-
	Diffusion	2,100	9.6	-	-	-	-	-
	Laser doping	2,200	5.6	11.2	11.2	-	28.0	22.4
	Etching	2,400	8.4	-	-	-	42.0	-
	Annealing	1,650	6.8	-	-	-	-	-
	Rear-side passivation	6,000	3.6	-	-	-	18.0	-
	Tubular PECVD-frontside	3,300	10.8	-	-	-	54.0	-
	Tubular PECVD-rearside	3,300	9.6	-	-	-	48.0	-
	Firing furnace	2,500	4.8	-	-	-	24.0	-
	Screen-printing	12,000	4.8	-	4.8	-	24.0	9.6
	Laser grooving	2,000	4.8	4.8	4.8	-	-	19.2
	Other equipment	437	6.0	-	12.0	-	-	-
Automation	Texturization automation	850	4.8	-	9.6	-	57.6	-
	Diffusion automation	900	4.8	-	9.6	-	24.0	-
	Etching automation	900	8.4	-	16.8	-	101	-
	Annealing automation	850	6.8	-	13.6	-	34.0	-
	Rearside passivation automation	1,750	3.6	-	7.2	-	18.0	-
	Tubular PECVD-frontside automation	950	10.8	-	21.6	-	162	-
	Tubular PECVD-rearside automation	950	9.6	-	19.2	-	144	-
	Testing & sorting machine	3,200	4.8	-	-	-	24.0	-
Inspection	Online coating color detection	130	22.4	-	-	-	-	44.8
	IV tester	1,300	11.2	-	-	-	56.0	-
	Online EL tester	300	11.2	-	-	-	56.0	22.4
	Appearance & color detection	300	11.2	-	-	-	-	22.4
	Four-point probe system	300	5.2	-	-	-	-	-
	Other inspection equipment	10	393.8	-	-	-	-	-
Quality testing		-	Several	-	-	-	-	1.0
Auxiliary		-	Several	-	-	-	-	-
Work fixture		-	Several	-	-	-	-	-
Warehouse		-	Several	-	-	1.0	-	-
Office and others		-	Several	-	-	-	-	-
Total				**16.0**	**130**	**1.0**	**938**	**142**

Source: LONGi, HCFA, and Bernstein estimates (number of automation devices used per GW capacity) and analysis

EXHIBIT 231: **Quantity of equipment and automation devices used in solar panel production (3): photovoltaic module**

Equipment	Unit price (RMB thousand)	Equipment quantity per GW	Number of automation devices per GW capacity				
			Laser source	Industrial robot	AGV	Servo	Camera-based vision
Cell cutting & soldering	2,800	8.0	16.0	32.0	-	104	16.0
Automatic lay-up machine	440	4.0	-	4.0	-	-	8.0
Tiling Ribbon machine	3,000	1.6	-	-	-	19.2	3.2
EL tester	500	4.0	-	-	-	20.0	8.0
Laminator	3,300	3.2	-	-	-	16.0	-
IV tester	600	1.6	-	-	-	8.0	-
Automatic framing & gluing	7,000	1.6	-	3.2	-	8.0	-
Automatic packing	3,000	0.4	-	0.8	-	2.0	-
Offline inspection	1,100	0.2	-	-	-	-	-
MES system	6,000	0.4	-	-	-	-	-
Automated guided vehicle (AGV)	300	5.0	-	-	5.0	-	-
Auxiliary	-	Several	-	-	-	-	-
Total			**16.0**	**40.0**	**5.0**	**177**	**35.2**

Source: Risen Energy, HCFA, and Bernstein estimates (number of automation devices used per GW capacity) and analysis

EXHIBIT 232: **Equipment and automation device investment in 1GW solar production capacity**

Unit: RMB thousand	Investment per GW capacity	Investment in automation devices per GW capacity				
		Laser source	Industrial robot	AGV	Servo	Camera-based vision
Silicon wafer production	242,338	-	2,176	600	4,404	345
Photovoltaic cells production	360,342	3,040	15,648	300	3,284	3,545
Photovoltaic module production	63,000	3,040	4,800	1,500	620	880
Total	665,680	6,080	22,624	2,400	8,309	4,770
% of total investment	100%	0.9%	3.4%	0.4%	1.2%	0.7%

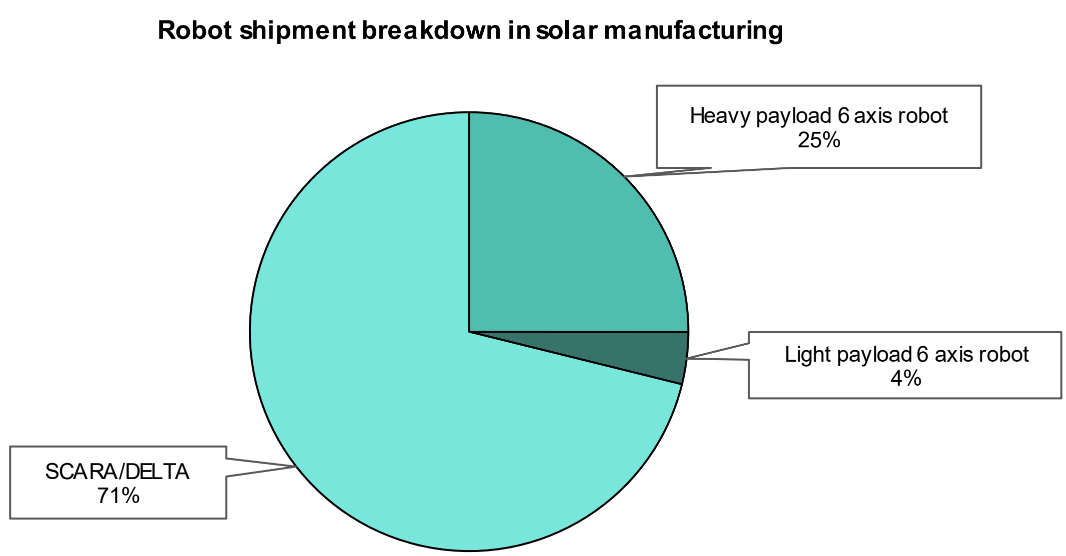
Source: LONGi, Risen Energy, HCFA, and Bernstein estimates (number of automation devices used per GW capacity) and analysis

EXHIBIT 233: **Common types of lasers used in solar production**

Step	Process	Laser source used			
		Wavelength (nm)	Average power (W)	Repetition rate	Pulse width (ns)
7	Laser doping	532	40	Single Shot to 400kHz	< 15
11	Laser grooving	532	50	10k-1MHz	1.5
15	Laser scribing	1064	300	2-4000 Hz	20-500

Source: IPG, InnoLas, and Bernstein analysis

EXHIBIT 234: **Robot type breakdown in solar production**



Source: MIR Databank, and Bernstein estimates (robot shipment breakdown in solar manufacturing) and analysis

EXHIBIT 235: **Estun has a dominant share in robots used in the lay-up process**

Source: Estun

EXHIBIT 236: **Estun robots carry wafer carriers**

Source: Estun

EXHIBIT 237: **Estun robots used in the packing process**

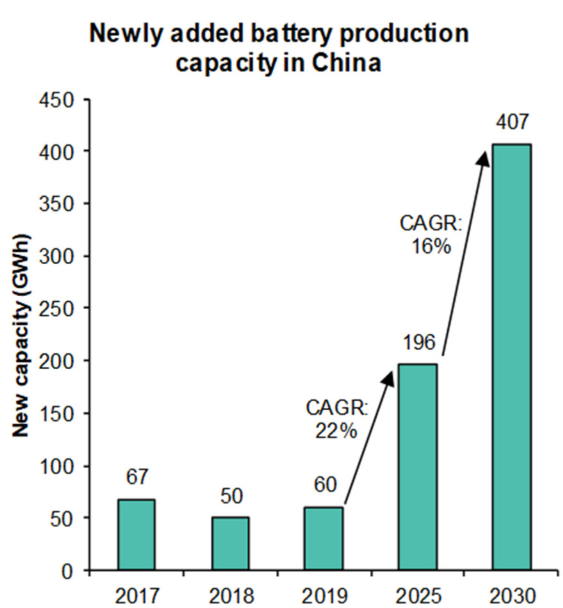
Source: Estun

QUANTIFYING THE IMPACT

China's new carbon policy started a multi-year investment phase for battery and solar panel production capacity. We estimate annual production capacity addition will grow at a 22% CAGR for battery over 2019-25, and at an 18% CAGR for solar module over 2020-25 (see Exhibit 238 and Exhibit 239). After 2025, annual capacity addition will continue to grow at a 16% CAGR for battery through 2030 and remain largely flat for solar. This estimate is consistent with global total production capacity of 2,623GWh for battery and 694GW for solar in 2030.

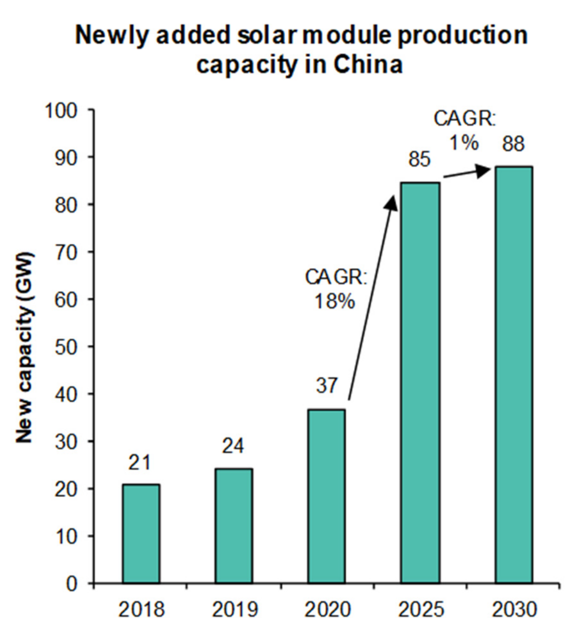
These two fast-growing industries should meaningfully increase the demand for automation and account for increasing shares in the total demand for industrial robot, servo motor, laser, and vision system in China (see Exhibit 214 and Exhibit 215; and Exhibit 240 to Exhibit 243). In these calculations, we have assumed the China market CAGR to be 16% for robot, 9% for servo motor, 16% for laser, and 20% for camera-based vision system through 2025; and 12%, 7%, 12%, and 15%, respectively, over 2025-30.

EXHIBIT 238: **Estimated annual addition of battery production capacity in China**



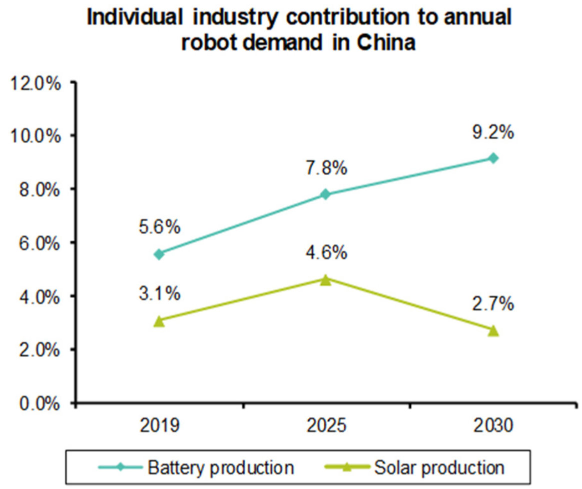
Source: Statista, Bernstein Memory & EV Battery team, and Bernstein estimates (2025+) and analysis

EXHIBIT 239: **Estimated annual addition of solar module production capacity in China**



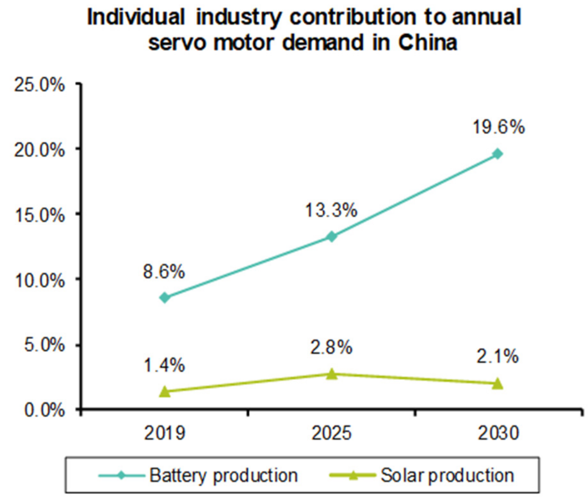
Source: CPIA, Bernstein Asian Renewables, Power and Coal team, and Bernstein estimates (2025+) and analysis

EXHIBIT 240: **Contribution from the two industries to robot demand in China**



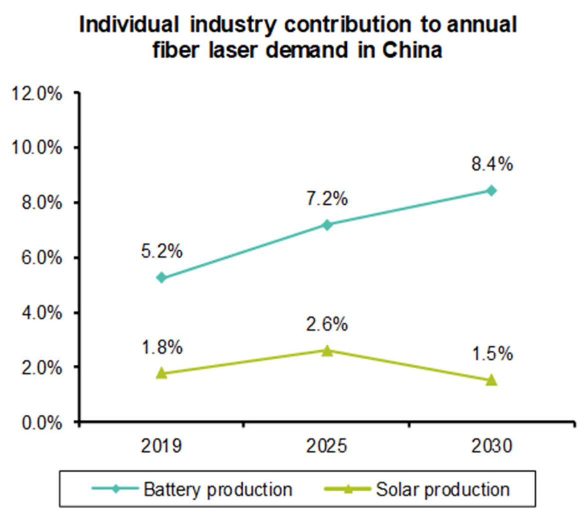
Source: MIR Databank, Statista, Bernstein Memory & EV Battery team, CPIA, Bernstein Asian Renewables, Power and Coal team, and Bernstein estimates (2025+) and analysis

EXHIBIT 241: **Contribution from the two industries to servo motor demand in China**



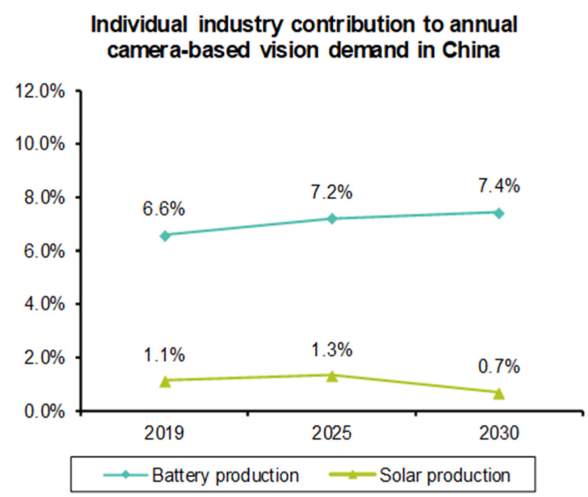
Source: MIR Databank, Statista, Bernstein Memory & EV Battery team, CPIA, Bernstein Asian Renewables, Power and Coal team, and Bernstein estimates (2025+) and analysis

EXHIBIT 242: **Contribution from the two industries to fiber laser demand in China**



Source: Annual report on Chinese Laser Industry, Statista, Bernstein Memory & EV Battery team, CPIA, Bernstein Asian Renewables, Power and Coal team, and Bernstein estimates (2024+) and analysis

EXHIBIT 243: **Contribution from the two industries to camera-based vision demand in China**



Source: CMVU, Statista, Bernstein Memory & EV Battery team, CPIA, Bernstein Asian Renewables, Power and Coal team, and Bernstein estimates (2025+) and analysis

The environmental impact of automation is already an important ESG topic for Estun, and China's carbon-neutral policy has made it even more so (see Exhibit 244). With its relative revenue concentration in the solar and battery verticals, Estun is among the top beneficiaries of the policy. In 2019, battery and solar industries contributed robot demand of 800-1,000 units to Estun. In our base case, we estimate contribution of ~5,900 units in 2025 and 8,900 units in 2030 (see Exhibit 245). In 2025, this would be 24% of Estun's total robot shipment (see Exhibit 246).

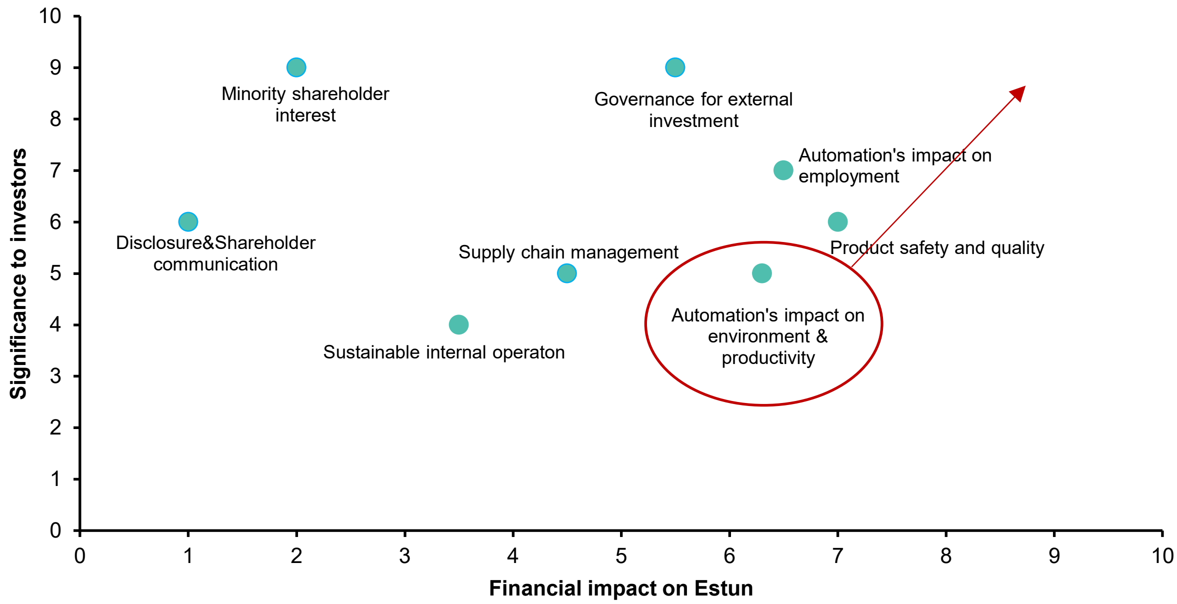
Although we do not know Estun's servo revenue breakdown by industry, the opportunity size dwarfs its current sales (see Exhibit 247). Estun's servo business earlier mainly focused on machine tools and a few other niche applications (plus internal use in robots). Recently, Estun has integrated intelligent control units together with servo motion. This allows advanced control and motion planning of up to 128 servo motors in equipment and production lines simultaneously. The technology came from Trio, a UK-based company Estun acquired in 2017. With this integration, Estun becomes much better positioned to capture servo motor opportunities in battery, solar, and electronics.

The base case scenario is reflected in our earnings model. In this scenario, the two industries will contribute 12% of the company's top line in 2025. In an optimistic scenario, in which Estun's market share in the two industries increases faster, there could be an additional RMB900mn contribution, raising our 2025 top-line forecast by a further 12% (see Exhibit 213).

Inovance's servo business will also see a strong uplift. For Inovance, the battery industry will likely continue to drive robust growth and account for ~20% of its servo revenue (see Exhibit 248 and Exhibit 249).

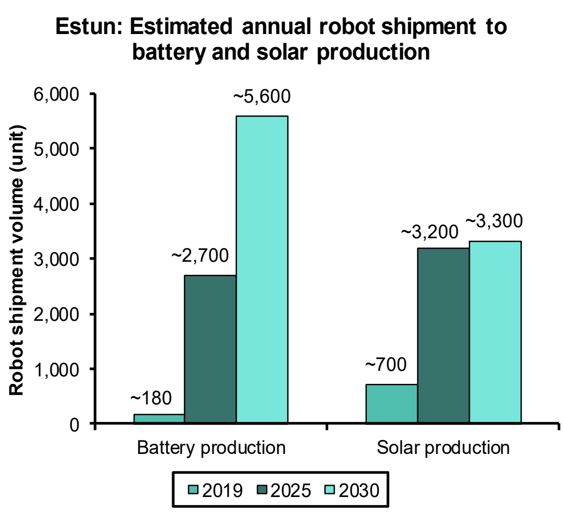
In laser (see Exhibit 250) and vision (see Exhibit 251), battery and solar opportunities will be very substantial to Chinese players such as Hikrobot (a subsidiary of Hikvision) and OPT, and the China business of IPG, Cognex, and Keyence. Hikrobot will additionally benefit from the AGV demand in battery and solar production, where the potential opportunity size in 2025 is about 3.4x Hikrobot's AGV shipment in 2020 (see Exhibit 252).

EXHIBIT 244: **Estun ESG materiality metrics**



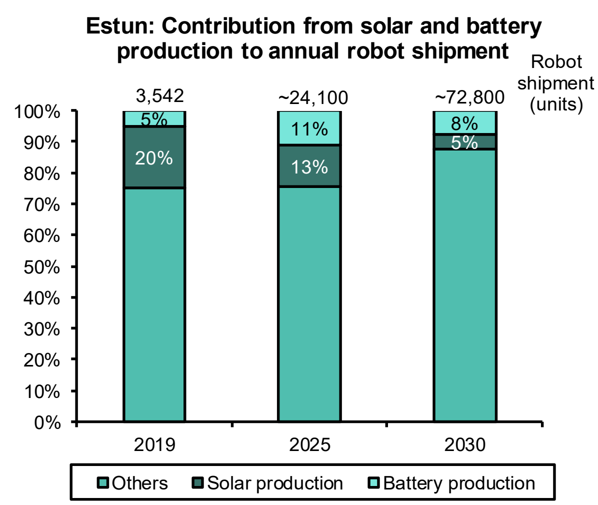
Source: Bernstein analysis

EXHIBIT 245: **The two industries will likely contribute to the strong growth of Estun's robot shipment**



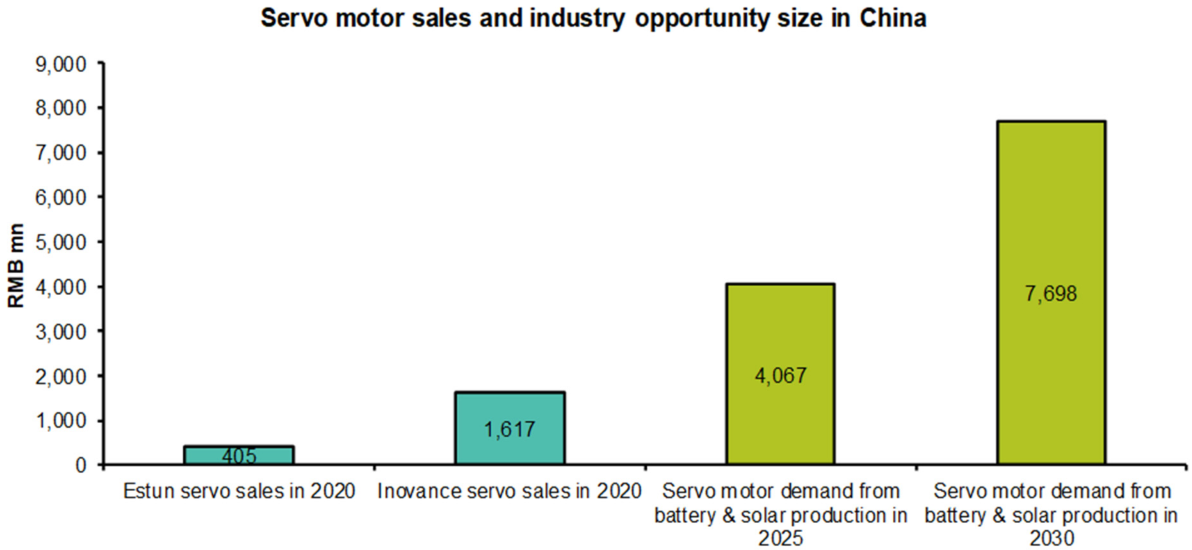
Source: Estun, MIR Databank, Statista, Bernstein Memory & EV Battery team, CPIA, Bernstein Asian Renewables, Power and Coal team, and Bernstein estimates (2025+) and analysis

EXHIBIT 246: **We estimate the two industries to contribute 30%+ of Estun's robot shipment in 2025**



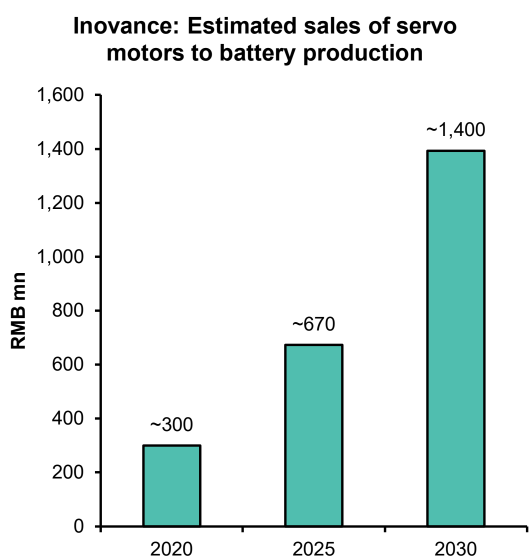
Source: Estun, MIR Databank, Statista, Bernstein Memory & EV Battery team, CPIA, Bernstein Asian Renewables, Power and Coal team, and Bernstein estimates (2025+) and analysis

EXHIBIT 247: **The two industries present a huge opportunity for Inovance's and Estun's servo motor business**



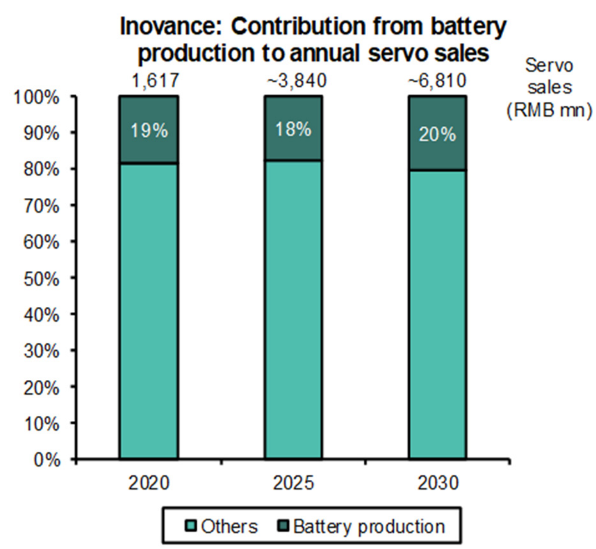
Source: MIR Databank, Statista, Bernstein Memory & EV Battery team, Bernstein Asian Renewables, Power and Coal team, and Bernstein estimates (2025+) and analysis

EXHIBIT 248: **Battery production will likely contribute to strong growth of Inovance's servo motor business**



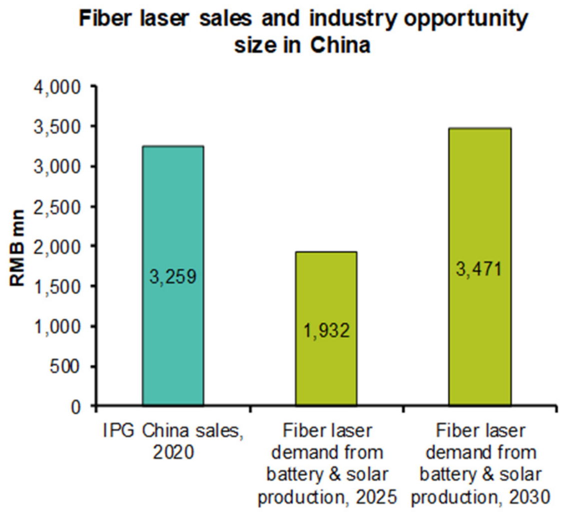
Source: Inovance, MIR Databank, Statista, Bernstein Memory & EV Battery team, and Bernstein estimates (2025+) and analysis

EXHIBIT 249: **We estimate the battery industry to contribute 18-20% of Inovance's servo motor sales**



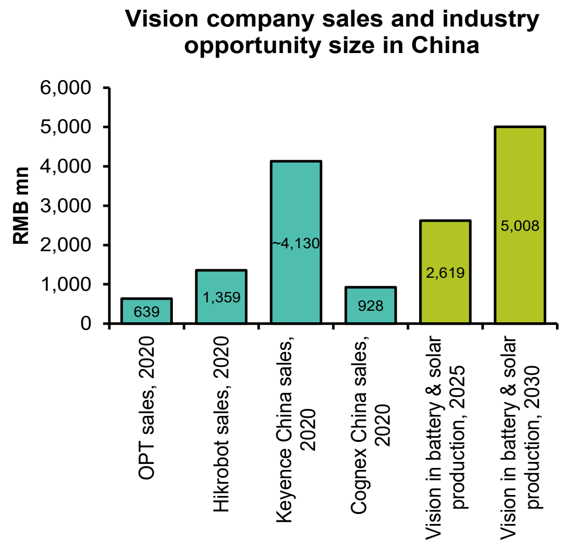
Source: Inovance, MIR Databank, Statista, Bernstein Memory & EV Battery team, and Bernstein estimates (2025+) and analysis

EXHIBIT 250: **The two industries present a decent opportunity for IPG's China business**



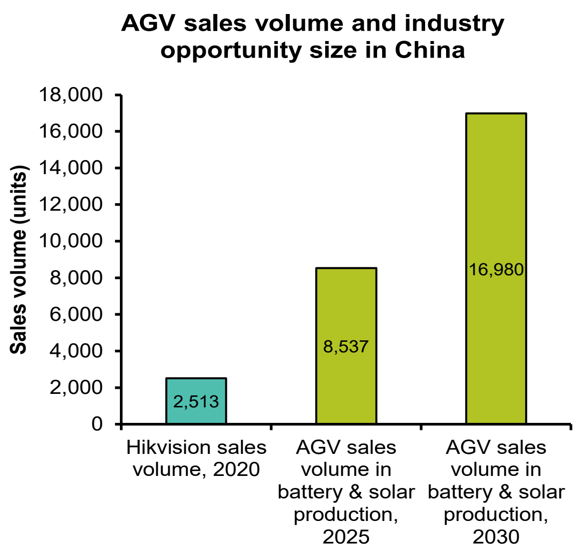
Source: Annual report on Chinese Laser Industry, MIR Databank, Statista, Bernstein Memory & EV Battery team, Bernstein Asian Renewables, Power and Coal team, and Bernstein estimates (2025+) and analysis

EXHIBIT 251: **The two industries present a significant opportunity for Hikvision, OPT, Cognex, and Keyence**



Source: OPT, Keyence, CMVU, MIR Databank, Statista, Bernstein Memory & EV Battery team, Bernstein Asian Renewables, Power and Coal team, and Bernstein estimates (2025+) and analysis

EXHIBIT 252: **The two industries present a huge opportunity for Hikvision's AGV business**



Source: MIR Databank, Statista, Bernstein Memory & EV Battery team, Bernstein Asian Renewables, Power and Coal team, and Bernstein estimates (2025+) and analysis

INVESTMENT IMPLICATIONS

We reiterate our Outperform rating for Estun, Keyence, Hikvision, and IPG, and Market-Perform rating for Inovance and Cognex.

TRYING THE IMPOSSIBLE? A MODEL FOR THE SIC MARKET

Starting with disclosures from Tesla and STM, we estimate the SiC content per car costs US$425 for chips and US$600 for modules now. STM guided for "well over US$550mn from SiC in 2021" and suggested ~80% is from Tesla. Dividing that with the number of Model 3 and Model Y vehicles sold, we arrive at transistor content per vehicle, and then module content with inputs from StarPower (not covered) and third parties.

Then we calculate the SiC content per horsepower (hp), as mainstream EVs will likely start to adopt SiC and their lower hp ratings will require lower power semiconductor content.

We assume SiC chip costs to fall by 37% from 2021 to 2025, based on the inputs of the US DOE, multiple auto and energy companies, third-party research, and an interview with an expert in SiC.

The SiC market will likely be US$2.4bn in 2025, below the guidance of Cree and STM, but above third-party forecasts, if: (1) 5 million EVs have SiC, (2) each EV has the average hp of current cars to contribute US$1.4bn in 2025, and (3) non-EVs contribute US$1bn additionally. One extra car and one extra hp to the adoption base will add US$280 and US$6.7 to the SiC market, respectively.

Cost reduction, adoption in EV and non-EV, and hp rating are key swing factors. Substrate accounts for the bulk of SiC device cost and, therefore, is key to cost reduction and deserves more research.

Overall, our finding suggest SiC in the non-EV segment can't be ignored and Infineon is well positioned there. For EV, silicon will likely remain meaningful and Infineon is the clear leader.

INTRODUCTION

By now, no one will question the merits of SiC. As an emerging semiconductor material, SiC delivers better efficiency for high-power applications. Particularly for EVs, SiC promises to extend the mileage by 5-10%, or even 15% according to Cree, and reduce charging time from two hours to seven minutes (see Exhibit 253). We overviewed this technology in our power semiconductor primer (Global Semiconductors: A Primer on Power Semiconductors) and analyzed Infineon's position (Weekend Tech Byte: SiC - 6 Reasons Infineon Will Be Competitive) previously. We further arranged an expert call in July 2021 and summarized the takeaways (Infineon: Summary of an interview with a SiC & power semi expert). Today, we try to address one of the major controversies — the size of the SiC market — and share our sizing model here (SiC Market Size Model).

EXHIBIT 253: **High-power, faster chargers can significantly reduce EV charging time**

EV Fast DC Charging Time

Technology	Power Output (kW)	Charging Time (min)*
SiC-based	350	7
Silicon-based	150	16
Silicon-based	50	48
Silicon-based	20**	120

* to charge for a reach of 200km

** incl. DC wall boxes

Source: Infineon and Bernstein analysis

STARTING WITH DISCLOSURES OF TESLA AND STM, WE ESTIMATE SIC CONTENT PER CAR COSTS US$425 FOR CHIPS AND US$600 FOR MODULES

Though the advantages of SiC are clear, modeling its market size quantitively is difficult as the market is nascent and there are no comprehensive disclosures from the supply chain. Third-party market research is limited, and their data and forecasts are often very different from what Cree and STM say. For example, Fuji Economics is the most conservative and forecasts only US$1bn in 2025, whereas Cree is the most bullish and guided US$5bn in 2024. Exhibit 254 compares these different forecasts.

Our forecast starts with STM as it is the largest SiC supplier currently, and its customer Tesla is the largest user. In its 1Q2021 earnings conference held in April 2020, STM guided its SiC revenue will be "well above US$550mn" in 2021. In a broker conference in March 2021, STM suggested Tesla was ~80% of its SiC business. Additionally, we know SiC is adopted in the Model 3 and the Model Y.[47] If we: (1) assume SiC will also be adopted in the upcoming pickup Cybertruck and (2) use what our US EV team forecasts for these car models, but (3) adjust it with the necessary lead time to produce SiC in advance of vehicles, we find the SiC content per vehicle is about US$400-US$450. This is within the guidance of US$300-US$600 per vehicle that Cree gave in June 2021.

Tesla is unusual in that it sources individual SiC chips from STM. Other OEMs often opt to buy power modules, and the content per vehicle earned by suppliers will then include the value of non-semiconductor components (e.g., passive parts and heat sink) of the modules, and, therefore, the content per vehicle will be higher. With (1) the disclosure from a Chinese power module company StarPower for silicon-based modules (see Exhibit 255), (2) third-party estimates on SiC modules (see Exhibit 256), and (3) the assumption of SiC chips likely representing a bigger portion of the module value than silicon ones, we estimate SiC chips are 70% of the SiC power module value. Thus, if an OEM chooses to buy SiC modules instead of chips, the value captured by suppliers will be around US$570-US$640. The content difference between chip and module is meaningful and will be incorporated into our model.

Another important point is an EV often has multiple motors and, hence, multiple inverters and power modules. For example, most SKUs of Models 3 and Y are All-Wheel Drive (AWD) and, hence, have one set of motor + inverter + power module in the front and another set in the rear. We estimate the blended average of these SKUs is 1.8 sets per vehicle. This

[47] https://www.marklines.com/en/report/Munro007_202105

information allows us to translate the content estimates earlier from per vehicle to per module or inverter.

For inverters, we take the input from a renowned car teardown expert, Munro & Associates, who estimated the inverters used in Models 3 and Y will cost US$522.[48]

EXHIBIT 254: **Forecasts for the power SiC market vary widely**

Power SiC Market Size Estimate (US$B)

Source Time of Est	Yole Dec 2020	Gartner Nov 2020	Fuji Economics Jun 2020	Cree Jun 2021	STM Apr 2021
Size in 2024	**1.8**	**2.2** (0.9 in EV inverter)		**5** (0.9 from Cree)	
Size in 2025	**2.6**		**~1**		**3.3** (1 from STM)

Source: Yole, Gartner, and Bernstein analysis

EXHIBIT 255: **For silicon-based power modules, chips are 44% of the module price, according to the disclosure of StarPower**

Si-based Power Module Cost Breakdown	
GM of StarPower High-Current Module	28%
Materials as % of COGS	90%
Chips as % of Materials	65-70%
Chips as % of Module Value	**44%**

Source: Company reports and Bernstein analysis

EXHIBIT 256: **Semiconductors represent 20-64% of the total SiC module cost, according to some estimates**

SiC-based Solution System Cost Breakdown

	Infineon Estimate (PV Inverter)	Yole Estimate (for a Module from ROHM)	Cree Estimate (EV Boost Converter)	NREL Estimate
Semiconductor	61%	64%	20%	27%
Non-semiconductor	39%	36%	80%	73%

Source: Infineon, Yole, National Renewable Energy Laboratory (NREL), and Bernstein analysis

CONTENT PER HP IS A BETTER METRIC AS IT ALLOWS US TO SCALE THE CONTENT ESTIMATE ACCORDING TO VEHICLE POWER OUTPUT

While content per vehicle and per inverter/module are the commonly used metrics, content per hp or, more precisely, per power output is actually a better measurement unit because the use of semiconductors is approximately proportional to the amount of power that needs to be managed. For example, known for their acceleration performance, Models 3 and Y have power outputs as high as 340kW (equivalent to 456hp) and will have higher-power

[48] https://chargedevs.com/newswire/teardown-expert-sandy-munro-compares-tesla-nissan-jaguar-inverters/

semiconductor content. VW's ID.4, with 201hp[49] (equivalent to 150kW) (see Exhibit 257), is more suitable for the mainstream segment and should have lower-power semiconductor content.

Taking a weighted average, we estimate a Model 3 and Model Y car has 290kW on average and accordingly, convert all estimates above to a per kW basis, as summarized in Exhibit 258. This conversion is important as it enables us to adjust our model based on a per hp assumption. It is also important as the EV cost target, including that for the supporting power electronics, set by the US DOE and many companies from the automotive and energy industry, is also on a per kW basis. This conversion allows us to compare our SiC cost reduction assumption with the target.

EXHIBIT 257: **Tesla's EVs generally have higher performance over mainstream EV models and, therefore, higher-power output and higher semiconductor content**

EV Electric Motor Power Output (peak)

Model	Variant	Power (kW)
Model 3	RWD	211
	AWD	258
	AWD Performance	340
Model Y	AWD Long Range	286
	AWD Performance	340
ID.4	-	150

Source: Company reports and Bernstein analysis

EXHIBIT 258: **We estimate SiC module cost will be US$2.1/kW in 2021 and will fall to US$1.5/kW in 2025, mainly driven by reduction in SiC chip cost**

Unit Value of SiC Inverter & Its Components in 2021 & 2025	2021E (US$/kW)	2025E (US$/kW)	Remarks
Inverter	3.3	2.7	US$2.7/kW is also the target set by the US DOE
Module	2.1	1.5	
SiC MOSFET Chip	1.5	0.9	
Others	0.6	0.6	Assume it has no change
Others	1.2	1.2	Assume it has no change

Source: Bernstein estimates and analysis

SIC CHIP COST MAY REDUCE BY 37% OVER 2021-25 IF THE US DOE, YOLE, AND THE EXPERT WE INTERVIEWED ARE RIGHT

After establishing the baseline content estimates for 2021, we now venture into the future and begin with the forecast for SiC cost reduction from now to 2025, as it is reasonable to expect larger commercialization scale will drive cost down and the transition from 6" to 8" substrate will further accelerate that.

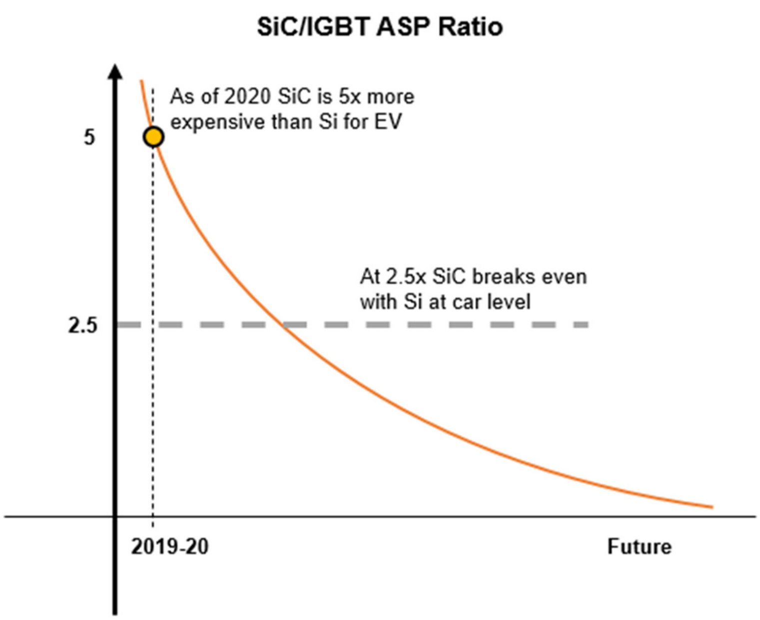
Forecasting is surely more difficult than estimating the current baseline, and we honestly don't have a lot of inputs on how fast SiC chip cost will fall. The expert we interviewed in July

[49] https://www.vw.com/idhub/content/dam/onehub_pkw/us/en/showrooms/id-4/2021/comparison/VW_ID4_ComparisonPoster.pdf

2021 expects the cost of SiC chips to drop from 4x of silicon now to 2.5x in 2025. Yole has similar forecasts and estimates the gap needs to fall to 2.5x for the saving in battery to offset the higher cost of SiC for BEV, probably around 2025 (see Exhibit 259). Both imply the SiC chip cost will fall 37% (=2.5/4-1) in this period. Most importantly, as mentioned earlier, in 2017 the US DOE and companies such as Ford, GM, BP, and Chevron together defined a technology and cost roadmap for EV[50] with their collective wisdom. They set the cost target for inverters to US$2.7/kW in 2025, which is consistent with a 37% drop from the cost of US$3.3/kW now, should we — for simplicity's sake — assume the non-SiC part stays unchanged and it is SiC chips that explain all the reduction.

Considering all these, we assume a 37% drop in SiC chip cost from 2021 to 2025 as our baseline assumption and summarize how that drop propagates through module and inverter level on a per kW basis in Exhibit 258. Despite our best guess, we acknowledge this cost reduction assumption is the most important swing factor that determines the size of the SiC market. Hence, our model offers investors the flexibility to adjust it.

EXHIBIT 259: **Yole estimates SiC cost premium over silicon needs to fall from 5x now to 2.5x to reach a breakeven at car level**



Source: Yole and Bernstein analysis

IF SIC IS ADOPTED IN 5 MILLION EVS IN 2025 AND EACH HAS 212HP, WE ESTIMATE THE SIC MARKET WILL BE US$2.4B, HIGHER THAN THE FORECAST OF STM AND CREE, BUT LOWER THAN THIRD PARTIES

The next key swing factor that decides the market size is the adoption rate of SiC in EVs. As battery electric vehicles (BEVs), especially high-end ones that have larger battery capacity, can get more saving from battery to offset the higher cost of SiC, this part of the market should have higher adoption. The expert we interviewed shared the same view. Plug-in hybrid electric vehicles (PHEVs) have inverter(s) too, but lower battery capacity and, hence, smaller headroom for saving will make the adoption of SiC much more limited.

[50] https://www.energy.gov/sites/prod/files/2017/11/f39/EETT%20Roadmap%2010-27-17.pdf

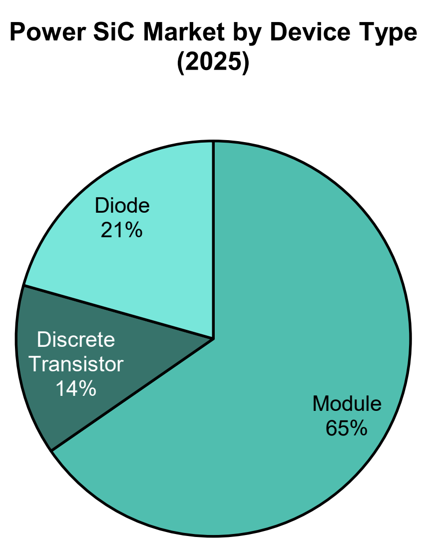
As a result, out of the volumes predicted by our European Auto team, we assume that in 2025, 65% of BEVs, 20% of PHEVs, and none of the other hybrid EVs will have SiC-based inverter(s). With these assumptions, we estimate SiC adoption will amount to ~5 million vehicles in 2025.

As discussed earlier, hp or power output rating is a critical factor too. As SiC costs drop and adoption increases, the mix of the adoption will extend downward more to the mainstream segment, and the power rating of Tesla Models 3 and Y won't be a good representation for 2025. We choose 212hp (=158kW) as our baseline as it is the average of cars in the US according to a study by the US Environmental Protection Agency (EPA).[51]

Finally, we need two more adjustments before we can derive the total SiC market size. The first is the inclusion of diode, on-board charger (OBC), and DC-DC converter. Our discussion so far only covers transistors used in inverters, but SiC can be used as diodes in these modules too. We assume this adjustment brings another 30% to the inverter transistor demand in EV, based on the inputs from Yole (see Exhibit 260 and Exhibit 261) and IHS (see Exhibit 262). The second adjustment is to incorporate SiC used in non-EV applications, based on the limited data available; we assume these applications to bring another ~US$1bn SiC demand in 2025 per the forecast from Yole (see Exhibit 263).

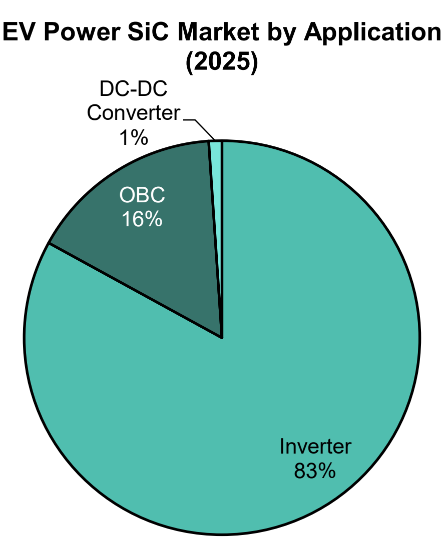
Putting it all together, our model finds the SiC market will be US$2.4bn in 2025, with US$1.4bn from EV and the remaining US$1bn from other applications (see Exhibit 264). Compared to what Exhibit 254 summarizes, this is lower than the forecasts from STM and Cree, but higher than the predictions from third parties.

EXHIBIT 260: **Yole projects 21% of the power SiC market will be diodes in 2025**



Source: Yole estimates (2025) and Bernstein analysis

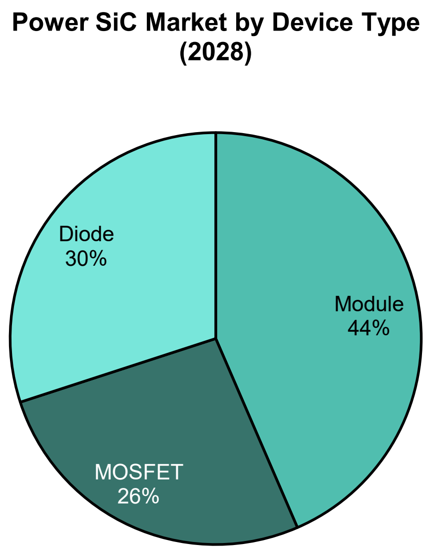
EXHIBIT 261: **In 2025, 17% of SiC used in EV will be for OBC and DC-DC converter, according to Yole**



Source: Yole estimates (2025) and Bernstein analysis

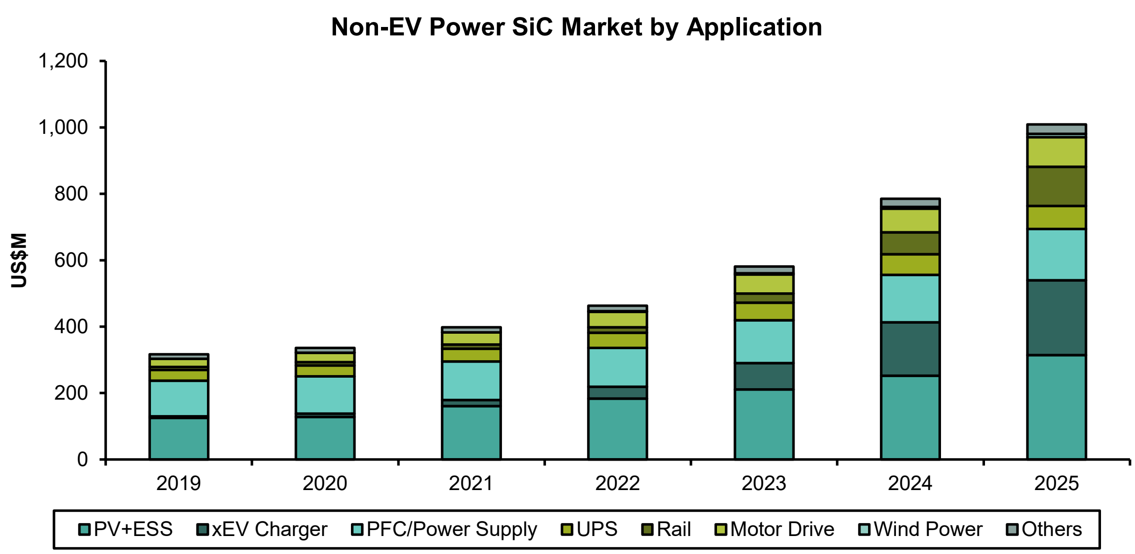
[51] https://jabberwocking.com/raw-data-horsepower-of-new-vehicles-in-the-us/

EXHIBIT 262: **IHS forecasts 30% of the power SiC market will be diodes in 2028**



Source: IHS estimates (for 2028) and Bernstein analysis

EXHIBIT 263: **Yole forecasts the non-EV power SiC market to reach ~US$1bn in 2025**



Source: Yole data and estimates (2020+) and Bernstein analysis

EXHIBIT 264: **We estimate the power SiC market to be US$2.4bn in 2025**

Power SiC Market Size Estimate

Forecast Assumptions		Remarks
Horsepower Assumption		
Target Horsepower per Vehicle (hp)	212	The avg of US cars per EPA; 247 hp if other vehicle types are included
kW per Horsepower	0.75	
Target Power Output per Vehicle (kW)	158	
Penetration Assumption		
BEV Shipment (M Unit)	6.8	Forecast of Bernstein European Auto team
SiC Penetration in BEV	65%	Assumption
PHEV Shipment (M Unit)	3.2	Forecast of Bernstein European Auto team
SiC Penetration in PHEV	20%	Assumption
BEV/PHEV with SiC (M Unit)	**5.1**	
Format of SiC Adoption		
% of Chip	30%	Assumption but calibrated with inputs from IHS and Yole
% of Module	70%	
SiC Content per Vehicle Estimate		
Value of SiC Diode & SiC Used in OBC, etc. vs. Inverter	30%	Assumption but calibrated with inputs from IHS and Yole
SiC Chip Value per Vehicle (US$)	188	
SiC Module Value per Vehicle (US$)	317	
Blended Average Value per Vehicle (US$)	**279**	
SiC Content per Vehicle Estimate		
SiC Chip Market Size from EV (US$M)	**1,415**	
Non-EV SiC Market Size in 2025 (US$M)	1,009	Forecast of Yole
Total SiC Market Size in 2025 (US$M)	**2,424**	

Source: Yole, IHS, US EPA, and Bernstein estimates and analysis

COST REDUCTION (ESPECIALLY FROM SUBSTRATE), ADOPTION BY EV, AND HP ARE KEY SWING FACTORS; SO IS ADOPTION OF NON-EV APPLICATIONS

Among all variables, cost reduction presents the largest uncertainty. And among all subcomponents of the cost, substrate brings the most uncertainty. Substrate represents a large part of the chip cost (see Exhibit 265), and the apparent supply constraint and subsequent long-term supply contracts may make its price significantly deviate from the long-term trend the industry tries to adhere to. On the other hand, capacity is being added, China is entering the market, and Cree estimates the transition from 6" to 8" promises to lower cost by ~40%. Whether substrate makers can overcome technological challenges is also a big question. Finally, price elasticity will result in more demand, and our model does not incorporate this relationship. Overall, substrate is key to the future of SiC, and we will devote more energy to it in our future research.

How many EVs the world will have in 2025 alone is a difficult question to start with. How many of them will have SiC is even harder to answer. Roughly, SiC content should be ~US$280 per vehicle in 2025, and readers can adjust their forecasts based on different views on EV and SiC adoption.

As discussed earlier, the hp of the vehicle directly affects the use of power semiconductors and the size of the SiC market. Approximately, adding 1 hp to each of the EVs that adopt SiC will result in US$6.7mn more to the SiC market size in 2025.

Finally, though they are not getting as much attention, many non-EV applications are adopting SiC too, and they together amount to a significant part of the overall SiC market (~40% in 2025 in our model). Infineon's SiC business had a late start in the EV segment but has a much stronger position in the non-EV part. That should give some comfort to the investors of the stock.

EXHIBIT 265: **At wafer level, SiC substrate represents about one-third to one-half of the total cost**

SiC Chip Cost Breakdown

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
SiC Substrate	55%	44%	42%	40%	35%
Subsequent Processes	20%	56%	38%	40%	45%
Yield Loss	25%		20%	20%	20%

Source: Yole, NREL, and Bernstein analysis

OVERALL, WE MAINTAIN OUR POSITIVE STANCE ON INFINEON AND REITERATE OUTPERFORM

The model we build provides a framework to estimate the SiC market, but is nowhere accurate enough to reach a definite and quantitative view on Infineon's future in this technology. More research is needed, but we maintain a positive outlook and reiterate an Outperform rating on the stock as we believe: (1) silicon will be still very meaningful for EV revolution in the next four to five years, and (2) the competition in SiC is still too early to predict who the final winners/losers are.

INVESTMENT IMPLICATIONS

We rate Infineon **Outperform**, with a target price of €39.

ROBOTAXIS IN CHINA: THE FUTURE OF ROAD TRAVEL?

OVERVIEW

Driverless taxis, also known as robotaxis, can be used commercially in China. Robotaxis were launched in May 2021 by Baidu with a fixed fare of RMB30 per ride. Current usage is limited to a small area in the Shou-Gang Industrial Park in western Beijing at a range of ~3km (a round trip of the area). In the next three years, Baidu plans to expand robotaxis to 3,000 vehicles in 30 cities. Unlike the West, China is likely to take the vehicle to everything (V2X) approach, which leverages roadside infrastructure to provide additional support for the autonomous driving (AD) algorithm, reducing hardware costs compared to the standalone strategy more commonly used in the US and Europe.

- **Safety is still the foremost concern, but Chinese passengers show high acceptance of AD and robotaxis.** Only 35% of Chinese passengers think AD is not safe, while 84% prefer robotaxis over owning a driverless car even if the monthly cost of a robotaxi is more than 20% higher.

- **Though we do not think wide adoption will happen soon, robotaxis should ultimately replace traditional cars in the private mobility service sector (taxis, ride hailing, and car rentals) — an RMB900bn market as of 2021 likely growing to RMB1,200bn in 10 years.** China has the largest private mobility service market in the world, accounting for ~35% of global totals and leading the second-largest market (US) by 70%. We expect robotaxis to take a meaningful share of this market once the concerns of safety, riding fee, and availability are behind us. Baidu, Didi Chuxing, and Huawei are leading the application of this driverless technology. Together, they have cumulated over 500,000km of safe driving. However, until robotaxis get a bulk volume of operating data, passengers may have reservations. Hence, operators will have to offer attractive incentives to passengers at the beginning, including free-rides, deep discounts, or additional safety measures, through the investment period.

- **Robotaxis will likely disrupt ride hailing. Leading player Didi is getting ready for the change.** Taking out the most expensive component, the driver, which is ~50% of the operating cost for ride hailing, robotaxis can be profitable at a running cost of RMB1 per kilometer, 50% below the average fee charged by Didi.

- **Didi is in a privileged position, with the opportunity to enhance its driverless technology through the tremendous data contribution by the drivers on its network.** With 10+ million ride-hailing cars running on the road every day, Didi processes a vast amount of road data through its 550 million users on the ride-hailing app, Didi Chuxing. Didi expects mass production of autonomous vehicles by 2025, targeting more than

1 million robotaxis by 2030, representing 3.3% of the currently registered vehicles on its platform.

- **Motorized travel is already on the rise after Covid-19; robotaxis may boost car rental demand for Trip.com**, which saw a significant increase in car rentals after Covid-19. Rental volume already recovered to see growth in 2020 at 30% YoY. This growth accelerated to 155% versus 2019 during the Qing Ming Festival in 2021. AD/robotaxis may boost car rental use further as travelers can enjoy vacations without having to drive in an unfamiliar location.

ROBOTAXI IS ABOUT TO TAKE OFF IN CHINA

Baidu is close to making driverless taxis (also known as robotaxis) in China a reality. The company received approval in May 2021 to offer paid robotaxi service in the Shou-Gang Industrial Park in western Beijing. This marks a milestone for the wide usage of robotaxis in the future. Baidu offers driverless robotaxi service in the 1 million sqm theme park (see Exhibit 266 and Exhibit 267). Customers have to go to designated stops to get on/off the taxi, and the total distance covered is about 3km. Currently, each ride has a fixed price of RMB30, but the company offers promotions during the Labor Day holiday for an Industrial Park entry ticket (worth RMB40) per taxi ride. Baidu currently has 10 cars in operation but plans to increase the number to 100 during the 2022 Beijing Winter Olympics and to 1,000 in 2025, serving the entire Shou-Gang area. The operation so far has been smooth, which gives us confidence that the technology of robotaxis is near a turning point.

Apart from Beijing, Baidu also received a permit to operate a public robotaxi service in Changsha (Hunan) and Cangzhou (Hebei). The operations are confined to pre-approved roads and require a passively seated safety driver in case things go wrong. In order for Baidu to offer AD service to the public, it has to pass the standards set by the local government. For example, Cangzhou requires 50,000km of total testing mileages as well as 10,000km+ to be driven per car. It took Baidu ~30 cars to be tested over four to five months to meet the requirement.

If the pilots are successful, Baidu plans to expand the robotaxi service to 30 cities and increase the number of vehicles to 3,000+ in three years.

EXHIBIT 266: **Baidu robotaxi in operation**

Source: Wikimedia Commons

EXHIBIT 267: **Area allowed for use of Baidu robotaxis in the Shou-Gang Industrial Park (3km per round trip ride)**

Source: Wikimedia Commons

WHAT IS ROBOTAXI DEVELOPMENT HISTORY IN CHINA?

Standards of AD

The Society of Automotive Engineers (SEA) sets five levels of AD, which are commonly used globally.

- **Levels 1 and 2:** A human (driver) is still in charge of driving ,while the advanced driver assistance system (ADAS) provides one (for L1) or multiple (for L2) features that help the driver avoid potential dangers/risks. Typical features include the likes of electronic brake assist (EBA), electronic stability program (ESP), traction control system (TCS), blind spot protection (BSP), lane departure warning (LDW), and lane-keeping assist (LKA).

- **Level 3:** The computer starts to take control over the vehicle. L3 is for conditional AD, where the autonomous system is responsible for driving the car, but the driver may be requested to take control under certain circumstances when the algorithm senses risks. L3 is also restricted to certain (easier) settings such as city, highway, and industrial parks. A robotaxi usually starts from at least L3.

- **Level 4:** The major difference compared to L3 is that L4 eliminates the human component, and the algorithm is authorized to operate from start to finish.

- **Level 5:** This is fully AD, without any constraint or condition attached.

Stages of robotaxi development

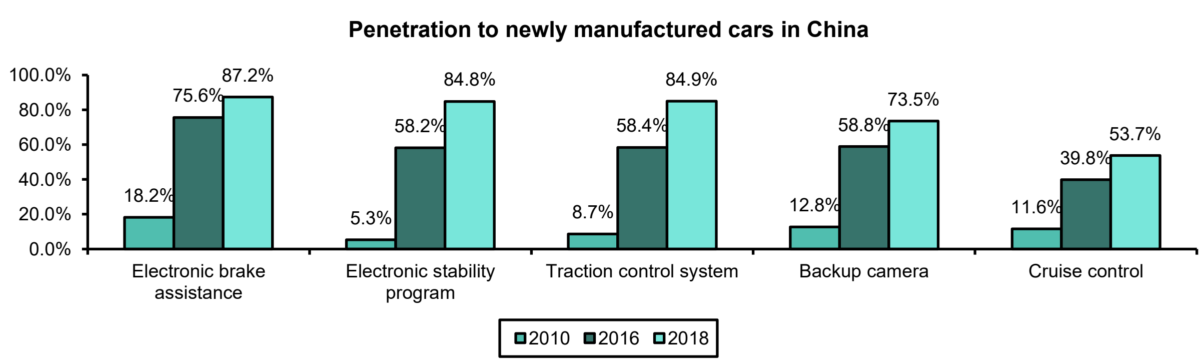
The development of AD in China can be broadly defined in three stages:

- **Phase 1 (2010-16) — The "Renaissance of Autonomous Driving":** The most typical signature of the era is the fast adoption of L1 technology in the country. Before 2010, there were negligible "smart features" in cars in China, but since 2010, some key ADAS features quickly gained traction. Penetration of EBA increased massively from only 18.2% (2010) to 75.6% (2016); and we note similar progresses made in ESP (from 5.3% to 58.2%), TCS (from 8.7% to 58.4%), and backup camera (from 12.8% to 58.8%). In 2017, nine of the leading Chinese automotive manufacturers signed a "Letter of Commitment to Equip ECS in New Cars," a unilateral consensus among Chinese manufacturers to ensure the adoption of key L1 functionalities. Compared to the US and Europe, China started ADAS adoption relatively late, but it caught up quickly. In 2018, it almost reached similar penetration levels as its developed peers (see Exhibit 268).

- **Phase 2 (2016-20) — The "Catching up on L2 Technology":** Chinese drivers started to access some of the more advanced ADAS functionalities in L2. Penetration of active braking rose quickly from nil (2016) to 24.2% (2020); similar trends occurred in 360-Panorama (from 3.9% to 24.2%), LDW (from 3.3% to 25.0%), BSP (from 2.3% to 19.3%), and LKA (from 0% to 18.5%). During this period, China was comfortably in the top tier of the global market in terms of advanced L2 adoption (see Exhibit 269).

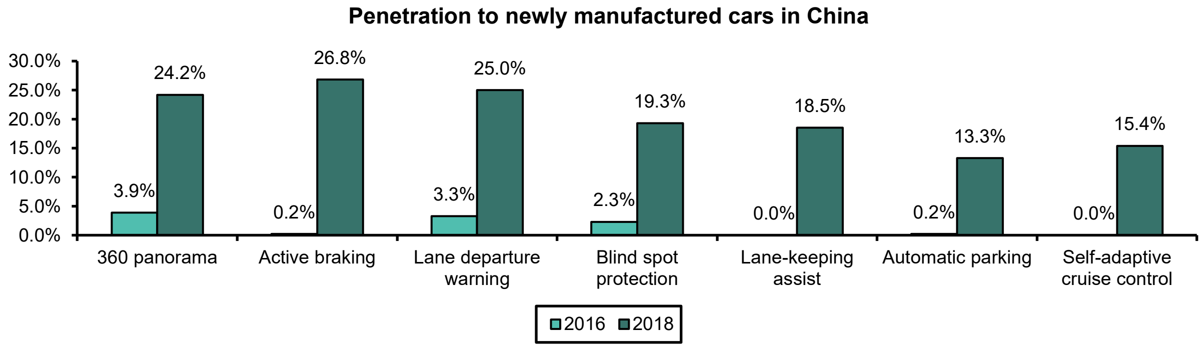
- **Phase 3 (2021 and beyond) — The "Emergence of True Automation":** 2021 is the year that L3 takes off in China. Both new-generation auto brands and traditional ones in China have rolled out exciting products with L3 capabilities: ET7 by NIO, P5 by XPEV, IM by SAIC, ARCFOX by Beijing Automotive Group, etc. China appears to be ahead of the US, Europe, and Japan in L3 rollout, which shows high customer acceptance as well as Chinese manufacturers' advanced technical competency in AD. Due to high overlap among hardware components, we believe the country's advanced progress in L3 sets a promising foundation for L4/L5; e.g., according to Yole Development, production cost of mechanical Lidar drops by 70% when its production increases from 1.2 million to 4.0 million, which will make AD economically viable for commercial deployment.

EXHIBIT 268: **China adopted L1 technology quickly between 2010 and 2016; L1 penetration increased further afterward**



Source: Autohome, Bosch, and Bernstein analysis

EXHIBIT 269: **L2 technology picked up rapidly in just four years between 2016 and 2020**



Source: Autohome, Bosch, and Bernstein analysis

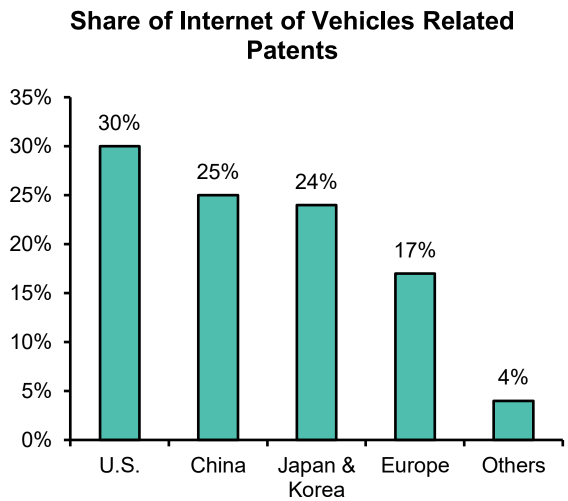
ROADMAPS TO AD AND CHINA'S CHOICE

There are two major paths to AD: standalone and V2X. The standalone approach builds everything into the car, while V2X takes road infrastructure into consideration (such as cameras on streetlights) for additional inputs. V2X is an efficient method to reduce car manufacturing costs (due to fewer on-car sensors needed) and lower the difficulty of algorithm to realize AD. Baidu estimates V2X can solve 54% of the algorithm bottlenecks currently in the standalone path. The downside is also obvious: to realize V2X, governments and corporates need to build supporting infrastructure, which may cost RMB1mn per 1km of road.

- Currently, players in the US and Europe are taking the standalone approach, while China will most likely take the V2X path. China is second globally in the number of Internet of Vehicles-related patents, behind the US (see Exhibit 270), but far ahead in C-V2X-related patents (see Exhibit 271). In terms of government policies too, we don't see any holdback — government policies show the country is committed to building up V2X infrastructure as fast as possible (see Exhibit 272). Lastly, we think China has the money to do it. The country has 150,000km of highways and 110,000km of tier 1 roads, so the total cost of tier 1+ roadside V2X upgrade shall be no more than RMB300bn, which is manageable compared to the RMB400bn investment in the Beijing-Guangzhou high-speed railway alone.

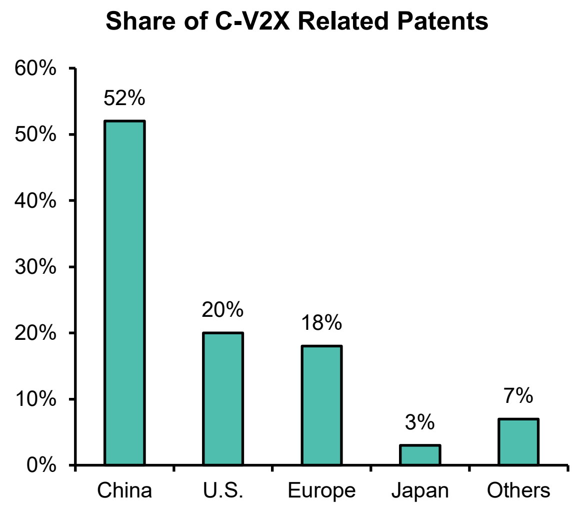
- We believe V2X offers China a golden opportunity to surpass the US in AD and robotaxi advancement due to its efficient reduction of algorithmic difficulties and cost of hardware. Western countries have made limited progress in V2X so far due to lack of government funding and citizen concerns regarding data privacy.

EXHIBIT 270: **China ranks second globally in the number of Internet of Vehicles patents...**



Source: China Institute of Communication and Bernstein analysis

EXHIBIT 271: **...but leads by a large margin in C-V2X patents**



Source: China Institute of Communication and Bernstein analysis

EXHIBIT 272: **Government orders and guidance related to V2X**

Year	Orders and Guidelines	Content Related to Autonomous Driving & V2X
2018	*"2018 Key Points of Standardization of Smart Connected Vehicle"*	Expedite establishment of industry protocol for smart vehicles; analyze feasiblity of building LTE-V2X networks
2019	*"Launch of Trial Programs for Telematics and Maps for Autonomous Driving"*	Organize building up of high-definition autonomous driving maps, and initiate data collection for future development of autonomous driving industry
2020	*"Innovation and Development Strategies for Smart Vehicles"*	The country to have LTE-VEX in key regions and 5G-V2X in selected cities and highways by 2025
2020	*"Technical Specification for Infrastructure (Road) Supporting Autonomous Driving"*	The country to post autonomous driving related guidelines for road infrastructure
2020	*"Industrial Development Plan for New Energy Vehicles"*	Research to break through technical difficulty in V2X and high-definition autonomous driving maps

Source: Media reports and Bernstein analysis

With regard to the regulatory regime in China, local governments have the authority to set their requirements and standards for robotaxi approval. There are three types of licenses: testing, operations, and driverless.

- Testing license is the easiest to obtain because a safety driver is required in the car to handle any potential crisis and no passenger is allowed.
- Operations license allows taking in passengers (with the presence of a safety driver) and is harder to get. For example, Guangzhou requires: (1) 30,000+km of accumulative testing mileages, (2) a remote safety driver per car, and (3) a "companion" car following each testing car.
- Driverless license is the hardest to get as no safety driver is physically involved in the trip.

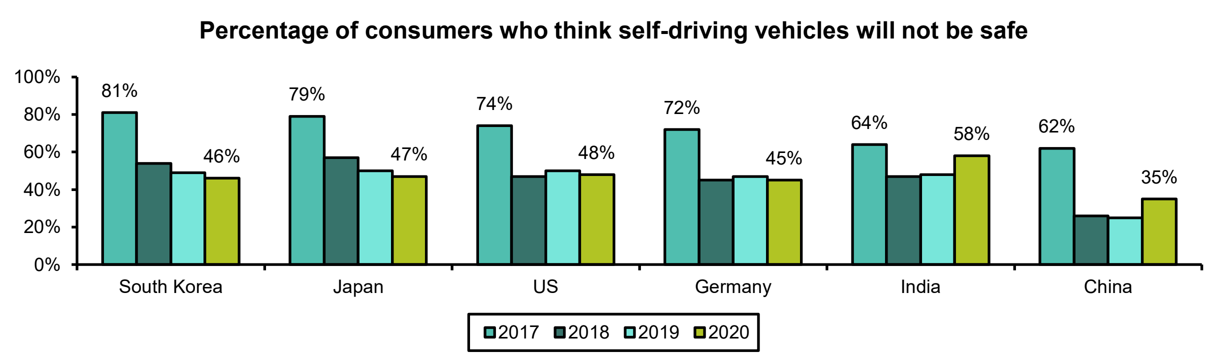
Compared to the US, China's regulatory requirements on AD are less stringent. For example, California Department of Motor Vehicles (DMV) demands that no safety driver be involved in the operation of driverless cars, even remotely. This is because Waymo pushed for a higher standard in October 2018 when it helped California DMV draft the guidance. On the contrary, cities in China have no problem allowing remote safety drivers, which greatly enhances the feasibility of a robotaxi operation. The more open policy in China helps with the industry advancement.

CHINESE SHOWING HIGHER ACCEPTANCE TO AD

Chinese passengers show high acceptance for the concept of AD and robotaxi. In a recent survey by Deloitte of consumers in six countries (with +1,000 respondents in each), Chinese consumers showed the least concerns on safety for taking driverless vehicles — only 35% respondents think they are "not safe" compared to an average of ~50% for other countries (US, Germany, Japan, etc.). Moreover, this percentage (in China) has seen a dramatic drop from 62% in 2017 (see Exhibit 273). Concurring with the Deloitte survey, AlixPartners' survey of customers' perception of higher-level (L4) AD again showed Chinese passengers' higher acceptance rate as well as a higher willingness to pay for premium L4 features (see Exhibit 274 and Exhibit 275).

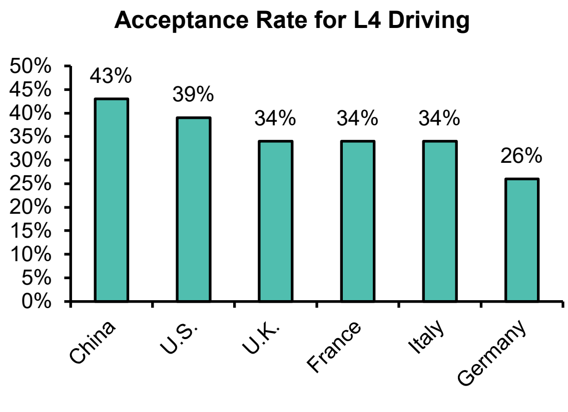
Regarding the choice between owning a driverless car versus a robotaxi, Chinese consumers showed extreme preference for the latter (see Exhibit 276). The same survey from AlixPartners revealed that when the monthly cost of a robotaxi is no more than 20% higher than owning a driverless car, 84% of Chinese passengers prefer robotaxis — a rate much higher than in other countries. Such a tendency (maybe due to the inconvenience of owning a car) implies a promising demand outlook for robotaxis in China.

EXHIBIT 273: **Only about 35% of respondents in China think driverless cars are not safe, significantly lower than other countries**



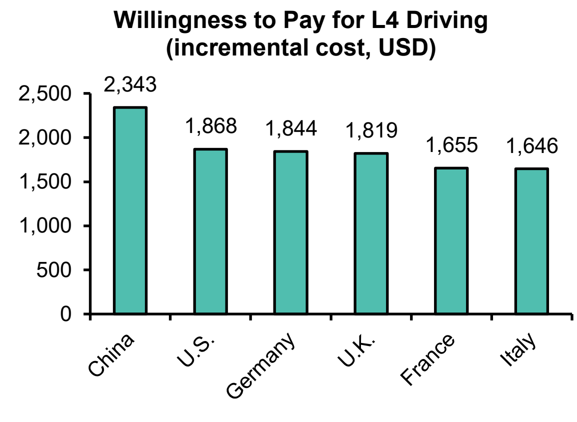
Source: Deloitte, Statista, and Bernstein analysis

EXHIBIT 274: **The acceptance rate for higher-level (L4) automation is higher for China...**



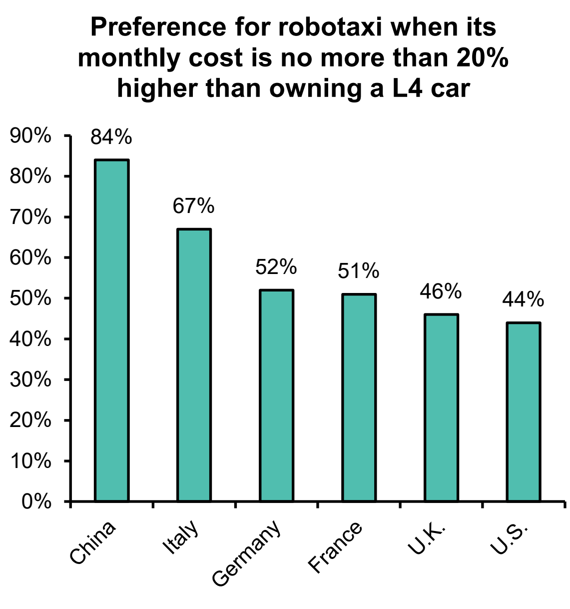
Source: AlixPartners and Bernstein analysis

EXHIBIT 275: **...as is the willingness to pay**



Source: AlixPartners and Bernstein analysis

EXHIBIT 276: **Chinese consumers also have a very high preference for robotaxis versus owning a driverless car**



Source: AlixPartners and Bernstein analysis

ROBOTAXI RACE IN CHINA

Apart from Baidu, Didi and Huawei are also in the process of commercializing AD in China.

- Didi is a natural player in robotaxis as it operates the largest ride-hailing platform in China. It started research on robotaxi back in 2016 and spun off the robotaxi division in 2019 as a standalone entity (see Exhibit 277). The Didi Robotaxi company has gained three rounds of financing with a total funding of US$1.1bn as of 2Q2021 (see Exhibit 278), the highest amount raised by any AD company in China. In June 2020, it successfully launched its first robotaxi operation that could take in passengers (see Exhibit 281). Until now, more than 50,000 passengers have tried the service in

Shanghai. The company plans to continue deepening the collaboration with hardware suppliers and auto manufacturers to design and produce 1 million robotaxis with L4 intelligence by 2030, which can be deployed on its ride-hailing platform. The company's main edge in this business is its massive ride-hailing platform that provides extremely valuable traffic situation data and application scenarios for its robotaxis.

- **Huawei** takes a different approach. As a company with strong hardware manufacturing capability, it aims to provide a total solution that includes both hardware (Lidar, SoC, etc.) and software (AD algorithm) to serve traditional auto manufacturers. It started its relevant research in 2018, having built a team of 2,000 people for AD software and 1,000 engineers for related hardware engineering. Its signature product is the ARCFOX Alpha S L4 sedan launched in April 2021 in collaboration with Beijing Automotive Group (BAIC) (see Exhibit 282). This car is the first in the country to be suitable for L4 AD in select urban areas in China, equipped with in-house-developed SoC and advanced 96-beam Lidar. Going forward, Huawei has planned to collaborate with Chang'An Auto and Guangzhou Automobile Group (GAC) in pipeline and will adhere to its collaboration mode with auto manufacturers.

- Coming back to **Baidu**, a software company at its core, Baidu aims to build "Android for Cars" — it has built its famous open-source AD platform Apollo. The company has invested RMB100bn in the past 10 years on AD technology and accumulated 10 million km of road-testing mileages (a distant leader in China). It surpassed Waymo in California DMV's 2019 disengagement testing, becoming the world's No. 1 in testing (see Exhibit 279). The company targets to have Apollo installed in over 1 million cars by 2024.

Baidu also has its own robotaxi service. Leveraging its Apollo platform and working with hardware suppliers and auto manufacturers, it has built a fleet of 500 cars, compared to 100 for Didi (see Exhibit 280). Its first public robotaxi operation was launched in Changsha in April 2019, followed by its first driverless robotaxi operation in Beijing's Shou-Gang Industrial Park in May 2021. So far, the company's robotaxi business has attracted more than 210,000 passengers with operations in Beijing, Changsha, and Cangzhou. Baidu targets to expand to 30 cities with 3,000+ cars running by 2023.

EXHIBIT 277: **Didi Robotaxi key milestones**

Time	Milestones
2016.7	Form of autonomous driving team
2017.3	Set up U.S. Research Academy focusing on big data & autonomous driving
2018.1	Set up China AI Lab and started heavily recruiting autonomous driving talents
2018.5	Gain road testing license in California
2019.8	Upgraded autonomous driving division to be standalone entity
2019.9	Gain road testing license in Suzhou, Jiangsu
2019.12	Formed collaboration with Nvidea in GPU and cloud computing
2020.6	Launched robotaxi operation in Shanghai accepting passengers

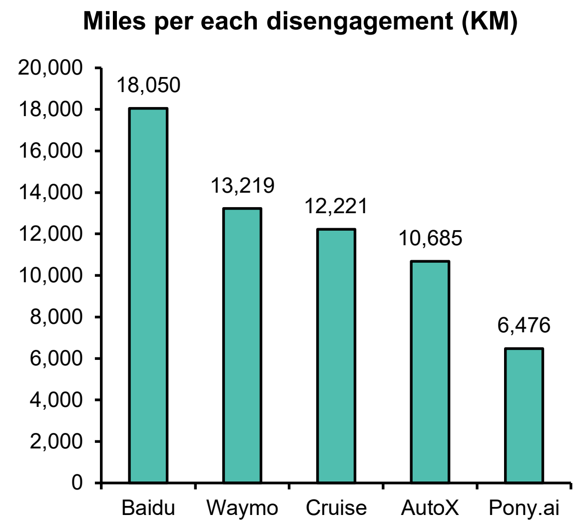
Source: Company website and Bernstein analysis

EXHIBIT 278: **Didi Robotaxi funding history**

Time	Investing Funds	Money Raised
2020.5	Softbank Vision Fund	US$ 500 MN
2021.1	IDG, CPE, RCFSI, etc.	US$ 300 MN
2021.5	GAC	US$ 300 MN
Total		**US$ 1,100 MN**

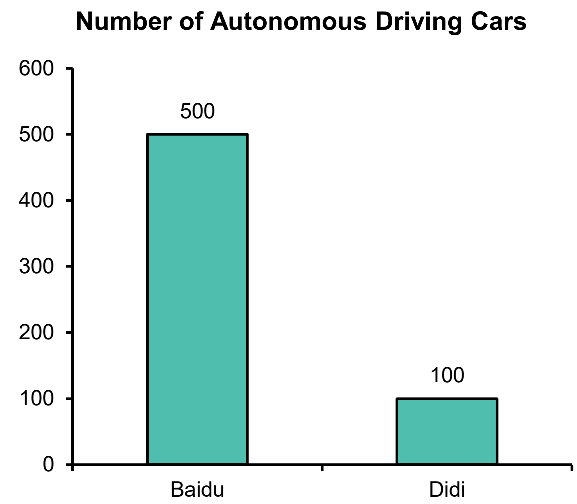
Source: Media reports and Bernstein analysis

EXHIBIT 279: **Baidu surpassed Waymo in disengagement test**



Source: California DMV and Bernstein analysis

EXHIBIT 280: **Baidu also has the largest AD fleet in China**



Source: Baidu, Didi, and Bernstein analysis

EXHIBIT 281: **Didi Robotaxi in Shanghai**

Source: Wikimedia Commons

EXHIBIT 282: **ARCFOX Alpha S with Huawei**

Source: Wikimedia Commons

To compare these three players in China's AD market, we look at four key areas (see Exhibit 283):

- **Patents and licenses:** Baidu is a distant leader in this category at the moment. It has accumulated 2,900 patents (in AD) and 221 testing and operating licenses, including 179 passenger-related ones, representing half the licenses released in the country. It is also the only player with a permit for driverless robotaxi operations (in Beijing). On the other hand, Didi has a testing license in Beijing and Suzhou, and an operating license in Shanghai; while Huawei mainly has a testing license in Hangzhou. However, we believe the current license advantage does not necessarily create an advantage for Baidu as other players also have the opportunity to build up their license portfolio going forward as long as their technology advances — we don't see any constraint in terms of policy to make Baidu's advantage exclusive.

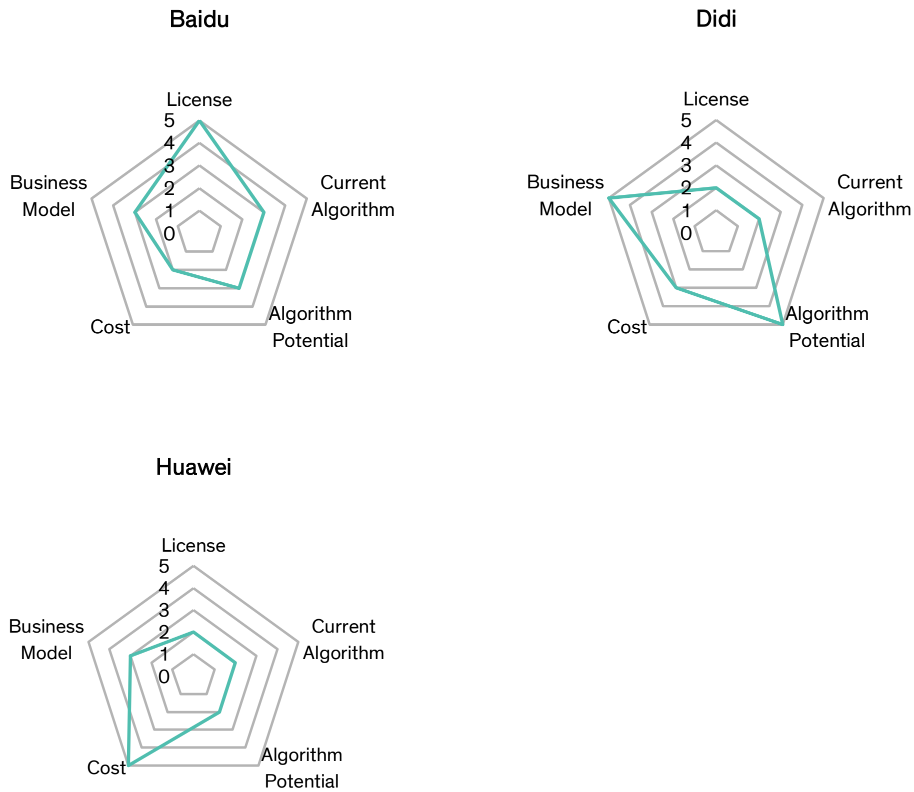
- **R&D and algorithm:** Baidu currently leads in this category too. Having invested RMB100bn in the past 10 years, the company has attracted 550,000 developers to its Apollo platform who have produced 700,000 lines of code. Leveraging 10 million km road-testing mileages, it has the most trained algorithm among all. In comparison, Huawei has built a team of 3,000 people working in AD-related algorithm and hardware engineering, with an annual spend of ~US$1bn in the past three years (compared to US$3bn for Baidu). It claimed to have achieved a 1,000km disengagement rate under city circumstances.

However, going forward, we think Didi has the highest upside, thanks to its massive ride-hailing business. Didi installed the "Jushi" system years ago on each driver's car, which has a front-facing camera that in aggregate collects 100 billion km of real traffic video footages every year. These footages can then be screened to select those that can help train the AD algorithm. Such an amount of data is unparalleled and unthinkable by any other competitor and, if used efficiently, shall help Didi soon catch up and surpass leading players in algorithm training.

- **Cost:** Huawei is a clear leader in this category. The standard version of ARCFOX Alpha by BAIC is sold at RMB250,000-RMB340,000, while its premium version with Huawei L4 functionality is priced at RMB390,000-RMB430,000, implying the "value" of Huawei L4 solution (including hardware) to be RMB100,000-RMB150,000. On the other hand, the AD cars built by Didi and Baidu currently cost more than RMB1mn each. Huawei is able to achieve such cost advantage due to its super strong supply chain capability — it has in-house development and manufacturing of key components of Lidar and SoC (computing unit for AD). Its 96-beam Lidar costs a surprisingly low US$200, 80% lower than the average cost in the industry. Going forward, we believe all players can benefit (cost-wise) from deeper collaboration with auto manufacturers and reduced key component prices, thanks to progress in mass production.

- **Leverage of existing business model:** We think Didi's business model stands out as its massive ride-hailing platform offers both data and an immediate use case for robotaxi. For the latter, Didi enjoys a much easier path to robotaxi profitability as soon as AD results in better unit economy than a human driver (see details in the next section of this chapter), making massive adoption and production of its robotaxi fleet come much quicker. On the other hand, what we like about Huawei's model is its strong manufacturing capability of key components, which dramatically drives down the cost of its integrated solution and improves compatibility between software and hardware. Baidu's advantage lies in its strong relationship with the government (having V2X infrastructure contracts with the local governments of Guangzhou, Chongqing, Hefei, etc.) and ownership of its AD cloud, which helps a more robust integration of its algorithm with partners.

EXHIBIT 283: **Relative competitive strength in key areas (5 – strongest, 1 – weakest)**



Source: BAIC, California DMV, and Bernstein estimates and analysis

LOOKING INTO THE FUTURE

There are six major prerequisites for robotaxis to be deployed in China on a meaningful scale, which is defined here as profitable L4 robotaxi operations (remote safety drivers allowed).

- **Cost:** Robotaxi, in essence, is using AD technology to replace the human part of driving. In a tier 1 city such as Beijing, an average full-time Didi driver earns RMB7,000 per month, or ~RMB80,000 per year. Thus, the robotaxi will make sense economically when its additionally charged premium distributed on an annual basis drops below RMB80,000. Consider (conservatively) an average life expectancy of five years for an EV taxi, the total charged premium shall not go beyond RMB400,000. Currently, one Didi robotaxi costs RMB1mn to build, by our estimate. Taking out the car (Volvo XC600) part, the AD part (including hardware) costs RMB600,000, still beyond the RMB400,000 threshold, but close. We consider from earlier deductions that Huawei's AD solution (including hardware) costs about RMB100,000-RMB150,000, meaning there is significant potential for Didi to bring down costs for its AD solution. We believe hardware components production costs will dramatically drop in the next three to five years. Hence, it seems to us robotaxi will pass the economic threshold test in the next few years, possibly by 2025.

- **Algorithm:** L4 shall be enough for a smooth robotaxi operation since its scenarios can be confined (e.g., in select cities) and a (remote) safety driver can be involved. Currently, Baidu has achieved driverless L4 operation in the Shou-Gang Industrial Park in Beijing, while BAIC's ARCFOX Alpha (in collaboration with Huawei) also claimed to have achieved L4 in urban settings. Currently, there are still issues and challenges for both, but they give us confidence the technology has already reached a significant level nearing full maturity. As large amounts of data continue coming in as these products are deployed to the market, we think It is possible the algorithm will become robust enough by 2025.

- **5G:** 5G network can expedite the complex calculation process for AD and enable a reliable connection between road infrastructure and the vehicle (V2X). China currently leads in 5G adoption and infrastructure construction, and we believe the country's 5G network will be ready by 2025.

- **V2X:** China is set to adopt the V2X path. Currently, we see most major cities have released supportive government orders and guidelines and even started V2X construction. We expect V2X construction in major cities to be completed before 2025, enabling AD.

- **User acceptance:** Chinese passengers have the highest level of preference toward AD and robotaxi. However, we are aware that a negative incident related to AD safety can be a setback. Thus, it's worth paying attention to how market sentiment evolves. Another aspect involved in this consideration is user incentive. If robotaxis offer a compelling price (as is expected due to better economics than a human driving a car), customers are more incentivized to try the service.

- **Laws and regulations:** The Chinese government views AD as part of its national strategy, and all policies and regulations so far have been supportive of the industry's development. Whether the government will further open up restrictions on driverless taxi services depends on the technological advancement of the industry itself. We feel positive, based on current progress, that the industry has been gaining trust from the government and that by 2025 laws and regulations will be further expanded to ensure healthy development of the industry.

Robotaxis will probably be ready for meaningful deployment in a few years (around 2025), with full-scale operation in select cities. Such development will greatly help platforms such as Didi tackle the severe supply shortage during peak hours in major cities. By 2030, we expect the robotaxi operation to expand nationwide and become an integral part of Chinese citizens' mobility.

TAXIS AND RIDE HAILING IN CHINA

As China's middle class continues to grow, the demand for taxis and ride hailing is on a rapid rise. China boasts the world's largest ride-hailing market, with 10 billion trips booked in 2020, and we project its market size to grow at a CAGR of 5.2% till 2030. Safety perceptions have increased significantly since the outbreak of Covid-19; passengers want more "private" space in transportation and would avoid going for mass transit transportation if possible. Apart from ride hailing, taxis and rental cars are the other two major methods for private mobility.

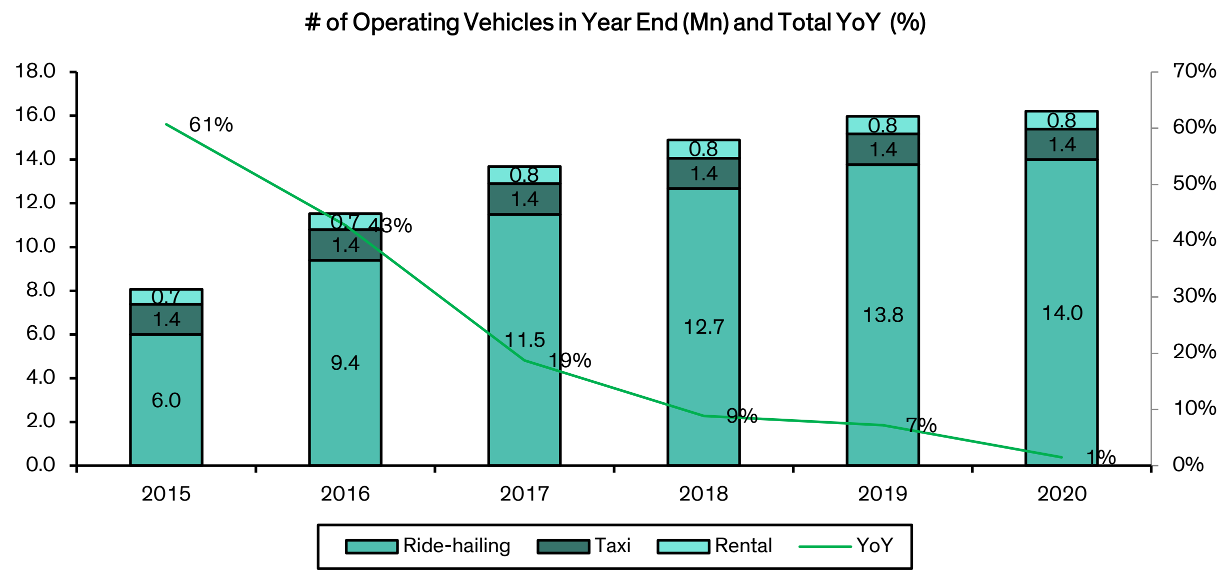
- **Taxis:** China has about 1.4 million taxis. The taxi market was worth RMB626bn in 2019 (and RMB562bn in 2020) (see Exhibit 284 and Exhibit 285). Disrupted by ride-hailing platforms, the taxi market is likely to shrink over time to RMB538bn by 2030 by our estimate (a 14% drop from 2019 levels), with the number of taxis dropping by 7% to 1.3 million.

- **Car rentals:** There are currently 0.8 million rental cars operating in China. The market size of RMB103bn in 2019 (and RMB90bn in 2020 due to Covid-19) (see Exhibit 284 and Exhibit 285) is small compared to taxis but is growing steadily. We believe the market will continue growing post 2020 due to increasing leisure and business trips. We expect the total market size to increase to RMB163bn by 2030, at a CAGR of 4.2%, and the total number of rental cars to increase by 50% to 1.2 million.

- **Ride hailing:** There are currently 14 million cars actively operating on ride-hailing platforms on a monthly basis, contributing to a total market size of RMB304bn in 2019 (and RMB250bn in 2020 due to Covid-19) (see Exhibit 284 and Exhibit 285). We expect the market to expand to RMB530bn by 2030 at CAGR of 5.2% and the number of operating vehicles to increase by 50% to 21 million, comparable to taxis. Leading ride-hailing platforms such as Didi will likely penetrate deeper to lower-tier cities and increase user engagement in top-tier cities.

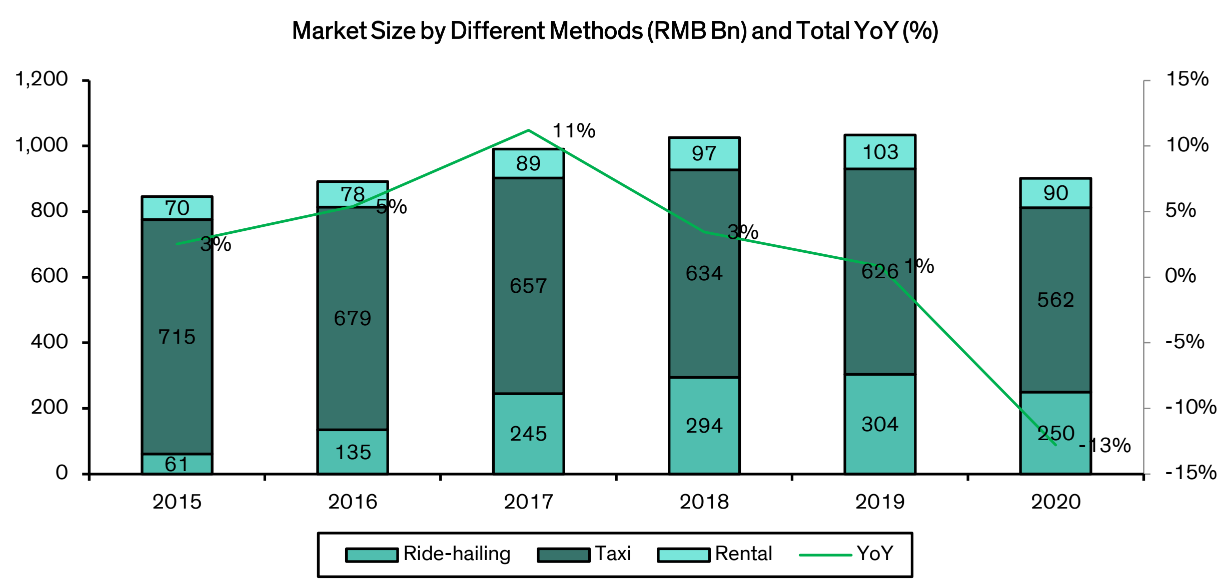
- Summing all three sectors, a total 16 million vehicles are operating in China's private mobility sector, contributing to a total market size of RMB900bn Worldwide, China leads in revenue share (35%) of the global private mobility market combining taxis, ride hailing, and car rentals, with the US in the second place (see Exhibit 286). We expect the number of vehicles in China to increase by 50% to 24 million by 2030 and the total market size to increase by 20% to 1.32 billion (see Exhibit 287 and Exhibit 288). We believe robotaxis will be a disruptive factor in the future. Didi announced it aims to roll out 1 million robotaxis by 2030, which is still a small fraction (~4%) of the total expected 24 million vehicles in 2030.

EXHIBIT 284: **The number of total operating vehicles on private mobility services has been increasing, mainly contributed by ride-hailing platforms, while the number of taxis remains flat...**



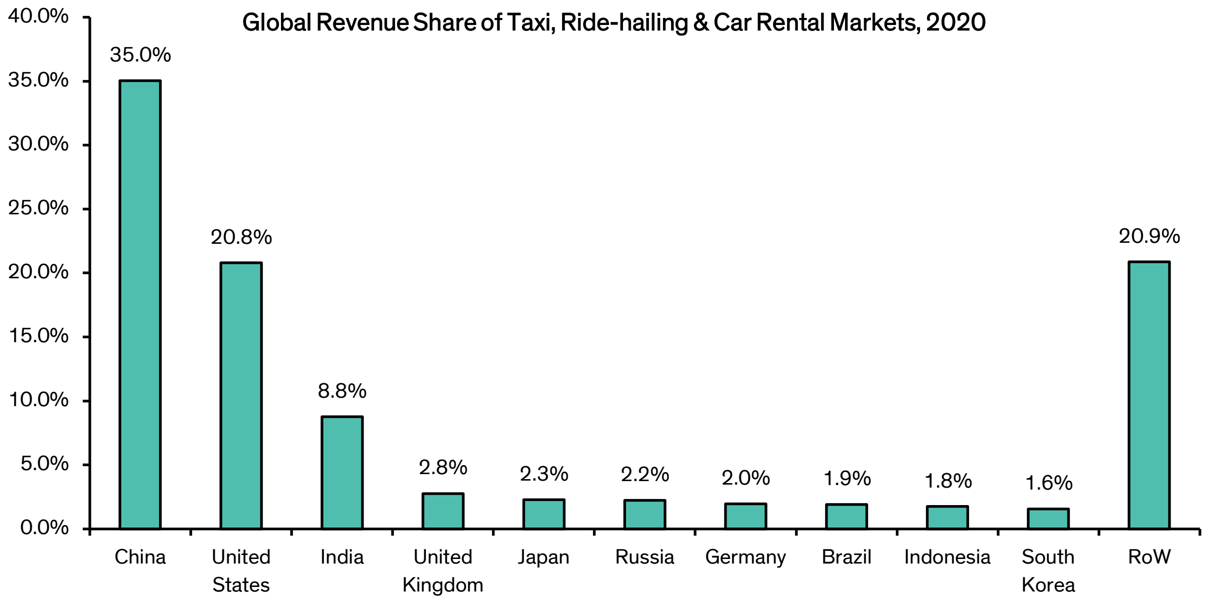
Source: Ministry of Transport China, FASTDATA, and Bernstein analysis

EXHIBIT 285: **...and the total market size has increased at a lower speed (except for a drop in 2020 due to Covid-19), with ride hailing and rentals taking shares from taxis**



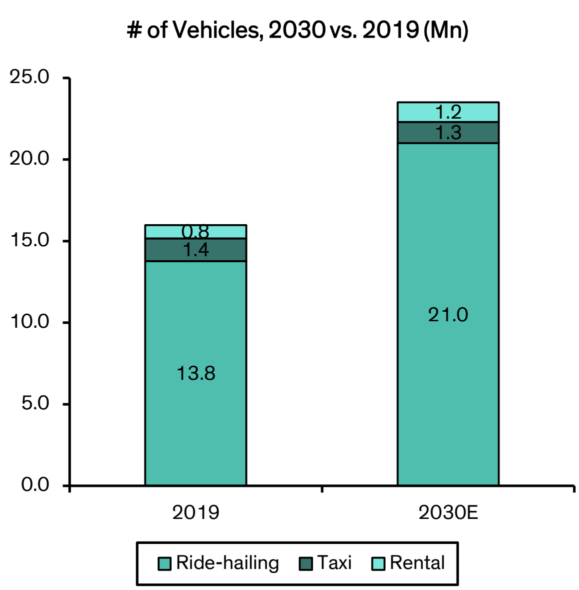
Source: Ministry of Transport China, FASTDATA, and Bernstein analysis

EXHIBIT 286: **China leads in revenue share (35%) of the global private mobility service market; its total size of RMB900bn in 2020 is 1.7x that of the US**



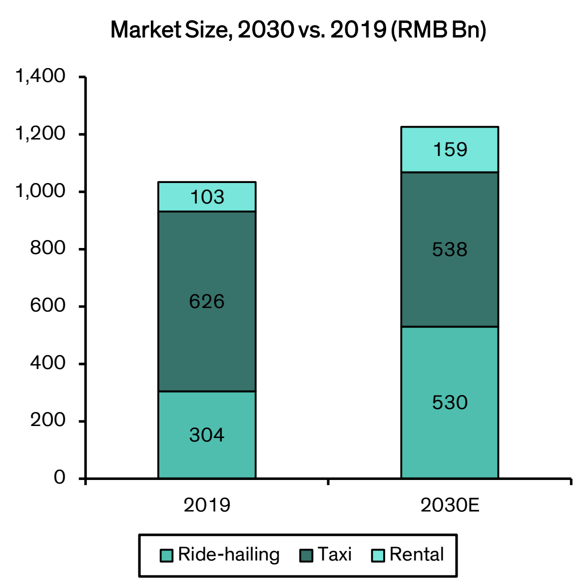
Source: Statista and Bernstein analysis

EXHIBIT 287: **We expect the number of vehicles on ride-hailing platforms to increase 50% by 2030...**



Source: Ministry of Transport China, FASTDATA, and Bernstein estimates and analysis

EXHIBIT 288: **...and the market size for ride hailing to increase by 74%, while that for taxi to drop by 13%**



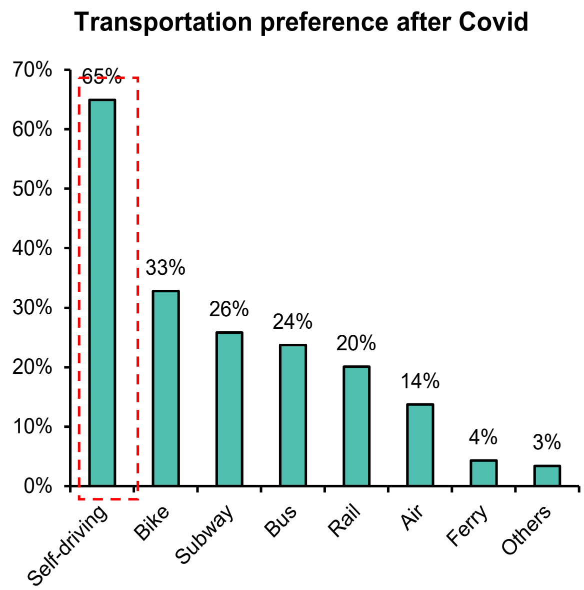
Source: Ministry of Transport China, FASTDATA, and Bernstein estimates and analysis

IMPLICATIONS FOR TRIP.COM

Short-haul road transportation, including taxi, ride hailing, and car rental, is an important component of a complete trip besides hotel and long-distance transportation (air/rail). Since the pandemic, travelers have shown strong preference for traveling options that offer more privacy. Flexibility during travel is also important, spurring demand for car rentals, especially short-term car rentals for driverless tours in 2020. More than 60% of respondents in an iResearch survey said they prefer driverless tours after the pandemic as hygiene has become the most important factor when choosing the mode of transportation. Data from FASTDATA suggested the overall scale of China's car rental market was only mildly affected during Covid-19, declining by 12% in 2020, while overall domestic travel spending decreased by more than 20%. However, car rental demand rebounded rapidly in 2H2020, and Ctrip led the car rental market recovery with more than 30% growth in 2020. This robust growth has extended to 2021. Ctrip's car rental volume increased by 82% and 155% versus 2019 during the recent Chinese New Year and Qing Ming Festival, respectively.

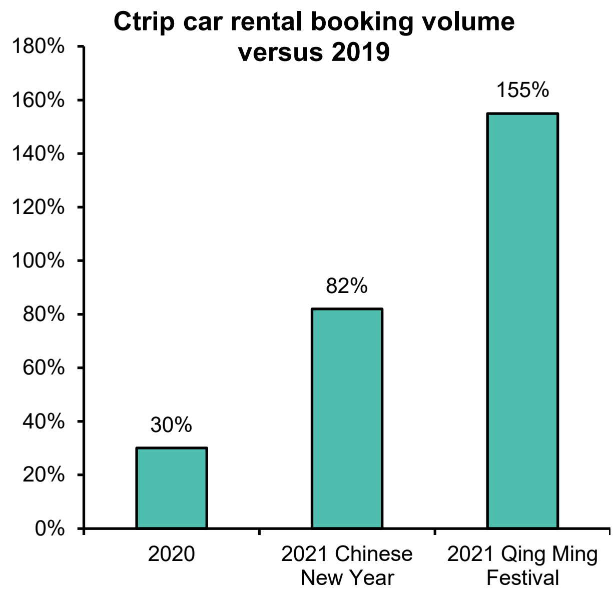
Ctrip reported RMB14bn revenue from transportation in 2019, of which 20-25% was ground transportation (~9% of company revenue). The majority of ground transportation revenue comes from railways. Thus, car rentals likely accounted for very low single digits of Trip.com's total revenue. If the robotaxi is widely adopted, it will be a better choice for travelers as they could enjoy a smooth and integrated at-destination transportation service on their trips. Travelers' transit between hotels, airports/rail stations, and attractions could be accurately connected using robotaxi, mitigating their burden to drive in an unfamiliar place. This could bring a new revenue stream for Trip.com or improve current car rental experience, further spurring demand for short-distance travel (see Exhibit 289 and Exhibit 292).

EXHIBIT 289: **Covid-19 spurred high demand for driverless cars and car rentals**



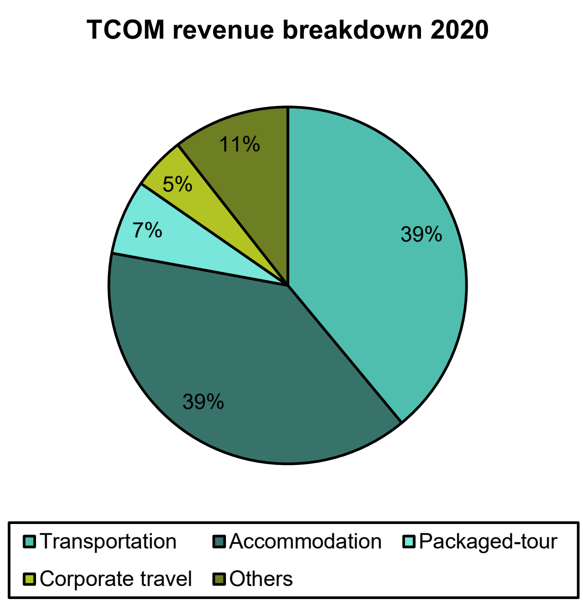
Source: iResearch and Bernstein analysis

EXHIBIT 290: **Ctrip has led the car rental recovery**



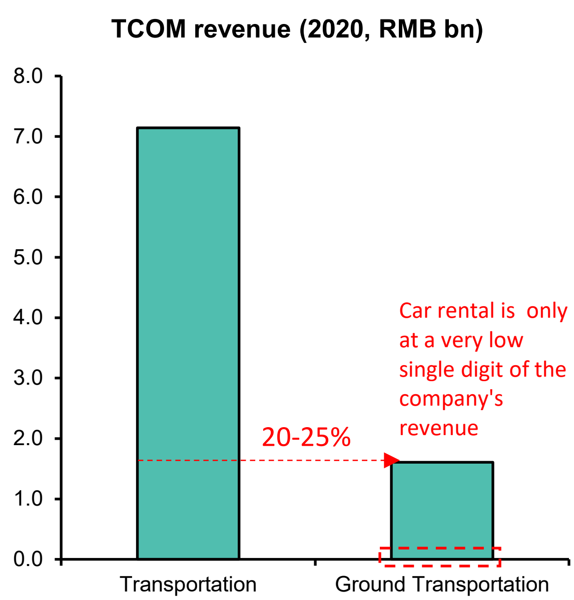
Source: Company reports and Bernstein analysis

EXHIBIT 291: **Transportation accounts for ~40% of Ctrip revenue, of which 25% is ground transportation...**



Source: Company reports and Bernstein analysis

EXHIBIT 292: **...car rental is very small in Trip.com now, but is growing fast**



Source: Company reports and Bernstein analysis

INVESTMENT IMPLICATIONS

We hold a positive view on the OTA sector in China, and expect Trip.com to benefit the most from travel recovery after Covid-19 due to its unique leading position in the affluent segment. After Covid-19, more travelers prefer road trips and the preference of the rising middle class in China for road transportation is shifting from public coaches to ride-hailing or private car rentals. Ctrip saw its car rental volume increase 155% during the Qing Ming Festival in 2021 and we expect the revenue contributed by car rentals to increase over time. Robotaxis may boost the demand for motorized travel as travelers can pass on the efforts of driving to the robotaxi completely as they relax on the road, relieving the concern of driving in an unfamiliar place.

NOTE: Special thanks to Patrick Zhou for his significant contribution to this chapter.

COMMERCIAL EV COMPETITIVE LANDSCAPE: THE TRANSITION FROM ICE TO BEV IS AT AN INFLECTION POINT

OVERVIEW

There is growing consensus among truck OEMs that by 2025 TCO curves of BEVs and ICEs will converge for a broader range of vehicles. YTD, several OEMs representing ~55% of medium-/heavy-duty (MD/HD) production in North America (NA), introduced zero-emissions truck sales targets: 100% by 2040 for Volvo, 60% by 2030 for Daimler, and 50% by 2030 for Traton.

80% of the 850,000 Class 3-8 CVs sold p.a. in North America will likely transition to a BEV powertrain. These vehicles tend to have routes <200 miles/day and return to a home base each night. Transit/school buses (~5% of BEV market) were first movers, but the upcoming wave will likely account for ~70% and include shuttle buses, refuse trucks, and regional/distribution trucks, followed by late movers — fire trucks and HD long haul.

BEV margin expectations are high, but the barrier to entry is relatively low in the lower class/specialty vehicles. New EV pureplays are guiding to 20% EBITDA margins at scale versus 10-13% for ICE incumbents. If these margins hold, then the transition will be EPS accretive for incumbents; every 10% increase in BEV sales mix drives EPS up by 8% for **Paccar** and 4% for **Oshkosh**. These margins are more achievable for high-volume manufacturers than specialty ones. The latter saw an influx of Special Purpose Acquisition Company (SPAC)-funded new entrants. The hurdle rate to breakeven profitability for some new entrants is 1,000 units/year. For high-volume manufacturers, scale and distribution are stronger competitive advantages (**Arrival** and **Proterra** are new entrants to watch).

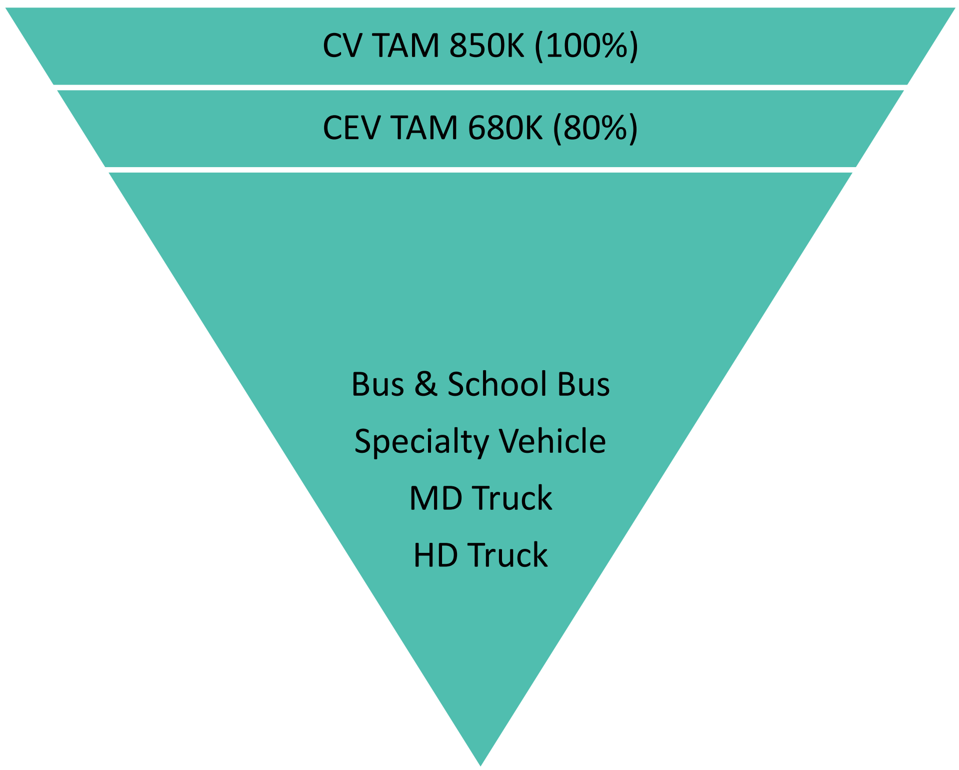
The distribution/service network will remain a differentiating factor and favor incumbents for now. Although maintenance intensity will likely decline in an EV world, fleet operators could need a lot of help in the BEV transition; there are many and they are geographically spread out. This dynamic favors incumbents and rapid scaling will be costly for new entrants.

There will be a bias toward vertical integration, when possible. Across incumbents and new entrants alike, there is a strong bias for vertical integration. This approach captures a greater share of vehicle profits, enables better optimization of the powertrain, and is more capital intensive, so incumbents will be most likely to take it. **Volvo** falls into this category, though **Paccar** does not yet. Bucking this trend are **Proterra**, **Lion**, and **Xos**, all of which plan to be third-party powertrain manufacturers. The biggest loser from this trend is **Cummins**, which derives 20% of its sales from this addressable market.

HOW BIG IS THE NORTH AMERICA COMMERCIAL BEV TAM?

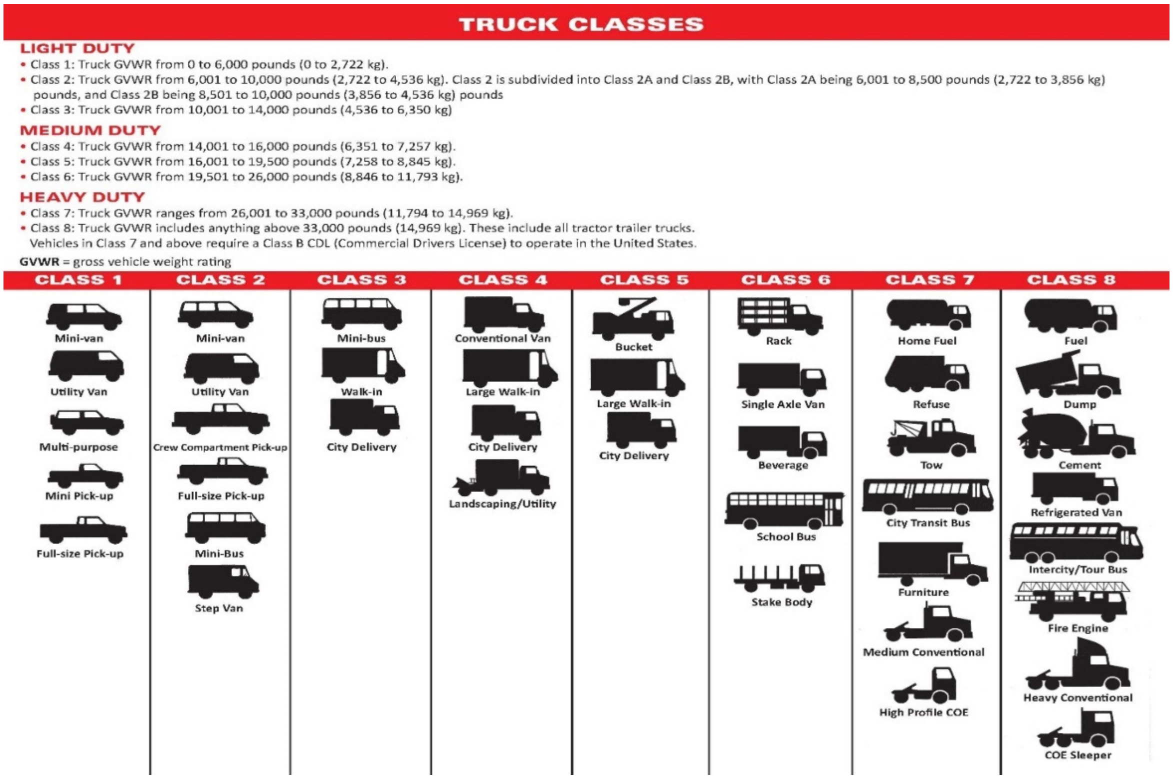
The BEV TAM is roughly 680,000 units (~80% of total CV market) in North America (see Exhibit 293). The scope of our commercial BEV analysis spans from Class 3 to Class 8 (see Exhibit 294). The North America CVs Class 3-8 market is roughly 850,000 units per year (see Exhibit 295 and Exhibit 296). The vehicles most suitable for early BEV adoption operate under 200 miles per day and/or return to base at the end of the day. These are typically urban and regional applications. Approximately 93% of Class 3-7 trucks (~500,000 units of annual sales) and one-third of Class 8 trucks (~80,000) in the US meet these criteria. As a result, we estimate the TAM of MD and HD BEV trucks is 580,000 units per year in the US or 680,000 units in North America, including Canada and Mexico.

EXHIBIT 293: **Around 80% of North America CV market is suitable for BEV**



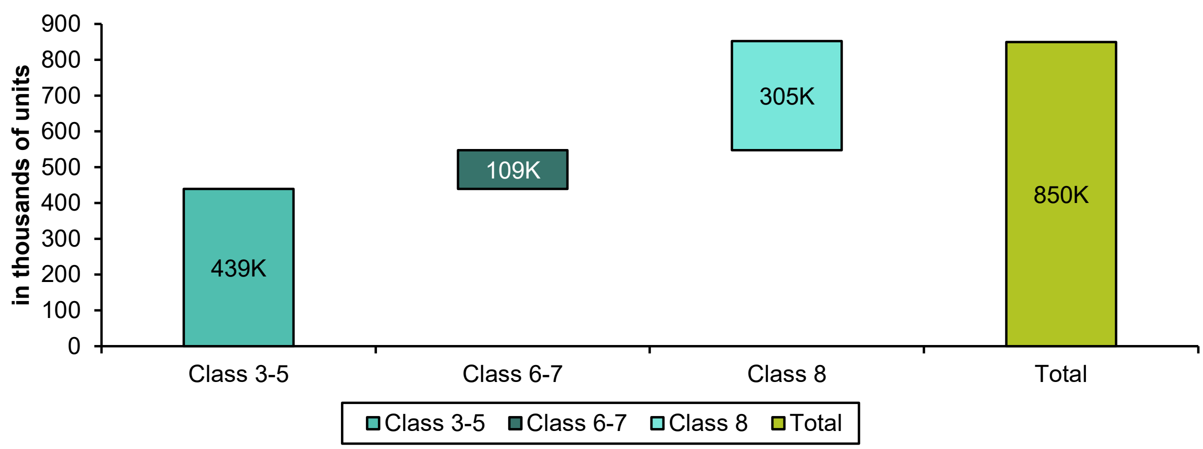
Source: Bernstein analysis

EXHIBIT 294: **Truck market breakdown**



Source: Arrow Truck and Bernstein analysis

EXHIBIT 295: **CV annual TAM in North America is ~850,000 units**



Source: IHS Markit, and Bernstein analysis

EXHIBIT 296: **US sales units by weight class**

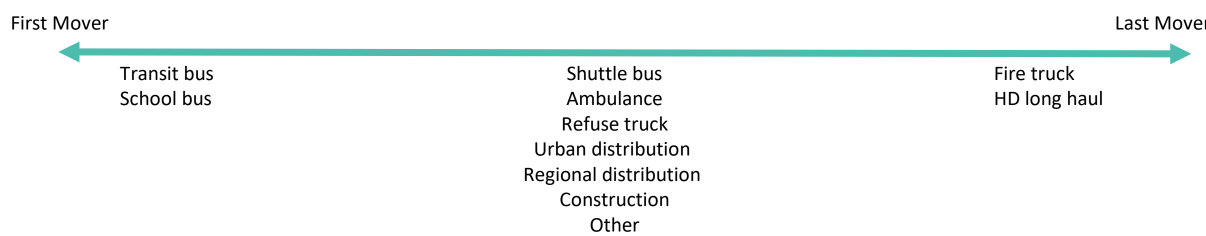
in K	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Unit Sales (2018)	301	21	81	72	64	256

Source: Lightning eMotors, ACT Research, and Bernstein analysis

WHAT IS THE TRANSITION CADENCE?

The dawn of CV electrification has arrived. Government regulations and corporate targets are tightening. TCO is crossing the tipping point with 40% lower fuel/maintenance costs versus diesel; battery costs are rapidly declining (85% decline over 2010-19), according to Proterra. EV adoption will vary by duty cycle — transit buses and school buses are expected to be first movers; refuse, last-mile delivery, and regional distribution, and construction trucks to be followed, and fire trucks and long-haul HD trucks to be the last movers (see Exhibit 297 to Exhibit 299). Additionally, in distribution, last mile and urban will electrify before regional haul and long haul. In construction, urban construction will electrify before heavy construction. Our BEV framework takes into consideration duty cycles (lighter is easier to electrify), range (shorter is easier to electrify), home base (return to base is easier to electrify), and TCO (when parity versus diesel can be reached).

EXHIBIT 297: **BEV adoption timeline across applications**



Source: Bernstein analysis

The BEV adoption curve across duty cycles and applications is largely driven by TCO economics. Transit buses can offer TCO advantage versus diesel today and that's why they are the first movers to battery. School bus TCO can be 8% better with V2G benefits today and, thus, they are electrifying rapidly as well. TCO parity is expected by 2025.

- **Transit buses are rapidly electrifying with 50% of the market expected to be electrified by 2025** according to Proterra. Annual transit bus sales are roughly 5,500-6,000 units (1% of total BEV TAM). Over 25,000 North America buses must be 100% zero emission by 2040.

- **School buses are an early adopter of electrification.** The North America school bus population is roughly 500,000 units. At ~10% replacement rate per year, the annual TAM is 45,000 units (7% of total BEV TAM). President Biden's infrastructure plan calls for electrifying at least 20% of the fleet. Additionally, EV school buses are used by utilities for V2G. First Student, the world's largest school transportation provider plans to electrify its national fleet of 43,000 yellow school buses and has partnered with NextEra, the world's largest wind and solar power generator to reduce EV fleet operation costs.

- **Shuttle buses are a logical category to electrify.** Roughly 15,000 units of shuttle buses are sold per year (2% of total BEV TAM). Airport shuttles are being targeted to electrify. So far, 29 states participate in the Federal Aviation Administration's Airport

Sustainability Plan,[52] California has taken the most progressive measures, requiring 13 state airports to deploy only zero-emission buses. The regulation will ultimately require that all airport shuttle fleets are zero-emission vehicles (ZEVs) by the end of 2035.

- **Ambulances are getting electrified.** Their annual TAM is roughly 6,000 units (1% of total BEV TAM). Lightning eMotors and REV Group are partnering to develop all-electric ambulances, with delivery planned by the end of 2021.

- **Refuse trucks are also a prime candidate for electrification, given their low fuel efficiency** (as little as 3 miles/gallon). Refuse trucks have two duty cycles (Class 7 and Class 8) and are ~8,000 units in size per year (1% of total BEV TAM). The return-to-base operations allow for charging at the end of the day and regenerative braking can help charge the batteries during the day. Additionally, refuse trucks have fixed routes, which makes it easier for charging. Apart from environmental benefits, residents and refuse workers also benefit from significant reductions in noise and noxious gases. Municipal budgets and political pressures play a role in the adoption as well. New York City has begun electrifying its garbage truck fleet, prompted by an executive order mandating a fully electric municipal fleet by 2040.

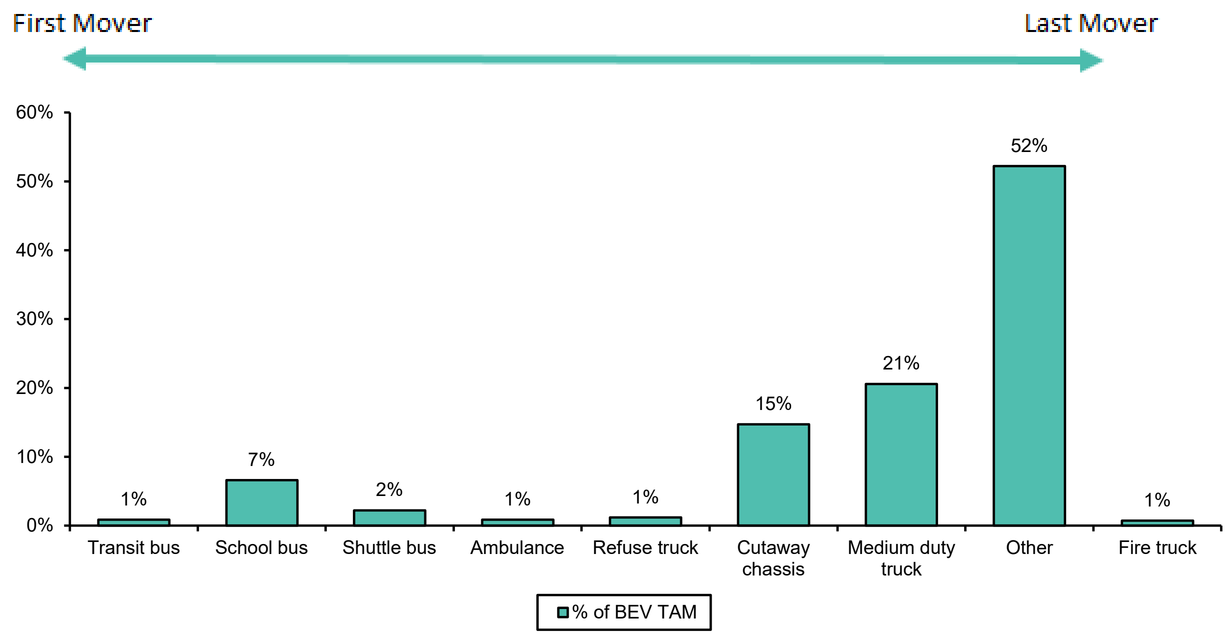
- **Urban/regional delivery is also suitable for electrification and makes up the bulk of the market.** In NA, cutaway chassis and MD trucks have annual sales volume of 100,000+ (15% of total BEV TAM) and 140,000+ units (21% of total BEV TAM), respectively, according to Proterra estimates. The remainder are smaller trucks, vans, and others. **Last mile delivery is where we will see the most EVs.** Over 350,000 last mile delivery vehicles are sold in the US per year, according to Workhorse, but the focus there is on the Class 2 segment, which is outside the scope of our TAM analysis in the prior section.

- **On the other hand, the fire truck market is expected to be a slow adopter of electrification.** The US fire truck market is roughly 4,200 units a year (peak of 5,000 units a year before the GFC). Assuming Canada and Mexico combined is 17% of the US volume, the annual TAM for North America fire trucks will be ~5,000 units (1% of total BEV TAM). Oshkosh recently launched the first battery electric powered fire truck, but expects the markets to remain small over the next couple of years.

- **Similarly, long haul is not suitable for BEV, given costs, weight, and infrastructure considerations.** The size and weight of the batteries required to power long-haul trucks make it uneconomical to deploy from a cost and space perspective. This is where FCEV offers a superior solution to BEV. The lack of infrastructure in rural and remote areas remains a concern.

[52] https://www.faa.gov/airports/environmental/sustainability/

EXHIBIT 298: **Commercial BEV TAM breakdown by application**



Source: ACT and Bernstein analysis

EXHIBIT 299: **Breakdown of TAM (annual unit sales)**

First Movers	Annual Sales Units	Medium-Term Movers	Annual Sales Units	Late Movers	Annual Sales Units
Transit bus	6,000	Shuttle bus	15,000	Fire truck	5,000
School bus	45,000	Ambulance	6,000	HD Long haul truck	200,000
		Refuse truck	8,000		
		Cutaway chassis	100,000		
		Medium duty truck	140,000		
		Other	355,000		
Subtotal	**51,000**	**Subtotal**	**624,000**	**Subtotal**	**205,000**
% of CV TAM	*6%*	*% of CV TAM*	*73%*	*% of CV TAM*	*24%*

Note: Numbers are rounded and reflect our best estimates for a typical year.

Source: Bernstein estimates and analysis

KEY OUTSTANDING QUESTIONS FOR THE BEV TRANSITION

ARE MARGINS BETTER IN AN EV WORLD?

Investors should watch how margin profiles develop for the new electric players, which will help to understand the EV transition impact on incumbent margins. Due to the early state of the industry and companies, the margin profiles of pureplay companies are all projections that will quickly change based on volume growth and R&D/capex investment needs (see Exhibit 300 and Exhibit 301). By comparing incumbents' cross-cycle average margins with newcomers' projected 2024 margins, we become less concerned about margin compressions — for Paccar, Oshkosh, and Cummins, we see opportunities across the board to maintain or increase existing margins. That said, the newcomers' margin forecasts may prove to be too optimistic or dependent on government subsidies to keep selling prices high. We believe high margins are supported by barriers to entry and differentiation, including technology/IP and customization, as well as economy of scale, especially after commercial EV technology becomes more mature over the coming years.

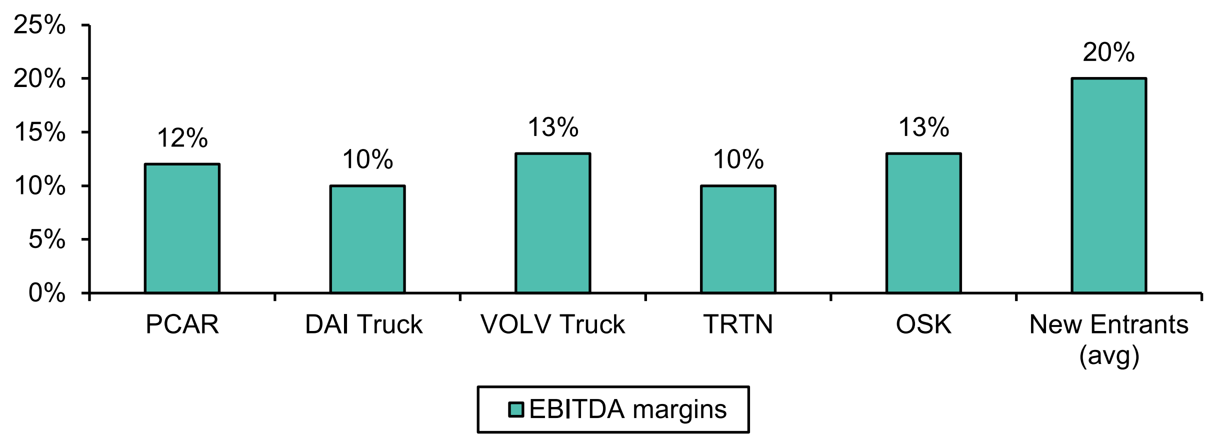
EXHIBIT 300: **EBITDA margin comparisons**

Trucks	EBITDA Margins	Specialty Vehicles	EBITDA Margins	Powertrains	EBITDA Margins
PACCAR	**12%**	**Oshkosh F&E**	**16%**	**Cummins Engine**	**15%**
Daimler Truck	**10%**	**Oshkosh Commercial**	**10%**	**Cummins Components**	**17%**
Volvo Truck	**13%**	Lightning eMotors	13%	Proterra	13%
Traton/Navistar	**10%**	Workhorse	9%	Hyliion	29%
Lion Electric	20%			XL Fleet	23%
Xos Trucks	21%			Lion Electric	20%
				Lightning eMotors	13%
				Xos Trucks	21%

Note: EBITDA margins for new entrants are based on company and consensus 2024 projections. EBITDA margins for incumbents are based on over the cycle averages. 2025 estimated EBITDA margins for Proterra and Lightning eMotors are 20% and 16%, respectively.

Source: Company reports, and Bernstein estimates and analysis

EXHIBIT 301: **Truck OEM EBITDA margin comparisons**



Note: Volvo Truck excludes buses.

Source: Company reports and Bernstein analysis

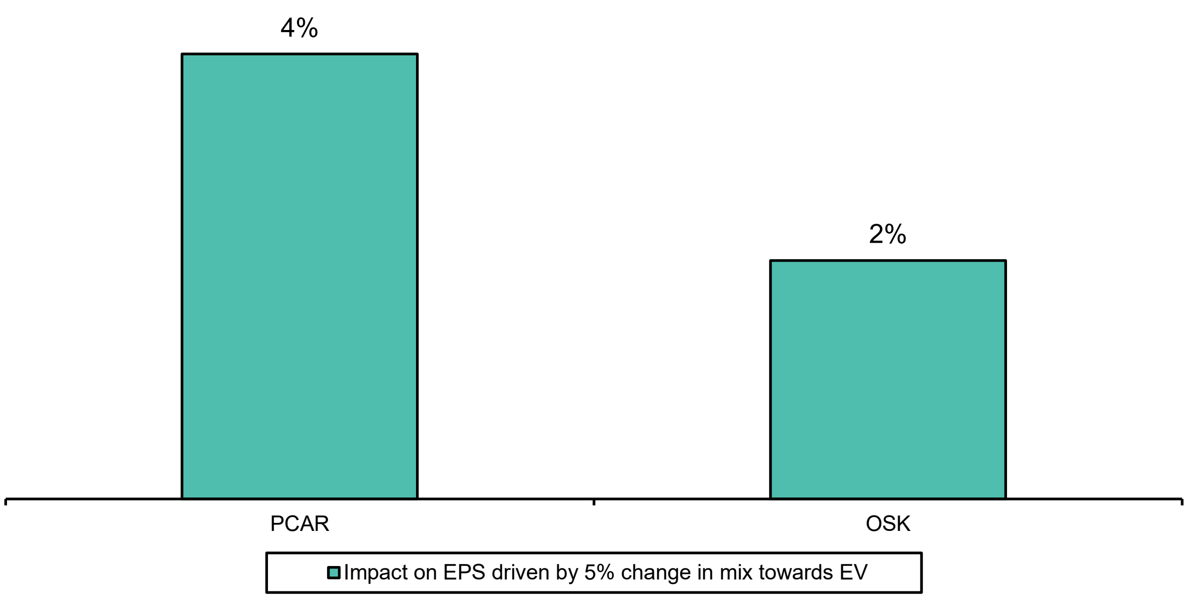
Assuming the incumbents' EV margins are going to be in line with the average of new entrants in each category and the upside to EBITDA margins is roughly the same as upside to EBIT margins, then the **EPS impact on Paccar, Oshkosh, and Cummins would be US$2.56 (44% upside), US$0.82 (12% upside), and US$1.12 (7% upside), respectively, as companies transition from ICE to BEV** (see Exhibit 302 and Exhibit 303). This assumes the incumbents can keep current market shares as we transition to EV and EV margins stay higher than diesel margins. Again, the new entrants' margin assumptions may turn out to be too optimistic.

EXHIBIT 302: **EPS upside potential driven by EV transition (based on new entrants' projected margins)**

	PCAR	OSK	CMI
Revenue ($M)	24,144	7,850	24,198
% Rev Exposure	60%	31%	22%
Impacted Revenue ($M)	14,486	2,434	5,324
Change in EBIT Margin	8%	3%	4%
Change in EBIT ($M)	1,159	73	213
Tax rate	23%	22%	23%
Change in NOPAT ($M)	893	57	165
DSO	348	69	147
EPS Impact	**2.56**	**0.82**	**1.12**
2021 EPS	5.79	6.70	15.90
% Change in EPS	*44%*	*12%*	*7%*

Source: Company reports, and Bernstein estimates and analysis

EXHIBIT 303: **Paccar and Oshkosh's EPS will likely increase by 4% and 2%, respectively, driven by potential uplift in margins**



Source: Bernstein estimates (all data) and analysis

IS IT BETTER TO BE VERTICALLY INTEGRATED?

Investors should pay attention to whether the company chooses a vertical integration or an assembly strategy (see Exhibit 304). In the case of powertrains, vertical integration means the company designs and makes its own battery modules and packs and owns all the software. In the case of whole vehicles, apart from integrated powertrains, vertical integration also means doing chassis and most other components in house.

Strategies vary among players in the industry. On one side, players such as Proterra, Lion Electric, Xos Trucks, and Volvo believe that vertical integration is the future of commercial BEV. In the middle, players such as Daimler believe having in-house R&D is important, but whether to pursue vertical integration is another question. Daimler is a customer and strategic investor of Proterra, which offers end-to-end powertrain and energy system integration solutions to Daimler's stepvans and school buses. On the other side, assembly-focused players, such as Paccar and Workhorse, follow a component sourcing strategy with limited internal R&D in EV, at least for the next few years.

The path of vertical integration gives companies more control over design and cost, and technological differentiation, but is investment heavy. This approach is generally more practical for deep-pocket incumbents versus cash-starved startups. That said, SPAC mergers have proven to be a strong source of funding for EV startups recently. Furthermore, if the company has a cash-generative segment (e.g., EV transit bus and school bus), it can potentially afford a new entrant a vertically integrated BEV business model.

All the EV companies we've spoken to source battery cells directly from Asian suppliers as cells are commoditized, but strategies differ beyond the cell level. Lion Electric is fully vertically integrated and builds its own powertrain, chassis, and vehicles. Workhorse is simply a hardware assembler which sources most components from external partners and only builds infrastructure for fleets using cloud-based software. Most companies in between talked about plans to insource battery production, making their own modules and packs in the future as volumes grow. As a next step, it's worth investigating how different: (1) battery making is from car making, and (2) PV battery making is from CV battery making.

EXHIBIT 304: **BEV strategy: vertical integration versus assembly**

	BEV Strategy	
Vertically Integrated	Semi-integrated/Flexible	Assembly Focused
Proterra	Daimler	Workhorse
Lion Electric	Lightning eMotors	PACCAR
Xos Trucks	Oshkosh	
Volvo		
Cummins		
Arrival		

Note: Proterra, Lion, Xos, Arrival, Lightning eMotors, and Workhorse are not covered by Bernstein.

Source: Company reports and Bernstein analysis

WILL DISTRIBUTION/SERVICE STILL MATTER?

Investors should watch the service needs of commercial EVs as more of these vehicles are being put into service on the road. This will help investors to evaluate the distribution/service model adopted by new entrants and discern whether it will become a hurdle for them to compete against incumbents with a large existing dealer network. On the one hand, incumbents such as Paccar strongly believe distribution is a competitive edge versus new entrants. Paccar has over 2,000 dealer locations and enjoys strong relationships with its customers. On the other hand, newcomers, such as Lion Electric and Lightning eMotors, believe having a large dealer network means leaving margins on the table and this will become more of a burden to incumbents as they transition from diesel to EV, especially as dealers' profitable parts and service revenues get eroded in an EV world. According to the new entrants, operating and maintenance costs on BEVs are 60-85% lower than on ICE vehicles. In contrast, Paccar thinks the parts opportunities on EVs are at least as good as in diesel, as 75% of part sales are not related to the engine. It's also because EVs have extra systems unlike ICE vehicles (e.g., battery cooling systems), especially considering the need for charging stations and their parts as the company enters the battery charging space. We think a large distribution and service network is going to be an advantage all else being equal. However, whether it's necessary for the new entrants to have their own service network in order to be competitive is another question that remains to be answered. Additionally, we believe distribution is less important for specialty vehicles as the barrier to entry there is higher, relationships with customers are key and are locked in at the corporate level, and customers are most likely to have their own maintenance operations.

IS BEV AN INCUMBENT OR A NEWCOMER WORLD?

While it is too early to tell who is going to win the EV race, we see certain companies are better positioned than others. On the manufacturing front, we believe it's challenging for new entrants to compete with incumbents on scale. As such, we think new entrants that have proven technologies, operate in some of the early adopter markets, and are open to partnering with OEMs are better positioned (e.g., Proterra). On the flip side, we think it's important for incumbents to enter the EV markets early to have products available for iterations and grab market share when there are policy tailwinds (and subsidies) behind it. Additionally, we see the need for incumbents to expand into charging solutions (Paccar, Daimler, and Volvo are all doing this), not as an energy provider, but as a one-stop shop for EV solutions. It appears that charging solutions, and fleet management design and consultancy are areas that can add a lot of value to fleet customers. And it's more important than ever to be close to the customers as they are challenged by the new energy transition. We believe the best approach to develop EV capability is standardization and modularization at the front end (adaptable scale manufacturing), and customization at the back end (delivery) as the technology matures and adoption accelerates. We see the most risk to Cummins as the company faces competitive threats from numerous players across the supply chain and does not have a meaningful competitive advantage in BEV powertrain.

THE INCUMBENTS

Paccar is competing head to head against Lion Electric and Xos Trucks because they are focused on last mile and return-to-base Class 5-8 trucks. **Oshkosh** is competing primarily with Lightning eMotors in the EV category and Workhorse in specialty vehicles and last mile delivery vans. **Cummins** is competing directly with Proterra, Lion Electric, Xos Trucks, and Lightning eMotors on their BEV powertrain offerings, as well as other traditional and new integrated powertrain players (incumbents such as BorgWarner, Meritor, and Dana, and new entrants such as XL Fleet and Hyliion). The incumbent truck OEMs (**Paccar, Daimler, Volvo, and Traton**) are also competing against each other (see Exhibit 305).

EXHIBIT 305: **Incumbent BEV strategy overview**

OEM	Zero emission targets	% CEV exposure	CEV models	Level of vertical integration	New competitors
PCAR	NA	60%	Peterbilt 220 EV, Peterbilt 579 EV, Peterbilt 520 EV, Kenworth 270E, Kenworth T680E, DAF CF Electric	Low	Lion Electric, Xos Trucks
OSK	NA	31%	Electric RCV, Volterra electric vehicle platform in F&E, USPS NGDV	Medium	Lightning eMotors, Workhorse
CMI	NA	22%	NA	High	Proterra, Lion Electric, Xos Trucks, Lightening eMotors
DAI	Targets carbon neutral in key regions by 2039	15-20%	FUSO eCanter (2.0 generation to start production in '21), Freightliner eM2 and eCascadia, Thomas Saf-T-Liner eC2 school bus, Mercedes-Benz eActros (HD) and eCitaro bus	Medium	Lion Electric, Xos Trucks, Proterra
VOLV	Targets net-zero greenhouse gas emissions by 2040	50%	Electric city buses, FE and FL electric series, FM, FH, and FMX trucks, VNR electric truck	High	Lion Electric, Xos Trucks, Proterra
TRTN	Targets 50% of Scania trucks, 60% of MAN's delivery trucks and 40% of its long-haul trucks will be zero-emission by 2030	50%	Scania's electric L and P-series cabs, MAN eTGM, Volkswagen e-Delivery truck (Brazil), electric city buses by Scania and MAN	Medium	Lion Electric, Xos Trucks, Proterra

Source: Company reports and Bernstein analysis

PACCAR (PCAR)

We estimate roughly 60% of Paccar's revenue is at risk of disruption in the medium term. Paccar's BEV strategy is best summarized as "wait-and-see" and the company continues to rely heavily on external partners for R&D in advanced technologies. Paccar designed its EV product strategy toward customer applications where trucks drive less than 200 miles/day, return to base, and with a lot of stop and go. This has led to three primary applications: garbage trucks (Class 7-8), port vehicles (Class 8), and local and regional distribution (Class 5-7). Paccar currently has six zero-emission truck models. DAF began producing CF Electric trucks in April, and Peterbilt and Kenworth are expected to produce their first BEV trucks in the second quarter. Current ASP of these BEV trucks are 2x that of diesel trucks. Paccar said it would not pursue a strategy to chase volume at the expense of gross margins. The company currently relies on its partners for most components as it believes BEV volume is going to stay small for the next four years. Paccar has partnered with two EV battery providers, CATL and Romeo Power, that supply electric batteries with a BMS, and cooling and monitoring systems. The company commented that it would take more in-house as the volume increases. Interestingly, Paccar thinks hybrid will play a big role during this transition and 40-50% of the market may become hybrid by 2027. We have identified two newcomers that compete primarily in the Class 5-8 truck market, Lion Electric and Xos. Lion Electric has four truck models available today (Class 6, 8, reefer 8, and refuse 8) and Xos is launching Class 6-7 and regional Class 7-8 models this year (Class 5-6 available now).

OSHKOSH (OSK)

Fire and emergency (F&E; 17% of revenue) and commercial (14% of revenue) segments represent over 30% of Oshkosh's total revenue and are exposed to the electric revolution in CV. We estimate 17% and 14% (fire trucks are 80-85% of F&E) of Oshkosh's revenue are at the risk of disruption in the medium term and long term, respectively. Oshkosh is experienced in electrification, given its prior work on JLG electric products. It recently introduced the Volterra Platform of EVs for the F&E market, with the first municipal fire truck already in service in Madison, Wisconsin. Municipalities and airports have identified green initiatives as a priority, compelling fire departments to seek fire apparatus that can reduce emissions and fuel consumption and produce less noise. Fire departments are typically slow adopters and EV adoption in this market will be affected by political pressures. Oshkosh thinks it will be a couple of years out before Volterra becomes more mainstream. Refuse trucks are well suited for electrification, given return-to-base operations allow for charging at the end of the day and regenerative braking can help charge batteries during the day. Adoption in refuse trucks is likely to be faster than in fire trucks, but they are subject to the same municipal political considerations. Lightning eMotor's primarily competes in the high-margin, customized specialty vehicle markets across Class 3-7. Lately, Oshkosh expanded into the last-mile delivery market through its newly won USPS contract by beating out Workhorse, a small EV startup focused on last-mile delivery vans and drones.

CUMMINS (CMI)

Currently, MD engines and HD engines each represent 11% of Cummins' revenue, while MD components and HD components represent 6% and 8% for Cummins' revenue, respectively. As a result, we believe at least 22% of Cummins' revenue (93% of MD and one-third of HD revenues) is at risk of disruption in the near to medium term across engines and components, with additional downside from distribution and power generation segments. Cummins offers integrated BEV powertrains, but does not manufacture battery cells. It builds modules from these cells and owns pack designs as well as BMSs. Cummins also makes power electronics, which the company believes is an area of differentiation and will benefit from shared economy of scale with its FCEV products. Integrated BEV powertrain new entrants include Proterra, Lion Electric, Xos, and Lightning eMotors. Proterra only sells powertrains for trucks (with the exception of buses), while Lion Electric is vertically integrated up from the battery cell level. Xos recently established its new powertrain division to sell powertrains to other OEMs (by hiring an industry veteran from Cummins) in addition to selling Fleet-as-a-Service and whole trucks. Cummins also competes with other integrated powertrain makers, such as Dana, Meritor, BorgWarner, and Magna on the incumbent side and Hyliion and XL Fleet on the newcomer side.

VOLVO (VOLVB)

Approximately 50% of Volvo Group sales are exposed to the disruptive potential of commercial EVs (trucks and buses account for 70% of Volvo sales). Volvo has adopted an aggressive strategy to transition its entire fleet of trucks to ZEVs by 2050, which will require all shipments of new vehicles to be zero emissions by 2040. The company began this migration process in 2010, with the rollout of electric city buses. Over the last year, the company has announced a suite of new products, which went into volume production in 2019. In late 2020, Volvo introduced the FM, FH, and FMX trucks, which initially focus on regional transport and urban construction uses in Europe (44 tons in weight, 300km range) and volume production will begin in 2022. Volvo also introduced the VNR electric truck series for the North America market, with a focus on regional transport — sales began in 2021. All these EV trucks are built on the same chassis as diesel trucks, which will simplify the customer transition. Volvo expects the transition to occur segment by segment, region by region, and market by market. From a use-case perspective, Volvo expects distribution to lead the adoption curve, followed by waste/refuse, then regional haul, then construction, and finally long haul. The company expects to use its commercial ICE business as a cash cow to fund investment in alternative propulsion, and it continues to invest in engine/aftertreatment systems to meet emissions milestones later in this decade. From a manufacturing perspective, Volvo has adopted a modular approach to the electric drivetrain — the same components will be used to manufacture buses, trucks, and construction equipment. This approach creates synergies in R&D, production, and service. To keep capital costs down, Volvo plans to use mixed-mode assembly and manufacture its EV trucks on the same line as ICE trucks, so no new plants will be needed, though investment may need to increase by 5-10%. Volvo already has commercial EV production lines in North America, Europe, and China, but plans to expand locations in 2022; by 2025, its commercial EV will likely be global (including Brazil and Australia by that timeframe). On the battery side, Volvo is partnering with Samsung — Volvo recently launched its second-generation technology and is in the final development of third-generation technology, which will be 40% more energy efficient and boast a lower kWh cost.

DAIMLER (DAI)

Approximately 15-20% of Daimler Group sales are exposed to the disruptive force of commercial EVs. Daimler expects the transition to ZEVs to happen in the next 10-15 years (five years ahead of the Paris Accord targets). By 2030, it expects 60% of its truck sales to be zero emissions. Driving this timeline is TCO parity, which it expects to reach in 2025 for battery and 2027 for fuel cell. The company is dually focused on benchmark technology and scaling fast to bring down variable cost. The path toward fully electric CVs began with the FUSO eCanter in 2017 (2.0 generation to start production in 2021), but has since progressed to include the Freightliner eM2 and eCascadia (focused on fixed/predictable routes in the 70-250km range, volume production begins in 2021 for both), the Thomas Saf-T-Liner eC2 school bus, the Mercedes-Benz eActros (HD offering), and eCitaro (bus offering). Daimler recently introduced its next-gen BEV product roadmap that boasts a 60% increase in range to 800km, a 25% efficiency improvement, 40% lower variable cost, and 2MW targeting (+170% versus current generation technology). To support R&D into ZEVs (nearly all spend going here), Daimler has outsourced MD ICE manufacturing to Cummins and is open to partnering on HD ICE. The company plans to develop the powertrain in house (e-motors, inverters, and BMS), while it has partnered with CATL for battery development, with a specific focus on HD commercial applications (supply agreement targets volume production in 2024 and extends to 2030). As for charging infrastructure, Daimler is partnering with Detroit Diesel (Power Electronics) to serve the North American market. Daimler will provide onsite consulting, installation, and support for 350kW chargers. In Europe, it is partnering with Siemens and Engie.

TRATON (8TRA)

Approximately 50% of company sales are exposed to the disruptive force of commercial EVs. Traton is targeting an EV penetration rate on its sales of 10% for Scania Europe and 50% for MAN by 2025 and then 50% for Scania, 60% for delivery trucks, and 40% for long-haul trucks by 2030. Unlike the other OEMs, which expect fuel cell to be the dominant propulsion system for HD trucks, Traton expects most of this vehicle type to BEV. The company cited a stark efficiency differential between BEV (75%) and FCEV (25%), a rapidly declining BEV cost curve and high hydrogen costs. Traton recently released its EV product lineup (L and P-series cabs) that include a vehicle with up to a 250km range focused on urban areas (refuse collector, F&E, concrete mixers, hooklifts, etc.), the MAN eTGM (focused on urban good distribution with a 190km range), the Volkswagen e-Delivery truck (Brazil market), as well as electric city buses by Scania and MAN that were launched at the end of 2020. As far as Navistar is concerned, it had previously mentioned that it was targeting school buses and MD applications. Traton has committed to ~US$1.3bn in electrification investment through 2025.

THE NEW ENTRANTS

Arrival (micro-factory strategy) and Proterra (aiming to also be a third-party EV powertrain provider) are new entrants to watch. The growth of the BEV industry has attracted a number of new entrants with varying focuses and strategies. We identified and spoke with seven key players in the OEM space. In our view, the key success factors include business model, technology/product validation, client base and partnerships, costs/economics, management team, and manufacturing capability. Given the industry is nascent and fast changing, it is too early to tell who ultimately will become winners and losers, especially given they all have slightly different business models and target segments. That said, we believe new entrants with a proven and cash-generative product (i.e., bus) and/or unique manufacturing approach (including partnering with OEMs to leverage their scale manufacturing capability) are better positioned (see Exhibit 306). Additionally, we believe the battery electric powertrain is a key differentiator in a BEV world and, thus, we favor vertically integrated players, particularly considering competition from incumbents that have a significant scale advantage. The profits generated from the first-mover CV segment will allow startups to continue investing in the technology and developing more capabilities. There is also the associated benefit of first-mover advantage, which allows the companies to iterate the technology faster. As such, we believe Proterra (a leader in bus, integrated powertrain provider, partnering with Daimler) and Arrival (although still a prototype company) are worth watching in the new entrant space.

EXHIBIT 306: **Competitive landscape of pureplay EV OEMs**

Company	Business Model	EV Target Segment	Vehicles in Operations vs. Prototype	Notable Partnerships & Client Base	Economics (Upfront Vehicle Cost)	Management Team Relevant Experience	Manufacturing Capacity	Breakeven Units	Revenue CAGR '21-'24
Proterra	OEM of EV Bus, EV powertrain, charging solution provider	N. America transit buses	600+ units on the road and 450+ in backlog; ~18M service miles	Daimler, Komatsu, Volta Trucks, Lightning eMotors, ETS, Dominion Energy	Currently @ 1.4x diesel	Tesla, Apple, Honda, Bosch, GM, Bloom Energy	1 battery, 1 bus, and 1 dual purpose plants; bus max annual capacity of 680 vehicles	NA	81%
Lion Electric	Vertically integrated EV OEM, charging solution provider	N. America class 5-8 (3 buses + 4 trucks models today)	400 units on the road, 817 in backlog; ~7 miles driven	Trucks: Amazon, Pride Group, IKEA, Sobeys, CN; Buses: STA, National Express, First Student, Transdev, Seguin	Currently @ 3x diesel, 40% of cost is battery	Tesla, Toyota, Ford, XL Fleet	1 plant with max annual capacity of 2,500 vehicles (1 shift), building a 5 GWh/year battery plant and a 20K vehicle/year facility	NA	161%
Workhorse	Assembler of last mile delivery trucks & drones	US last mile delivery trucks (class 2)	~40 units delivered YTD, 8K in backlog	UPS, Pritchard, Pride Group	Currently @ 1.6x diesel	Bourns, GE Aviation, P&G, Cumulus Interactive Technologies, Ray Technology, Sysco	1 plant ramping up capacity to 200 trucks/month by mid 2022	200/mon	105%
Arrival	OEM of EV bus and vans	Global vans (class 2/3) and buses	Prototype, with first bus production planned for Q4 '21	UPS, Hyundai, Kia Motors, Comau, Uber	NA	GM, Intel, Apple, Nokia, Yota, LG Electronics, Google	Building 4 microfactories in '21-'22 with annual capacity of 1K buses or 10K vans each	1K buses or 10K vans	269%
Lightning eMotors	OEM of BEV and FCEV and powertrain provider	Urban class 3-7 (w/ high customization)	141 units on the road, 1,569 in backlog	DHL, Amazon, CBRE, COX, BorgWarner, Ford Hino, Plug Power, BP	Currently @ 3.5x diesel	Tesla, BorgWarner, Romaco, Schlumberger, Woodward, ICE Energy	1 plant with max annual capacity of 3K vehicles (1 shift)	1K/year	164%
Xos Trucks	Fleet-as-a-Service (also sells trucks and powertrains separately)	Last mile and return to base class 5-8	40 units on the road, 6K in backlog (2K firm orders)	UPS, Thompson, Lonestar, Southern CA Edison, UniFirst, Loomis, Wiggins	Currently @ 1.2x diesel	Tesla, fleet mgmt and ownership experience	1 plant can produce 5K vehicles, vehicle and battery assembly under the same roof	Does not disclose	499%
Nikola	OEM of BEV and FCEV, H2 stations	Class 8 short haul	In trial builds stage; production begins in 4Q'21	CNHI IVECO, Bosch, Ryder, WABCO, EDAG, RIG360 service network	NA	GM, Worthington Industries, Russell & Associates, Caterpillar	2 manufacturing facilities; Coolidge facility capacity expected to be 2.5-3K units by Phase 1 and 35K by Phase 3	NA	357%

Note: None are covered by Bernstein.

Source: Company reports and Bernstein analysis

PROTERRA (PTRA, UNCOVERED)

Proterra has three business segments: battery electric powertrain, electric bus, and charger and energy management systems. Currently, 90% of revenues are from electric buses, where the company enjoys huge success. Proterra is the #1 electric transit bus OEM with a 50%+ market share and a 10+ year vehicle service track record. The company's development cycle is in three stages. Act 1 (2015-20) was all about transit buses, Act 2 (2020-25) is focused on the short-haul MD and HD markets, and Act 3 (2025 and beyond) will be focused on long-haul trucking.

Proterra pursues a vertical integration strategy. It believes that the battery electric drivetrain is where the edge lies, and it can use the bus to iterate its products. The company believes that differentiation matters more than scale for now (during the first decade) because as we push up energy density, the technology becomes much harder. Four key attributes that matter in battery are mutually exclusive: energy density, life, safety, and cost. Proterra's edge is about optimizing these attributes. It currently has two battery manufacturing facilities and eight customers, and the company believes its battery systems are highly applicable to even rail, marine, etc. Notably, Daimler is a customer and strategic investor. Proterra has entered into a contract with LG Energy Solutions to secure cell supply at competitive prices through 2022 and is in discussions to invest in domestic cell manufacturing to lock in long-term supply. The company believes it is 70% about batteries and 30% about integration. Proterra projects a 25% gross margin (already gross margin positive currently at 4%) and 20% EBITDA margin in 2025.

WORKHORSE (WKHS, UNCOVERED)

Founded in 1998, Workhorse has pivoted to focus on the US Class 2 last-mile delivery electric van and drone market over the last few years. The company is essentially a pre-revenue assembler that outsources most of the components (i.e., assembly strategy). The company started producing in late 2020 and has delivered 38 trucks YTD (as of the last earnings call). The company believes it is approaching the inflection point this year and expects to produce 200 trucks/month by mid-2022, which is also the breakeven point. Workhorse mentioned that a delivery that costs US$1 by ICE would cost ~US$40 by its vans and ~US$4 by its drones. The reduction in cost is primarily due to the build of the truck using lighter materials (a thousand pounds lighter than average EVs). In its prior experience as an ICE stepvan maker, Workhorse was able to produce up to 60,000 chassis per year in its manufacturing plant.

LION ELECTRIC (LEV, UNCOVERED)

Founded in 2008, Lion Electric is a Canadian OEM of electric school buses and trucks with three bus and four truck models in the market today. The company is vertically integrated and offers 100% electric purpose-built CVs with its own powertrain, chassis, BMS, and power and thermal management systems. Lion Electric believes controlling battery design is key and the next phase of EV is based upon the continued optimization of battery. It is building a battery plant to control cost (enabled by more integration) and eliminate dependency on other suppliers. The company estimates that by year-end 2024, the overall cost of its vehicles will be reduced by 50%, with 55% cost reduction in batteries and 40% cost reduction in non-battery components. On distribution, Lion Electric uses its own experience centers to provide full-service training, infrastructure assistance, and maintenance support. So far, the company has established nine experience centers across North America and aims to get to 20 of them down the road. On the infrastructure side, Lion Electric partners with providers such as ABB and ChargePoint to help clients choose the right infrastructure (Lion is the reseller). The company is growing rapidly, increasing its employee base from 20 people a year ago to 650 today.

XOS TRUCKS (MERGING WITH SPAC, UNCOVERED)

Founded in 2016, Xos was started by former fleet owners. The company focuses on regional Class 5-8, where trucks operate less than 200 miles per shift and/or return to base. Management thinks owning proprietary technology is their key competitive advantage versus peers. Half of the building of materials is proprietary. Xos follows the vertical integration model that requires heavy R&D. The company designs and builds its own chassis and battery modules (makes everything from the cell level up). The battery packs are modular and stackable to make a battery box. Each battery box has a battery management and a cooling system. Modularity allows for customization. Xos plans to bring power electronics in-house. The company enjoys a large backlog of 6,000+ units, of which

2,000 are firm orders (fully slated for 2021 and 2022). In addition to outright sales, Xos also offers Fleet-as-a-Service that provides a one-stop solution at a fixed monthly fee. The company is still working through financing and distribution. Management expects aftermarket to be 10-15% of revenue in 2025. Xos recently unveiled a new division through which it will offer its powertrain technology along with design and integration expertise to other OEMs.

LIGHTNING EMOTORS (ZEV, UNCOVERED)

Lightning eMotors primarily makes Class 3-7 battery electric specialty vehicles with low volumes and high customization. The company is already in production and has sold out on every bit of volume. It has shipped to 47 fleets so far. Lightning eMotors is the only company making Class 3 and Class 5 electric shuttle buses and electric ambulances today. It chooses to be in the higher-margin customization space and does not want to compete in the more commoditized truck space. The company is semi-integrated today — it makes certain parts in-house (DC fast chargers, power distribution units, and all software) and buys power steering pumps and battery packs through the supply chain.

Lightning eMotors provides both retrofit and built-to-purpose EVs with an ASP range of US$50,000 (Class 3 repower) to US$400,000 (motorcoach). The company recently negotiated for a 15% lower battery cost versus 2020 levels and is seeing COGS declining by 50% by lowering wiring and harness costs, and outsourcing to cheap labor; thus, it expects ASP to drop by 40% by 2022. Lightning eMotors mentioned that customers are willing to pay a 250% premium today. After a 40% price reduction, ASP will be 1.6-1.7x diesel and the TCO will be compelling, given EV operational costs are 85% lower. Breakeven units are 1,000 per year and it will likely hit this run rate in 4Q2021. Gross margins will likely turn positive by then and EBITDA could turn positive shortly afterward. The company is targeting to sell 3,000 units in 2022, which it will be able to produce with a single shift in the current facility. Currently, complete vehicles make account for 95% of the business, but management thinks powertrain is a good business and could make up 70% of the business in the future. Compared to its competitors, Lightning eMotors described itself as being more holistic — doing extensive consulting-type work for customers.

ARRIVAL (ARVL, UNCOVERED)

Arrival was started in 2015 with the goal of offering quality EVs at a good price. It was backed by a Russian billionaire and was privately funded for a long time. Arrival is still a prototype stage company with the first bus model going into production in 4Q2021, followed by planned productions of a 4-ton van and a 7-ton large van in 2H2022 and a car in 2023. The company views itself as a tech company more than an auto company. Arrival employs 1,900 people, over half of whom are software engineers. This enables upgradability of the vehicles from the Cloud, which enhances residual value. Through its own IPs on design, Arrival believes it can make lighter vehicles using standard raw materials. Arrival takes a unique micro-factory approach to manufacturing. Micro-factories have smaller footprints and lower costs (up to US$50mn of capital cost each) than traditional OEM plants. The key idea is uniformity across vehicle classes. Arrival is building four of them right now — two in the US, one in the UK, and one in Spain. Each plant needs 250 employees and two shifts to optimize production at 1,000 buses or 10,000 vans, which is also the breakeven volume. As to distribution/service, Arrival plans to partner with service network providers in addition to leveraging fleet operators' own service networks. The company makes most of its components in-house, but the business model is still evolving, given the early state of the company.

NIKOLA (NKLA, UNCOVERED)

Founded in 2015 and better known for its FCEV offerings, Nikola plays in both the BEV and FCEV space for Class 8 trucks. Its core business includes selling BEV trucks for short-haul applications with a range of up to 350 miles and FCEV trucks for long-haul applications with a 500- to 750-mile range, as well as H2 stations. In FCEV, the company offers a "bundle pricing" model including truck, fuel, and maintenance. Nikola is leveraging its existing FCEV work and partnership with CNH Industrial to co-develop BEV trucks for production in 4Q2021. The company views these two products as complementary offerings with significant overlap in components. Currently, Nikola is trial-building and testing its Tre BEV trucks. It has delivered 14 beta trucks so far — the first batch of five trucks are exceeding management expectations in winter testing. Nikola's BEVs are ideal for port drayage and metro distribution operations. Tre BEV is coming to the market with a 750kW battery, 200kW higher than the closest competitor. The company is also making progress on building out its two manufacturing facilities. Nikola also reported significant progress on construction of its Arizona greenfield manufacturing facility, which upon completion of Phase 1 will have a capacity of 2,500-3,000 trucks per year (15,000 by Phase 2 in 2022 and 35,000 by Phase 3 in 2023). On May 6, 2021, Nikola announced collaboration with Total Transportation Services to expedite zero-emission transportation at the Port of Los Angeles and Long Beach. The collaboration includes trials on 30 Nikola Class 8 BEVs and 70 FCEV semi-trucks.

INVESTMENT IMPLICATIONS

BEV margin expectations are high. If these margins hold, then the transition will be EPS accretive for incumbents; every 10% increase in BEV sales mix drives EPS up by 8% for Paccar and 4% for Oshkosh. These margins are more achievable for high volume manufacturers (Paccar, Daimler, Volvo, and Traton) than specialty manufacturers (Oshkosh). The biggest loser from the trend toward vertical integration is Cummins, which derives 20% of its sales from this addressable market.

APPLE CAR...YES/NO? HOW GOOD? HOW BIG? WHO GETS HURT?

OVERVIEW

Apple has been working on a car/autonomy for at least six years, with seemingly shifting ambitions, leadership, and levels of commitment. A car is not expected to launch before 2025. We wrote in detail about the opportunity in early 2015,[53] and speculation about the car has ebbed and flowed since, with recent news pointing to Apple potentially looking to secure a manufacturing partner.

Apple's interest in the automotive market makes sense for several reasons: (1) the auto market is a uniquely large end-market (US$2tn+); (2) Apple has a history of achieving attractive margins (and a disproportionate share of industry profits) in low-margin industries through its premium product positioning; and (3) it will likely be able to subcontract manufacturing of the vehicle and leverage a broad industry supply chain, a core competency of the company.

That said, we don't think a car offering from Apple is certain. Apple is highly selective in introducing new products and was arguably much further along toward commercialization of its own television and over-the-top television (OTT) service, both of which Apple never brough to market.

If Apple is to launch a car, we suspect it will be both all-electric and have a high-level autonomy, with potentially a passenger cabin that is more living room than traditional transport vehicle. We note the threshold for bringing any product to market is very high at Apple — executives frequently assert that its objective is to make the "greatest products on earth" — pointing to a very high hurdle, which will likely be even higher for a car, given the outsized profile the offering would have and the required commitment. Moreover, Apple's product design is typically uncompromising, pushing technology progression (sometimes at the expense of consumer convenience) in what we refer to as "feature absolutism."

Although CEO Tim Cook has spoken zealously about autonomy and press reports suggest Apple may be developing breakthrough battery technology, it is unclear from the California driver tests or its patent portfolio that Apple has a leadership role in either, and we believe the initial basis for differentiation might be design, user interface (UI), and unique feature/functionality.

While difficult to dimension, if we were to "guesstimate" assuming a 2025 launch, we believe that very optimistically, Apple could sell 1.5 million cars by 2030 — which would add roughly US$75bn in revenues, or about 15% of Apple's total. In other words, a very

[53] AAPL: 5 Reasons Why We Believe Apple May Indeed Be Looking to Build a Car

successful car launch could add ~300bps to — or effectively double — Apple's overall growth rate, although the EPS impact would be more muted.

What impact might Apple have on Tesla and traditional auto OEMs? We would view Apple as a potentially formidable new entrant — but view its impact to be more likely felt by traditional (premium) auto OEMs than Tesla. Analogously, we note that when Apple entered the smartphone market, incumbents were most impacted (Nokia and Blackberry), while new vendors (Samsung, HTC, and later Chinese OEMs) ultimately benefited.

APPLE'S PLANS TO ENTER THE AUTO INDUSTRY

Apple has been working on a car/autonomy for at least six years, with seemingly shifting ambitions, leadership, and levels of commitment. We don't expect it to launch a car before 2025.

- Reports have indicated that Apple has been working on a car (code named Project "Titan") since 2014, with 1,000 employees on the project in 2016. It is possible/likely that the current team is larger — we note that Tesla employed ~3,000 at the time of launch of its Model S in 2012, and Lucid currently employees 2,000, with the launch of its car set for 2H2021.

- Six years ago, amid early press reports of Project Titan, we published a note discussing why we believed Apple was indeed looking to build a car.[54] Since then, Project Titan has undergone several leadership changes, as well as layoffs (including hundreds of engineers) and high-profile personal additions and executive departures (see Exhibit 307). Moreover, in August 2017, in an usual disclosure, Tim Cook stated "we are very focused on autonomous systems from a core technology point of view. We do have a large project going and are making a big investment in this," potentially suggesting that Apple's focus might have shifted to software/autonomy. In 2018, Apple hired John Giannandrea from Google to lead its AI efforts, including oversight of Project Titan. Doug Field — a former Apple hardware engineer who spent five years at Tesla — returned to Apple in August 2018 and is believed to be the lead day-to-day manager of the effort. Exhibit 308 shows the timeline of the Apple car.[55]

- Project Titan includes experts focused on nearly all elements of a car, including autonomy, interior and exterior design, drivetrain, and battery technology. Reports were that the initial target launch date for the car was 2020 or 2021; current reports suggest that a launch is more likely in 2024-25 or later.

[54] AAPL: 5 Reasons Why We Believe Apple May Indeed Be Looking to Build a Car
[55] For more detailed background on the Apple car, see https://appleinsider.com/inside/apple-car.

- Apple received approval from the California DMV to begin testing self-driving vehicles on public roads in California in April 2017. Self-driving test vehicles covered more than double the mileage (19,000 miles in California) in 2020 versus 2019 (7,500). In 2020, Apple reported 23 self-driving vehicles undergoing testing in California, down from a peak of 72 in 2018. Recent news reports have reaffirmed Apple's continued interest and progress in developing a car. Notably, reports have indicated that Apple has held discussions with OEMs (Hyundai/Kia and Nissan) about potentially building a car,[56] and with LIDAR makers about purchasing advanced, customized sensors.[57]

EXHIBIT 307: **Apple Project Titan: Key/high-profile external hires and departures**

Date	External Hire	Former Role/Employer
2016	Chris Porritt	VP of vehicle engineering at Tesla
2016	Alexander Hitzinger	Race program lead at Porsche
2018	Jamie Waydo	Senior engineer at Waymo
2018	Mark Rober	Engineer at NASA
2018	Doug Field	SVP of engineering at Tesla
2018	Andrew Kim	Senior Designer at Tesla
2018	At least 46 people (not all for Titan)	Tesla
2019	Michael Schwekutsch	VP of engineering at Tesla
2019	Employees from acquired Drive.ai	Drive.ai
2019	Steve MacManus	VP of engineering at Tesla
2020	Jonathan Sive	Engineering manager at Waymo
2020	Stuart Bowers	VP of engineering at Tesla
2021	Manfred Harrer	VP of chassis development at Porsche

Date	Departure	Role at Apple	New Employer
2016	Steve Zadesky	VP of product	?
2016	Bart Nabbe	Computer vision engineer	Faraday Future
2017	Chris Lattner	Creator of Swift	Tesla
2017	17 engineers	NA	Zoox
2019	Alexander Hitzinger	Head of Product Design	Volkswagen
2021	Benjamin Lyon	Senior manager	Astra (startup)

Note: Steve Zadesky reportedly left Project Titan in 2016 for personal reasons; that said, his LinkedIn pages suggests that he remained with the firm until 2019.

Source: Press reports and Bernstein analysis

[56] https://www.wsj.com/articles/apple-in-talks-with-hyundai-about-car-ambitions-auto-maker-says-11610079864, https://www.wsj.com/articles/kia-is-preparing-to-build-apple-cars-in-the-u-s-11612498065, https://www.wsj.com/articles/apples-talks-with-hyundai-break-down-11612750704, https://www.ft.com/content/29d4aa6b-fba5-4a53-876e-3f097fdef1d2

[57] https://www.bloomberg.com/news/articles/2021-02-19/apple-in-discussions-with-suppliers-for-self-driving-car-sensors?sref=u7LPHEPh

EXHIBIT 308: **Project Titan: Timeline**

Date	Update	Press
2014	Apple began working on "Project Titan," which was initially led by Steve Zadesky, a former Ford engineer	
2014-2016	It was reported that Apple started with a team of about 200 employees working on the Apple car, and grew to more than 1,000 employees in about 18 months	WSJ and NYT
2016	Apple hired retired Bob Mansfield (hardware engineering VP) to head the project, and also hired Dan Dodge (the founder and ex. CEO of QNX, BlackBerry's automotive software division), which was reported to have signaled a shift to prioritize software development for autonomous vehicles	Bloomberg
2016	120+ software and hardware engineers were laid off	
Early 2017	Apple received a permit from CA DMV to begin testing self-driving vehicles on public roads in California (w/ "several 2015 Lexus RX450h SUVs leased from Hertz")	
Jun-17	Tim Cook confirmed Apple's work on autonomous driving software, and called it as "the mother of all AI projects"	Bloomberg TV
Aug-18	Apple rehired Doug Field after his stint as SVP of engineering at Tesla	
Jan-19	Apple cut ~200 employees from the team as part of internal restructuring	
Apr-19	Apple held talks with 4+ potential suppliers of LiDAR sensors for self-driving vehicles	Reuters
Jun-19	Apple acquired Drive.ai, a self-driving shuttle service startup	
2020	Apple's self-driving test vehicles more than doubled the mileage (18,805 miles in California) vs. previous year (7.5k), and had 130 disengagements vs. 64 in 2019, which is to say Apple's cars experienced a disengagement every 144.6 miles vs. every 117.8 miles in 2019	
Early 2020	Apple talked to EV minivan company Canoo about potential investment/acquisition opportunities, which didn't come to fruition	The Verge
In 2020	Former head Bob Mansfield retired, John Giannandrea, Apple's AI and machine learning chief, succeeded his role	
Dec-20	It was reported that Apple targeted to produce an autonomous passenger vehicle that could include its own breakthrough battery technology as early as 2024	Reuters
Jan-21	It was reported that the Apple car won't be ready to launch until 2026 to 2028	Bloomberg
Jan 7 2021	It was reported that Apple held talks with Hyundai about autonomous electric vehicle	WSJ
Feb-21	It was reported that the Apple car will be the autonomous EV designed to "operate without a driver and focused on the last mile"	CNBC
Feb 5 2021	It was reported that Apple and Hyundai subsidiary Kia explored a partnership to build vehicles for Apple in Georgia	WSJ
Feb 7 2021	It was reported that Apple's talks with Hyundai fell apart without an agreement	WSJ
Feb 14 2021	Nissan said it was no longer in talks with Apple on autonomous projects after disagreements over branding	Financial Times

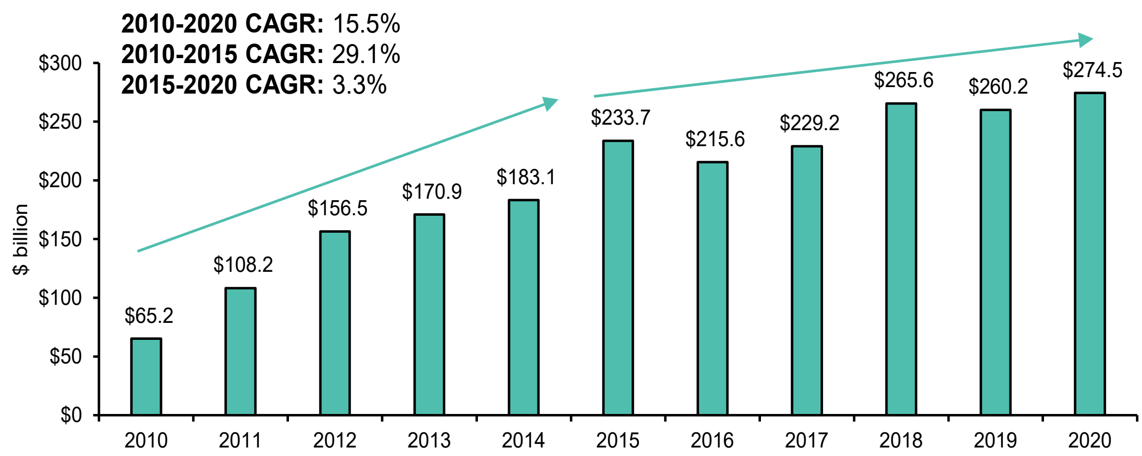
Source: Bernstein analysis

Apple's interest in the automotive market makes sense: the auto market is a uniquely large end-market (US$2tn+); Apple has a history of achieving attractive margins in low-margin industries through its premium product positioning; and Apple will likely be able to subcontract manufacturing of the vehicle and leverage a broad industry supply chain, a core competency of the company.

- **Uniquely large and addressable consumer market.** Apple's growth has slowed materially since 2015, with revenues at a CAGR of just 3.3% (see Exhibit 309) as the smartphone market has matured and Apple has lost some share in the premium segment (see Exhibit 310). The challenge now is that Apple is a US$300bn+ revenue company, making it increasingly difficult to drive incremental growth (e.g., the entire global PC market is just US$80bn in revenues!). In fact, we think 3% annualized growth is a realistic base case for top-line growth for Apple over the next five to 10 years. Given its revenue base, few addressable markets are sizeable enough to impact Apple's financials, but the auto sector offers a uniquely large, addressable consumer market with ~US$2tn+ in annual revenues from new vehicle sales, which is close to 5x the entire global smartphone market (see Exhibit 311). Accordingly, a 5% share of the global auto market would amount to ~30% of Apple's 2021E revenues.

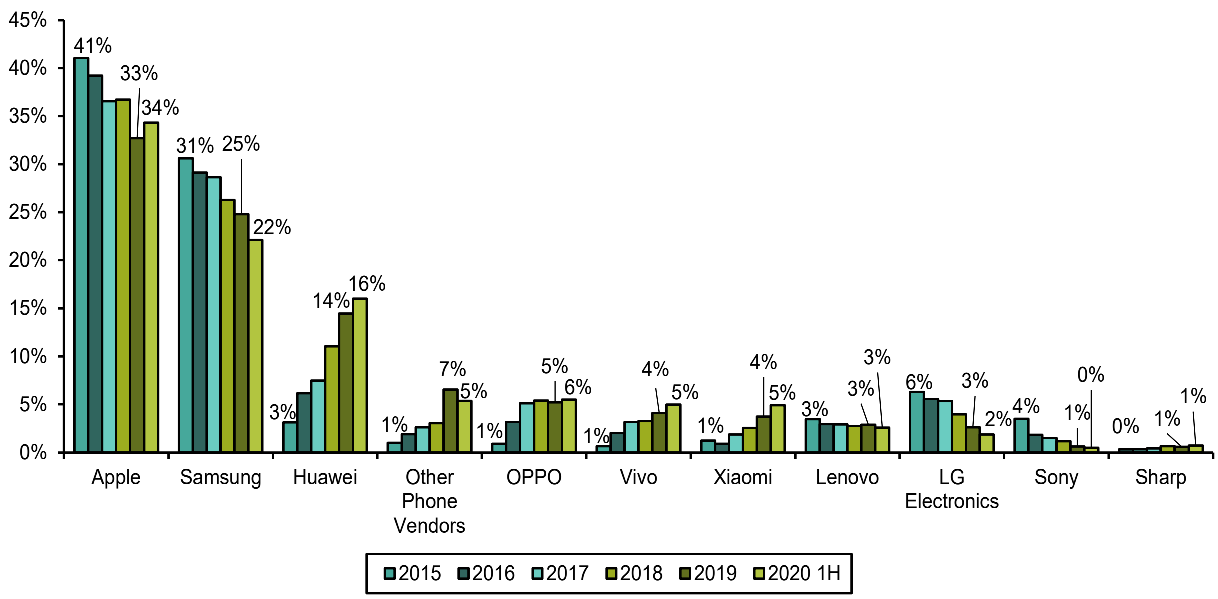
- **Although automotive industry margins are middling, Apple's premium-priced products have historically enabled it to capture a disproportionate share of industry profits in industries with single-digit profitability.** Apple is a premium product company, and its current major products (smartphones, Macs, and iPads) are typically priced at 2-4x the average offering in their category and, as a result, command an outsized portion of industry profits (see Exhibit 312). For example, in the smartphone market, Apple's ASP was US$837 in CY2019 compared to <US$200 for the rest of the industry, and we estimate that despite having just 11% unit market share, the iPhone commands an estimated 80%+ of industry profits. The same story is true in consumer PCs and tablets — Apple sells premium products and is able to capture outsized margins in industries with relatively low (i.e., single-digit) operating margins. We believe Apple would look to replicate this in the auto industry. While the largest manufacturers in the auto industry have operating margins ranging from 3% to 8%, premium players such Porsche command margins in the mid-teens (see Exhibit 313). While lower than Apple's company average, such margins are similar to what we estimate Apple enjoys on Macs, iPads, Apple Watch, and AirPods today.

EXHIBIT 309: **Apple revenue CAGR**



Source: Bloomberg, company reports, and Bernstein analysis

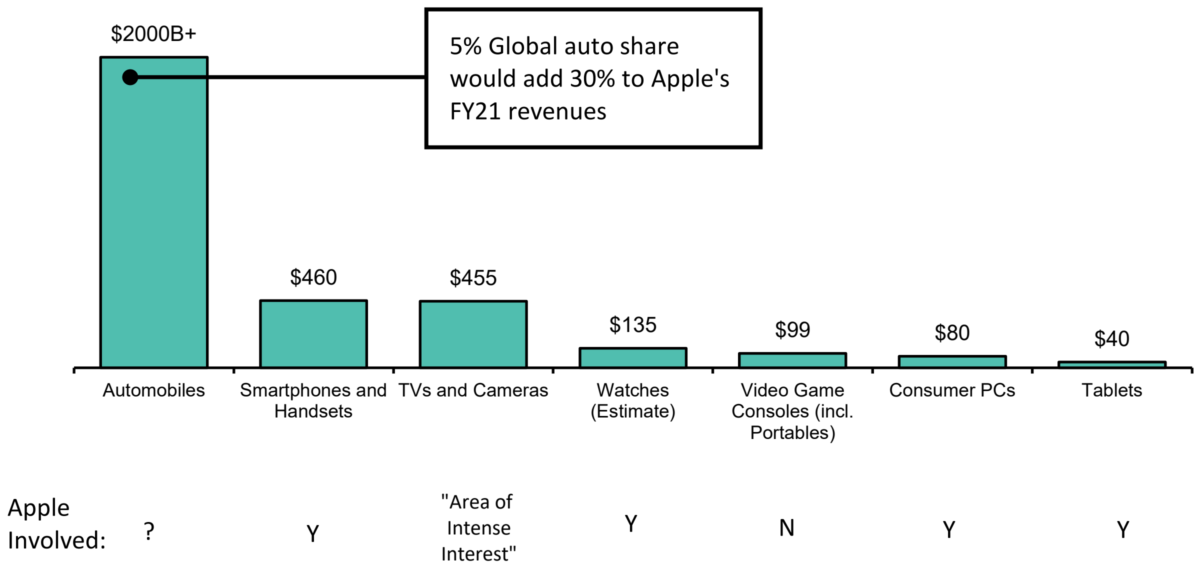
EXHIBIT 310: **Global premium smartphone: Unit share by top 10 vendors**



Note: Apple, Samsung, and LG Electronics are covered by Bernstein.

Source: Gartner and Bernstein analysis

EXHIBIT 311: **Annual consumer spending by market (US$bn)**



Source: IDC, Federation of the Swiss Watch Industry, and Bernstein estimates and analysis

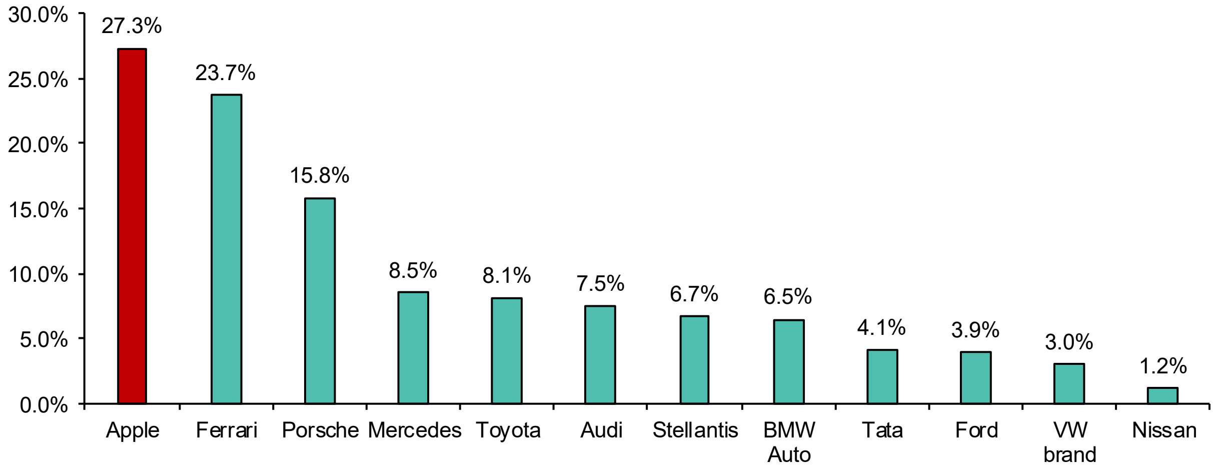
EXHIBIT 312: **Apple: price premium, ASP, market share, and estimated % of industry profits, CY2019**

	Apple Price Premium	Apple ASP	Industry ex. Apple ASP	Apple Unit Market Share	Estimated Op. Margin	Estimated % of Total Industry Profits
Smartphones	368%	*$837*	*$179*	11%	~30%	80%+
Consumer PCs	136%	*$1,388*	*$587*	10%	~15%	60%-70%
Tablets	196%	*$479*	*$162*	32%	~10-15%	80%

Note: Data in blue/italics are from Gartner; others are Bernstein calculations

Source: Gartner, company reports, and Bernstein estimates and analysis

EXHIBIT 313: **Operating margins of Apple and auto OEMs, 2021 forecasts (note most premium OEMs target 8-10% operating margins, Porsche >15%)**

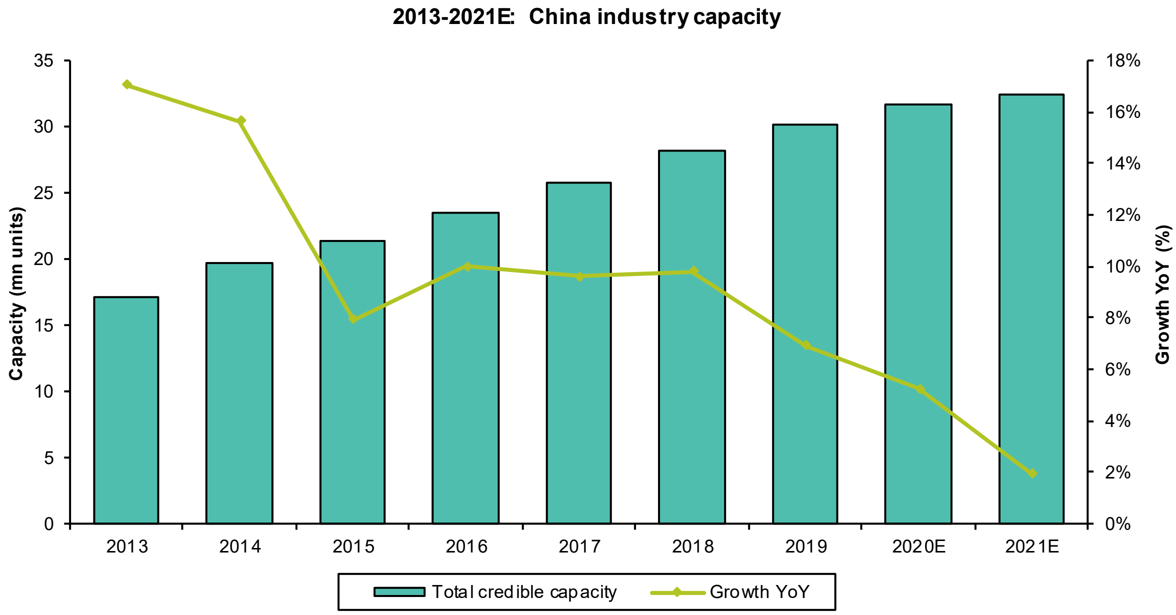


Note: Apple, Ferrari, Porsche, Mercedes, Audi (Volkswagen), and BMW are covered by Bernstein.

Source: Bloomberg consensus (Toyota FY2022, Tata FY2022, Ford FY2021, and Nissan FY2022), and Bernstein estimates (all other data) and analysis

- **As it has with its other products, Apple will likely be able to subcontract manufacturing of the car to established OEM(s) and potentially partner with leading battery makers.** Apple traditionally subcontracts manufacturing entirely to Asian manufacturers, such as Foxconn and Pegatron, and airfreights finished products overnight to the location of demand. The company sources key components, such as displays, processors, and memory, from third-party suppliers, some of whom it also has historically competed against (e.g., Samsung). Apple also invests intensely in its component and manufacturing partners — we estimate it has spent ~US$20bn on product tooling and process manufacturing equipment in the past four years alone. We suspect — as has been reported in recent news — that Apple will seek out a similar model for the car, and note that manufacturing alternatives exist in both China (see Exhibit 314) and among established OEMs.

EXHIBIT 314: **China auto capacity, 2013-21E**

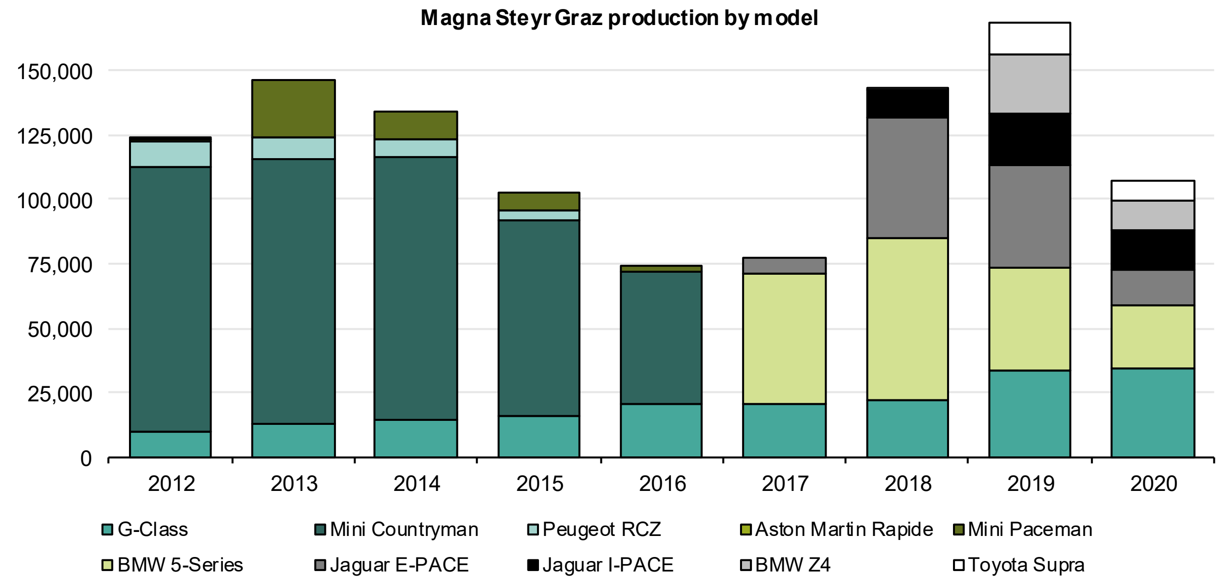


Source: Company reports, and Bernstein estimates (Global Autos team) and analysis

- **Who could and should Apple partner with to manufacture a car?** In our eyes, traditional carmakers will be very careful when exploring a manufacturing partnership with Apple. Clearly, any OEM does not want to end up becoming a mere enabler for one of the world's largest and best financially equipped tech players, dealing with its extreme supply chain management and ultimately creating another significant competitor in the EV TAM. Having said that, if an OEM would find some industrial logic, it would most likely be an auto company with very limited segment overlap. It hence doesn't surprise us that alleged discussions between Apple and Hyundai/Kia came up in the press recently. In our view, BMW would be the ideal partner for Apple. Both companies have a leading innovation claim, superior brand equity and design, and are excellent in global manufacturing/value chain management.

- **Could an auto supplier build the car for Apple?** Obviously, a supplier would not have the direct competitive conflicts that an OEM would face. Having said that, any auto supplier would need to be mindful of potential unintended consequences from establishing a serious rival to its bread-and-butter customers. With regard to well-established contract manufacturing capabilities, Magna, and its Austrian subsidiary Magna Steyer, spring to mind as a potential manufacturing partner for Apple. Magna Steyer (see Exhibit 315) has a strong history in high-quality and flexible manufacturing, particularly for premium brands. Having said this, an Apple car would be a different ballgame in terms of size and global manufacturing requirements.

EXHIBIT 315: **Magna has a long history in contract manufacturing; however, its flexibility has always been a focal strength; it has never scaled beyond 250,000 units/year (peak production in 2006)**



Source: IHS Markit and Bernstein analysis

- **Apple is already a partner for many OEMs:** Apple has various partnerships with carmakers, and many have integrated Car Play into their infotainment systems. Furthermore, BMW is the first brand to offer a digital car key via an iPhone (can be shared with up to five people). Therein lies an important question for Apple to answer: "Building a car" versus "getting into the car." Samsung has opted for the latter, with its US$8bn acquisition of car infotainment specialist Harman in 2017. Intel went down a similar route with the acquisition of Mobileye for US$15.3bn, also in 2017. Clearly, with 1.4 billion vehicles on the road and consumers spending >1 hour/day in their car, extending Apple's reach across all devices into the car is a game changer and offers services that traditional OEMs will likely struggle to deliver.

That said, we don't think a car offering from Apple is certain. Apple is highly selective in bringing new products to market and was arguably much further along toward commercialization of its own television and OTT service, both of which Apple never brought to market.

- **Many R&D projects remain R&D projects.** A former Apple engineer once told us, "80% of products I worked on never saw the light of day." Indeed, Apple engineers work on myriad new offerings, materials, features, and technologies, many of which are ultimately not commercialized — as quite frankly is the case with R&D initiatives at most tech companies. Perhaps most importantly, however, is that Apple is not shy in pulling the plug on major new offerings at late stages of development if it ultimately doesn't believe conditions are ripe for success. Two notable case studies highlight this propensity: the Apple TV set and an Apple OTT service (see Exhibit 316).

EXHIBIT 316: **Apple: Timeline of reported Apple TV set and OTT initiatives**

Date	Update
2007	Apple introduced Apple TV
2009	Apple reportedly was in talks with TV networks to launch an iTunes TV subscription at $30 per month
2011	Ex-CEO Steve Jobs stated in his biography that he had envisioned an “integrated television set that is easy to use” and had “finally cracked” the user interface for a TV
late 2012	Apple reportedly had negotiations to launch a set-top box with live TV capabilities with several large US cable operators including Time Warner Cable, which all fell apart
2012 and 2013	CEO Tim Cook said: 1) the TV market was an “area of intense interest” for Apple; and 2) Apple had a “grand vision” for the television
2012 - 2014	Apple tested TV with ultra-high-definition display and sensor-equipped cameras for viewers to make video calls
Early 2014	Apple renewed its conversations with Time Warner Cable and Comcast (fell through in 2015)
2015	Apple purportedly planned to offer 25 channel services (which don't include Comcast-owned NBC) for $30-$40 per month in fall
Sep 2015	Apple announced 4th gen Apple TV with no live TV service
2017 - Present	Apple has reportedly been spending $1B+ per year in content development since 2017
Nov-19	Apple announced its own streaming service, Apple TV+

Source: Company reports, press reports, and Bernstein analysis

- **Case study — television set:** Apple reportedly spent almost a decade researching the idea of building an Apple-branded television set. After first introducing Apple TV, a set-top box to stream video to TVs, in 2007, ex-CEO Steve Jobs stated in his biography published in 2011 that he had envisioned an "integrated television set that is easy to use" and had "finally cracked" the user interface for a TV. Apple's interest in the TV hardware space was again openly confirmed by CEO Tim Cook in 2012 and 2013.[58] That said, the company reportedly decided to shelve plans for a 4K TV set by 2014. After exploring features including an ultra-high-definition display and sensor-equipped cameras for viewers to make video calls, the company purportedly believed that its offering was not sufficiently unique or groundbreaking, according to the *WSJ*, and disbanded the research team.

[58] In May 2012 and 2013, Tim Cook said: (1) the TV market was an "area of intense interest" for Apple, and (2) Apple had a "grand vision" for the television.

- **Case study — over-the-top TV service:** Similarly, Apple's long running initiative to launch a full-fledged over-the-top TV service was ultimately thwarted. As early as 2009, Apple was reported to have been in talks with TV networks to launch an iTunes TV subscription at US$30 per month. In late 2012, Apple reportedly had further negotiations to launch a set-top box with live TV capabilities with several large US cable operators including Time Warner Cable, which all fell apart. Apple unsuccessfully renewed conversations with Time Warner Cable and Comcast again in early 2014, to no avail. Apple then pursued its own online bundle of TV channels and came to licensing partnerships with ABC, CBS, and Fox, but notably not with Comcast-owned NBC. Purportedly, Apple was planning to offer a 25-channel service for US$30-US$40 per month in fall 2015, but ultimately decided not to do so, given it felt the offering was incomplete/not compelling. Since then, Apple shifted its focus to buying and creating its own TV content and has reportedly been spending US$1bn+ per year in content development since 2017. In November 2019, Apple announced its own streaming service, Apple TV+.

If Apple is to launch a car, we suspect that it will be both all-electric and have high-level autonomy, with potentially a passenger cabin that is more living room than traditional transport vehicle. That said, while CEO Tim Cook has spoken zealously about autonomy, and press reports have reported that Apple may be developing breakthrough battery technology, it is unclear from California driver tests or its patent portfolio that Apple has a leadership role in either, and that the initial basis for differentiation in Apple's car might be design, UI, and unique feature/functionality.

- **We note that the threshold for bringing any product to market is very high at Apple** — executives frequently assert that its objective is to make the "greatest products on earth" (see Exhibit 317) — pointing to a very high hurdle, which will likely be even higher for a car, given the outsized profile the offering would have and the required commitment. Moreover, Apple's product design is typically uncompromising, pushing technology progression (sometimes at the expense of consumer convenience) in what we refer to as "feature absolutism" (see Exhibit 318).

EXHIBIT 317: **Tim Cook's comments on Apple's product philosophy**

Q121 Earnings	The framework that we use is very much around we ask ourselves if this is a product that **we would want to use ourselves or a service that we would want to use ourselves**, and that's a pretty high bar. And we ask ourselves if i**t's a big enough market to be in unless it's an adjacency product**, of which we're looking at it very much from a customer experience point of view. And so there's no set way that we're looking at it, no formula kind of thing. But we're taking into account all of those things. And **the kind of things that we love to work on are those where there's a requirement for hardware, software and services to come together because we believe that the magic really occurs at that intersection.**
Q320 Earnings	We're a product company and we love making the whole thing and -- **because we can own the user experience in that way and with the goal of delighting the user.** And that's the reason that we're doing the Apple silicon is because we can envision some products that we can achieve with Apple silicon that we couldn't achieve otherwise. And so that's how we look at it.
2019 annual general meeting	Apple is “rolling the dice” on future products that will “blow you away”
Q319 Earnings	(Besides consumer hardware), we continue to focus on the enterprise market, and we think that continues to be a big opportunity for us. Then we've got lots of what I would call core technology kinds of things like augmented reality, where we're placing big bets, and I think we have a big future in addition to the health kinds of things that may fall out of the Watch...
Q418 Earnings	Our objective is to **make great products, provide the best customer experience and get our customers satisfied, engaged and loyal to our ecosystem**.
Investor Tech Conference (February 2015)	And so, we're actually not focused on the numbers. We're focused on the things that produce the numbers, right? And so, if you look at accomplishments over last year, we're a product company. And our most important thing is to make great products. But, **what we won't do is do something that's second rate or that's only a good product, not a great product** because that's not what Apple stands for. And that's not what we think customers want.
Q115 Earnings Call	Apple's mission is to **make the greatest products on earth and to enrich the lives of others.** Through the success of iOS, we have provided hundreds of millions of people with powerful personal technology that is simple and fun to use. Our customers are using Apple products to transform education, discover new ideas for business, and express their creativity in ways that no one could have imagined when we sold the first iPhone less than eight years ago. It's amazing to watch, and it reminds us that people and great ideas are the reason we make the things we make.
Q114 Earnings	As I've said before, our objective has always been to **make the best, not the most.** And we feel we are doing that.
Q209 Earnings	We believe that we’re on the face of the Earth to make great products, and that’s not changing. We’re constantly focusing on innovating. **We believe in the simple, not the complex. We believe that we need to own and control the primary technologies behind the products we make, and participate only in markets where we can make a significant contribution.** We believe in saying no to thousands of projects so that we can really focus on the few that are truly important and meaningful to us. We believe in deep collaboration and cross-pollination of our groups, which allow us to innovate in a way that others cannot.

Source: Company reports and Bernstein analysis

EXHIBIT 318: **Apple's historical "feature absolutism"**

Source: Apple.com, company reports, and Bernstein analysis

- **All electric and autonomous?** The question is, how might Apple "reinvent" cars in a way that it did with smartphones, the iPad, and the Apple Watch? In many ways, Tesla delivered in 2012 with the Model S, a product that was Apple-like: uncompromising in being all-electric, unique in its streamlined and elegant UI, and differentiated in having over-the-air updates to deliver incremental functionality. Press reports suggest an Apple car will be all-electric (unquestionable, in our view) with a unique battery technology ("monocell" design and LFP chemistry[59]), and also offer a high level of autonomous capability with at least highway L3 driving. For both regulatory and technical reasons, we struggle to see L4 autonomous feasible by Apple's assumed launch date in the mid-2020s (i.e., no driver intervention in most situations). Ultimately, given Apple's feature-absolutist design mentality, we suspect the aspiration would be to make the car truly self-driving, enabling a fundamentally redesigned interior. The key question concerning the highest levels of autonomy is more related to the "where" rather than the "when" in our view.

- **What might be the source of differentiation?** That said, it is unclear whether autonomous capability beyond Level 3 and/or off highways will be technologically in place, let alone accepted by regulators by 2025. Moreover, based on publicly available filings,[60] it is unclear to us whether Apple's autonomous technology has achieved a leadership position. The company's vehicles drove 18,000 miles in 2020, considerably fewer than the 600,000-800,000 miles by Cruise and Waymo, and its disengagement per 1,000 mile[61] metric also lagged the two leading competitors (6.91 versus 0.035/0.033) and is largely middle of the pack among myriad competitors[62] (see Exhibit 319 and Exhibit 320).

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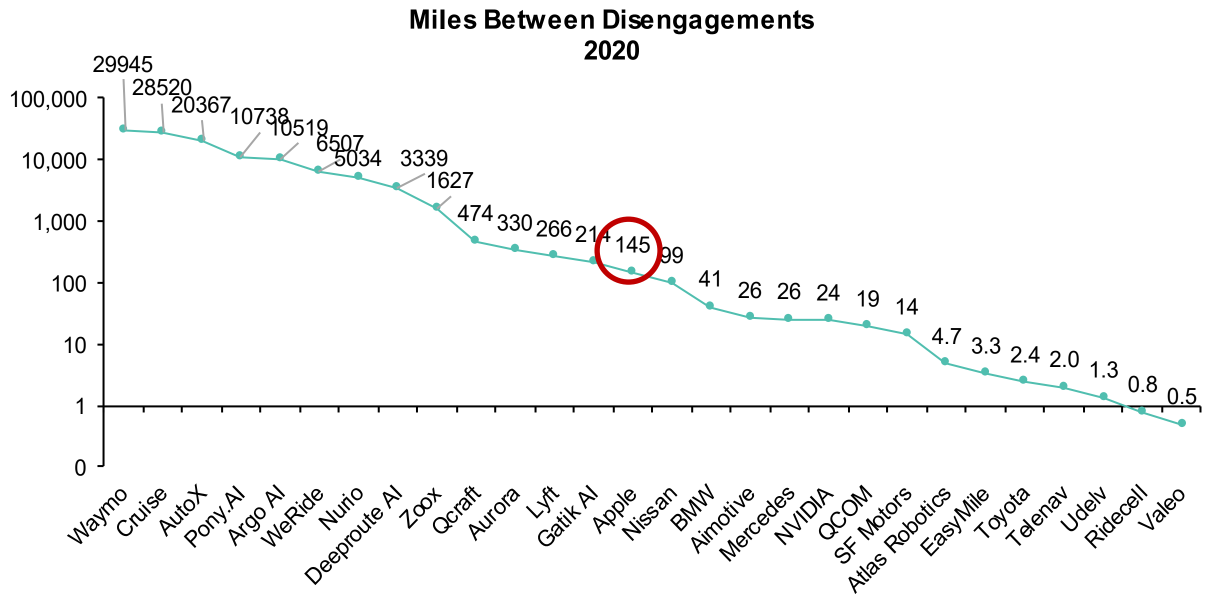
[59] https://www.reuters.com/article/businessNews/idUSKBN28V2PY
[60] https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles/disengagement-reports/
[61] Measures the number of times a failure of the technology is detected or a safety driver takes control of the vehicle. Although this is the only public metric available in the California reports, experts and companies have warned that it is not fully indicative of the reliability of underlying technologies. Apple, for example, has stated that the company was penalized on this metric for initiating disengagements more conservatively in their road tests. For more detailed analysis, see U.S. Semiconductors - Five exhibits on autonomous driving progress.
[62] https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles/disengagement-reports/

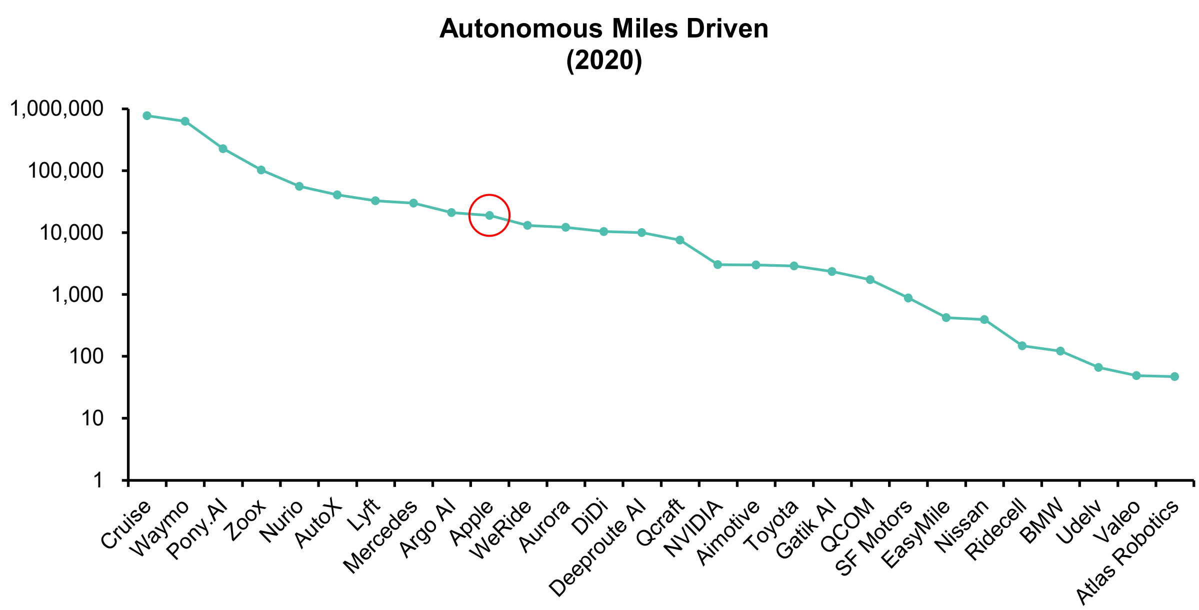
EXHIBIT 319: **The rate of autonomous disengagements varies hugely between companies...**



Note: Waymo (part of Google), Lyft, BMW, Mercedes, NVIDIA, and QCOM are covered by Bernstein.

Source: California DMV and Bernstein analysis

EXHIBIT 320: **...as does the total number of autonomous miles driven**



Source: California DMV and Bernstein analysis

- On the battery side, Apple's auto-related patent filings include detection sensors, active suspension system, adjustable windshields, and climate control (see Exhibit 321), but do not point to any unique cell or battery pack technology. Moreover, we suspect that a unique partnership with an established battery vendor is unlikely, given Apple's late entry into the field. Finally, we believe that the hurdle for Apple being able to offer a unique driving range will be high, given vehicles today are currently at 400+ miles (Tesla and Lucid) and battery makers (Tesla, CATL, Samsung, and LG Chem) have discussed a potential doubling of energy density (e.g., Tesla to ~400 Wh/kg) over time.[63]

EXHIBIT 321: **Project Titan: Key car tech patents granted/filed in the last three years**

Select key patents (75+)	#	Description	Status	Date filed
Autonomy				
Active suspension system	10,906,370	Implementations of suspension assemblies and suspension actuator assemblies	Granted	Feb-2021
Retroreflector system	10,908,328	a visibility system for vehicles designed to assist drivers in viewing key road signs in poor weather conditions such as snow, fog dust, smog	Granted	Feb-2021
Vehicle real-time depth sensing	10,891,745	a hybrid system for real-time depth sensing that can determine more accurate range and reflectance measurements; can be incorporated into the space typically occupied by each headlight on the front of a vehicle	Granted	Jan-2021
Three-dimensional object detection	10,872,228	Provides a method and system for detecting objects in a three-dimensional space using sensor information and for determining information associated with the detected objects using the sensor information; The sensor information can include but is not limited to LIDAR point clouds (e.g., 3D LIDAR point clouds).	Granted	Dec-2020
Hazard detection sensor	10,871,555	An advanced hazard detection sensor system that can be built into both the front and rear of a vehicle	Granted	Dec-2021
Traffic direction gesture recognition	10,909,389	A system that can see and respond to gestures from humans on the ground	Granted	Feb-2021
Realtime 3D mapping by LiDAR	20200348418	A LiDAR system placed behind a windshield to help view the road under various whether conditions and to track people or animals on the road ahead	In application	Nov-2020
Smart Car				
Holographic head-up display	10,866,414	Provides improved head-up displays for displaying information for the occupants of a vehicle in a wider range of locations	Granted	Dec-2020
Climate control system	10,875,380	The climate control system uses sensors inside and outside a vehicle to monitor changes in the environment, changes the settings within a vehicle correpondingly	Granted	Dec-2020
Gesture-based control of autonomous vehicles	10,913,463	This system enables a user to communicate and direct an autonomous vehicle using hand gesturing and combinations of signals of different modalities (e.g., voice, gesture, gaze direction etc.)	Granted	Feb-2021
Adjustable windshields	10,730,368	Electrically adjustable components of windows may be used to adjust the optical properties of the windows in a building or vehicle	Granted	Aug-2020
Sunroof System	10,632,905	A system where the driver can adjust the tint levels as needed when driving to control brightness in the vehicle	Granted	Apr-2020
Extendable bumperse for vehicles	10,336,290	A system that could inflate and deflate to allow the bumper to move in and out	Granted	Jul-2019
Wireless power transfer system	10,164,469	An equipment with a source of power such as a wireless power transfer unit that can transfer power wirelessly to target equipment, which could be a vehicle	Granted	Dec-2018
Electrification				
Vehicle thermal management system		Thermal management system for a BEV or HEV	Filed	Apr-2019

Source: USPTO and Bernstein analysis

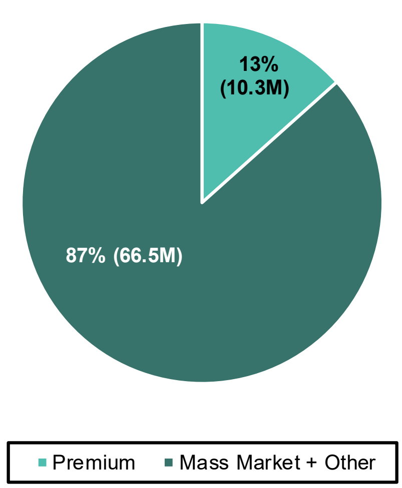
[63] Tesla is aiming to double battery energy density over the next three to four years. Neither Samsung nor LG Chem has specified the timeframe for its target; the former tested a doubling of pouch cell energy density to >900 Wh/L, while the latter is researching cylindrical batteries that have five times more energy density. BMW has also announced plans to double its EV battery energy density by 2030, although we suspect it would likely do so in partnership with battery makers.

- Accordingly, if Apple is to launch a car by the middle of this decade, we suspect that distinctive styling/interior/UI could be its basis for differentiation. Apple has filed patents regarding sunroof design, retractable bumpers, wireless charging, an anti-glare system and unique lighting, among others.

While difficult to dimension, if we were to guesstimate, assuming a 2025 launch, we believe that very optimistically, Apple could sell 1.5 million cars by 2030 — which would add roughly US$75bn in revenues, or about 15% of Apple's total. In other words, a very successful car launch could add ~300bps to — or effectively double — Apple's overall growth rate, though the EPS impact would be more muted.

- **Base assumptions.** Without knowing its product offering and/or pricing, it is particularly challenging to gauge what kind of traction an Apple car could ultimately gain. That said, let us put a few stakes in the ground: (1) We suspect that Apple will launch an all-electric vehicle, and we currently forecast that total global PHEVs and BEVs sold might amount to 13 million in 2025 and potentially 40 million by 2030.[64] An Apple car arguably could materially accelerate adoption. (2) We believe that Apple will play in the premium part of the market, with ASPs likely at US$50,000 or above. Currently, the automobile market is about 13% premium today (10.3 million units, see Exhibit 322) — so potentially, at least in the early EV rollout, the premium segment could be a higher percentage — perhaps 15%+, suggesting 6 million to 7 million premium EVs sold globally in 2030. Given combined volume aspirations from traditional premium OEMs and new pureplay brands, the premium EV market appears increasingly crowded.

EXHIBIT 322: **Premium vehicle sales as % of all light vehicle sales globally**



Note: As of December 2020

Source: IHS, and Bernstein analysis

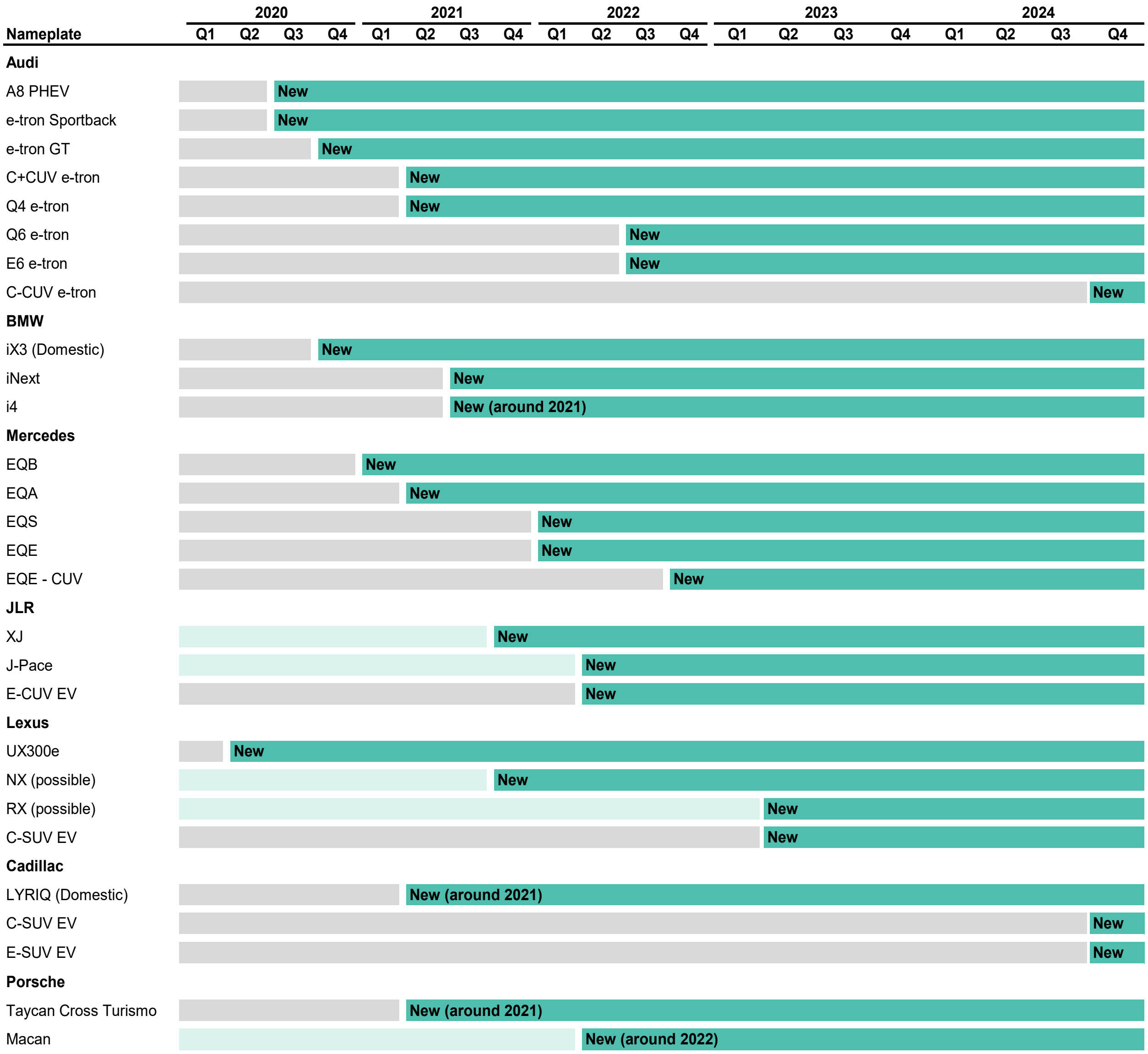
[64] TSLA: EV penetration has increased 5x in the last 4 years...Where to from here?

- **Rough scenarios.** So, how much of the market could Apple possibly grab? **One approach** is to assume that Apple could have similar traction to Tesla. We note that Tesla launched its first mass-market premium car — the Model 3 — essentially at the beginning of 2018. Assuming Tesla is able to grow units at its targeted 50% per year from current levels (500,000 in 2020), it would result in total units sold of 1.7 million in 2023, five years after the launch of its first mass-market car. From a timing perspective, this would be analogous to Apple launching in 2025, with units sold in 2030 of 1.7 million. We could argue that Apple would be launching its EV into a much more established market than when Tesla launched the Model 3, making it easier for Apple to sell a similar number of units. That said, competition will invariably be rife, with nearly every luxury auto OEM having a relatively complete line-up of EVs then (see Exhibit 323). **A second approach** would be to assume Apple captures the same share it has in the premium smartphone market — which historically has been about 35%. This would suggest 2 million+ units in 2030 (35% of a market of 6 million to 7 million).

- **Do these scenarios make sense?** Tough to know. Purchasing a premium car is clearly different from purchasing a premium phone. The auto market is much more fragmented than categories that Apple currently plays in, with different geographies having different form factor needs and brand preferences. Moreover, the top 3 selling OEMs in this segment are Mercedes, BMW, and Audi with 2.4 million, 2.0 million, and 1.7 million unit sales in 2020 (see Exhibit 324),[65] respectively, meaning Apple would become among the largest premium brands by offering only EVs in only five years. Importantly, we also note that essentially no premium model sells more than 400,000 units per year (see Exhibit 325), suggesting Apple will likely need to offer 3-5+ SKUs to sell 1-2 million+ units. Finally, it is not clear whether Apple will be able to secure a manufacturing partner with the capacity and global reach to deliver 1.5 million or 2 million+ units by 2030, although we note that Apple has a history of funding tooling and equipment for its suppliers, which it could clearly do for automotive partners, and its capital base is nearly limitless. On net, we believe 1.5 million units is likely an aggressive forecast for the Apple car in 2030.

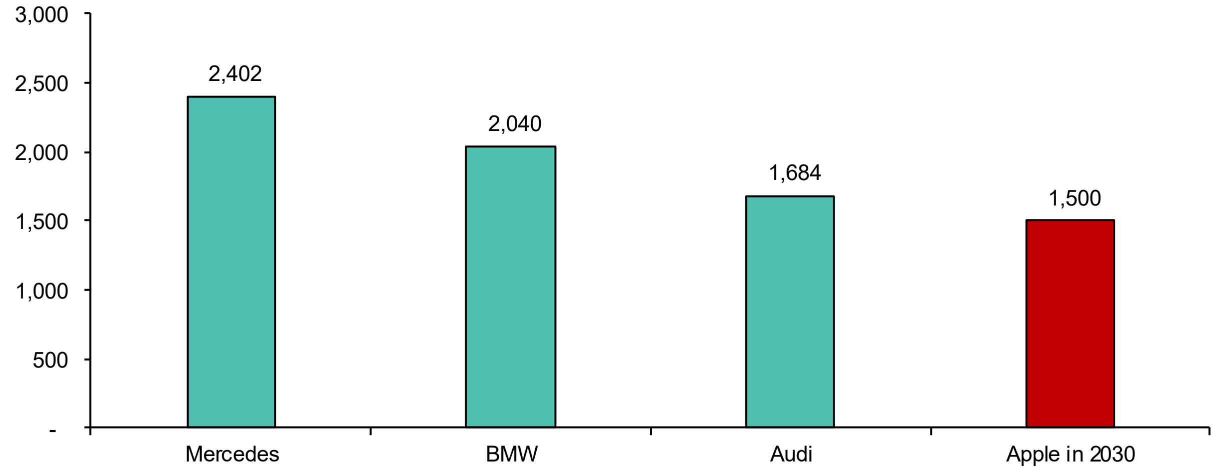
[65] Tesla Model 3 was the top selling model in the premium segment in 2020 with 327,000 deliveries (Tesla estimate).

EXHIBIT 323: **Most global premium brands are launching EV models in the coming years**



Source: IHS, company reports, and Bernstein analysis.

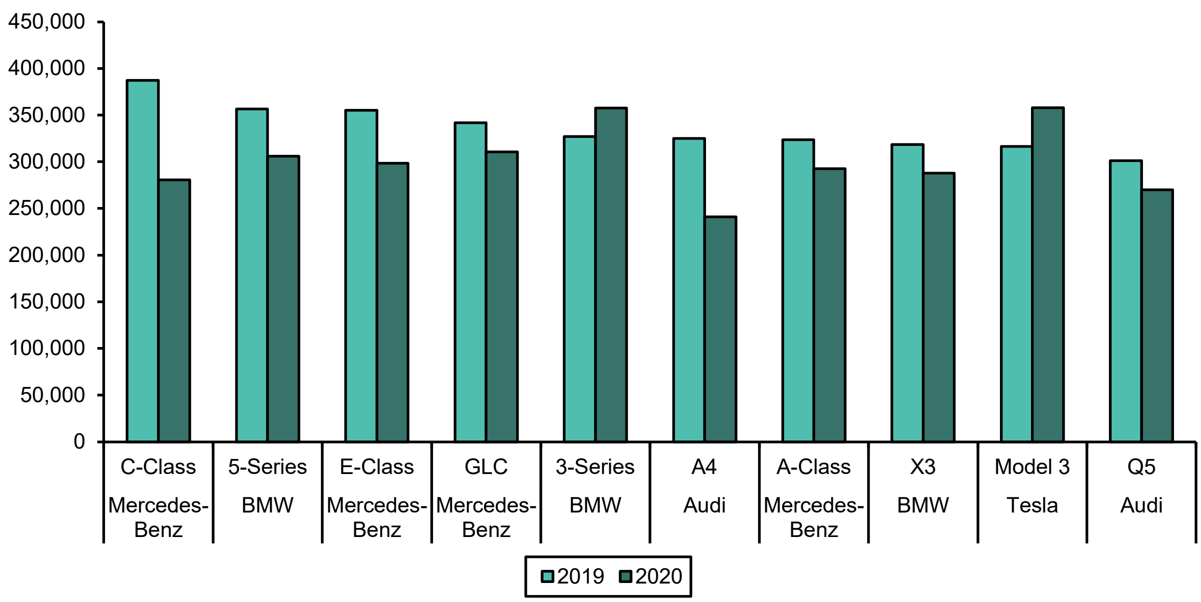
EXHIBIT 324: **Top 3 selling OEMs in the premium segment in 2020 versus guesstimated Apple car sales (aggressive scenario) in 2030**



Note: As of December 2020

Source: IHS, and Bernstein estimates (2030) and analysis

EXHIBIT 325: **Global autos: Unit sales of top selling premium models in CY2019 and CY2020**



Source: IHS and Bernstein analysis

- **What impact would a successful car launch have on Apple?** We assume an Apple car on average might cost US$50,000-US$60,000. While many investors speak about incremental services (the car could become the next living room, after all), we note that 5G will likely be ubiquitous and inexpensive over the next few years, suggesting consumers will not be captive to entertainment options provided by the car/Apple (a large iPad/PC/Monitor with a 5G connection will suffice to provide myriad entertainment alternatives). Like Tesla, we suspect that the largest software/services opportunities will be around autonomy, and a potential ride sharing service, but we believe that over time prices on both will decline (several Level 1 and 2 autonomous driving features are now standard on premium automobiles). On net, assuming that an Apple car has an average price of US$50,000-US$60,000, and a steady ramp in volume from 2025 through 2030 (see Exhibit 326), the Apple car could amount to US$75bn in revenues by 2030, or potentially 15% of Apple total company revenues, adding ~300bps of growth and effectively doubling Apple's revenue growth during the period. We suspect that margins would likely be lower (operating margins of perhaps 10-15%), likely not dissimilar from what Mac, iPad, Apple Watch, and AirPods margins are today. Under these margin assumptions, the Apple car would amount to close to 10% of Apple's earnings by 2030 under a 1.5 million unit scenario.

EXHIBIT 326: **Potential impact of the Apple car on overall revenue growth under an assumed 1.5 million units sold scenario in 2030**

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Unit Sales (K)	-	-	-	-	250	375	619	928	1,206	1,507
YoY Growth						***50%***	***65%***	***50%***	***30%***	***25%***
ASP ($K)					$ 65.0	$ 62.0	$ 59.0	$ 56.0	$ 53.0	$ 50.0
Apple Car Revenue ($M)	-	-	-	-	$ 16,250	$ 23,250	$ 36,506	$ 51,948	$ 63,915	$ 75,371
Contribution to Annual Growth					4.2%	1.6%	2.9%	3.1%	2.1%	1.9%
Apple Revenue ex Car	$ 343,547	$ 353,853	$ 364,469	$ 375,403	$ 386,665	$ 398,265	$ 410,213	$ 422,519	$ 435,195	$ 448,250
YoY Growth		***3.0%***	***3.0%***	***3.0%***	***3.0%***	***3.0%***	***3.0%***	***3.0%***	***3.0%***	***3.0%***
Overall Apple Revenue	$ 343,547	$ 353,853	$ 364,469	$ 375,403	$ 402,915	$ 421,515	$ 446,719	$ 474,467	$ 499,109	$ 523,622
YoY Growth		3.0%	3.0%	3.0%	7.3%	4.6%	6.0%	6.2%	5.2%	4.9%
Apple Car Revenue as % of Total Revenues	-	-	-	-	4.0%	5.5%	8.2%	10.9%	12.8%	14.4%
Apple Car Op Margin					***0%***	***0%***	***5%***	***8%***	***11%***	***15%***
Company ex. Car Op Margin	***27%***	***28%***	***29%***	***30%***	***30%***	***30%***	***30%***	***30%***	***30%***	***30%***
Apple Car as % of Total Operating Income							1.4%	3.1%	5.1%	7.7%

Source: Company reports, and Bernstein estimates (2021+) and analysis

What impact might Apple have on Tesla and traditional auto OEMs? We would view Apple as a potentially formidable new entrant — but view its impact to be more likely felt by traditional (premium) auto OEMs than Tesla necessarily.

- **Growing the pie but eating it too.** Revolutionary new product offerings can accelerate market adoption of a new product or service, as evidenced by the Tesla Model 3, Netflix, or iPhone and, accordingly, an Apple car could expand the premium segment of the automotive market and/or accelerate the migration to EVs. That said, Apple will invariably be a share gainer.

- **The challenge for incumbent EVs.** Ultimately, the challenge for incumbent EVs is that new OEMs (Tesla, Rivian, Xpeng, Nio, Lucid, etc.) are rapidly building brands and gaining traction in the EV marketplace, pressuring the addressable market for traditional incumbents. Looked at a different way, if new EV vendors sell 10 million or 20 million EVs at end state, then the addressable market for incumbent EVs will decline by a commensurate amount (i.e., from 90 million to 70 million or 80 million).

- **Incremental pressure on traditional premium OEMs, rather than Tesla?** To that end, a successful EV launch from Apple would add a formidable, well-capitalized competitor to the automotive industry, further shrinking the total available pie for traditional OEMs. In the premium space, Apple capturing 1.5 million units would amount to >10%

market share. That said, regardless of whether Apple's entry accelerated adoption of EVs, we still see the EV market growing at a CAGR of 20%+ for the next 10 years,[66] providing ample opportunity for all EV players (i.e., even if one was losing share, an EV maker could grow double digits for a decade). Analogously, we note that when Apple entered the smartphone market, incumbents were most hurt (Nokia and Blackberry), while new vendors (Samsung, HTC, and later Chinese OEMs) ultimately benefited. Traditional premium brands that have strong brand equity will need to deliver a convincing product that addresses all areas of relevant innovation to defend their market positions.

- **Apple would trigger an accelerated pace toward powertrain electrification.** As we have seen with Tesla, consumers from all parts of the traditional brand universe and new car buyers are turning into EV customers. Tesla hasn't just cannibalized premium auto brands. We would expect the same to happen with an Apple car. Increasingly, we see the automotive landscape dividing into the "haves" and "have nots." Companies that are late to prepare for electric, connected, and increasingly autonomous driving will lose traction with consumers and regulators. These are the companies that are most at risk of being cannibalized from the influx of new mobility market entrants.

INVESTMENT IMPLICATIONS

AAPL has had a tremendous run over the last 1.5 years, and trades in line with large tech companies with higher growth rates and at nearly 30x consensus 2021 EPS, close to the high end of its five-year history. With limited opportunities for upward revisions through year end and the company facing very tough comps and a more muted iPhone cycle next year, we struggle to see the case for material outperformance from current levels. We rate AAPL Market-Perform.

[66] TSLA: EV penetration has increased 5x in the last 4 years...Where to from here?

RAMP OF EVS IN NEXT TWO DECADES DRIVES PREFERENCE FOR GAS MIDSTREAM

OVERVIEW

- We are frequently asked by investors **whether EVs could be good for US natural gas** (albeit bad for oil demand). Every few years, we do a deep-dive walking through our auto analyst's outlook for EVs to 2040, and the implications, if correct, on US gas demand and gas price. Notably, EV penetration projections have all moved up substantially since 2017 (the last time we published a similar report), showing how much traction there has been on the topic in the last four years.

- We find **high penetration of EVs would indeed be good for US gas price, but perhaps not for the reason that most might think**. The **new demand for gas, even in a relatively bullish case, is actually quite small**, owing to the high fuel efficiency of EVs (4-5x more fuel efficient than gasoline cars). Moreover, gas only makes up two-fifths of electricity generation, leading to only ~5bcfd of incremental gas demand by 2040 (6% of today's gas demand), even with high EV penetration.

- **However, the larger and perhaps underappreciated impact on the gas market would be the decline in oil demand and, therefore, oil and associated gas supply, which should move gas price up.** Associated gas is around 30% of supply today, but has provided nearly all the growth in the gas market the last few years; it is by far the cheapest source of supply (free). If this declines by 10-20% as is suggested in the EV penetration scenarios, gas demand remains constant. With the increase from EVs offsetting losses due to wind and solar growth, meeting gas demand would require bringing the higher-cost dry gas basins back into the equation faster — **thus a view of high EV penetration might be most beneficial in the oil and gas sector to Fayetteville and Barnett players**.

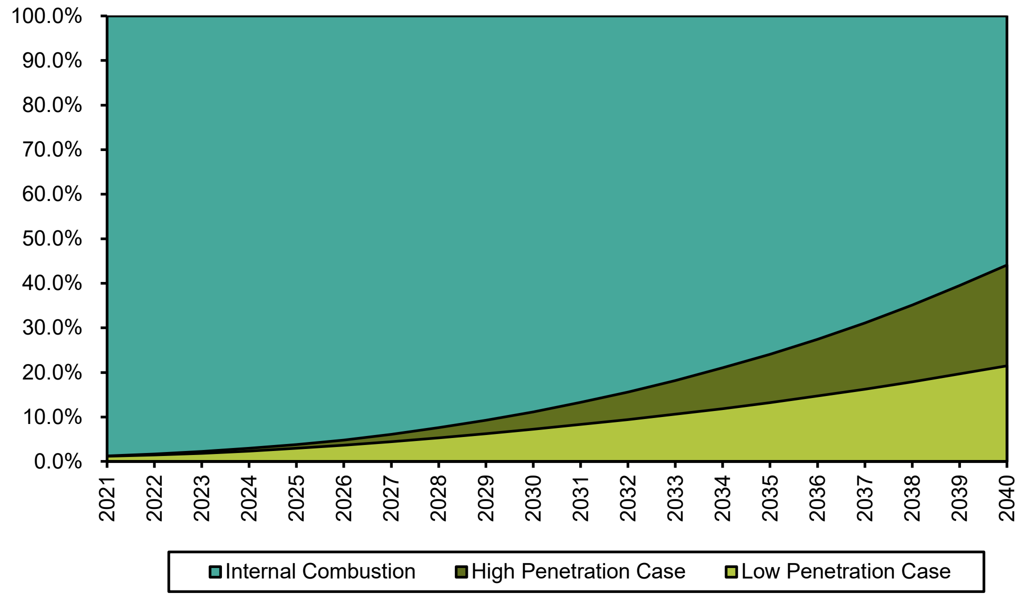
- Finally, we have noted this a number of times,[67] but we do not think that gas midstream gets the relative credit it deserves compared to oil midstream, given how much more long lasting gas flows should be in the US.

[67] Williams (WMB) - ESG in Action...Improvers and Enablers…the underappreciated role of US gas basins in the energy transition
https://www.bernsteinresearch.com/brweb/ViewResearchStreamer.aspx?cid=3irFp0rAUQnhEV02mYvOrCMtdBx0q%2bKYSaPe49aTCbDnMJXCTRnm0MocevIHShi1

EV GROWTH AND GAS DEMAND

We are frequently asked by investors **whether EVs could be good for US Natural Gas** (albeit bad for oil demand). Every few years, we do a deep dive walking through our auto analyst's outlook for EVs to 2040, and the implications, if correct, on US gas demand and gas price. Notably, EV penetration projections have all moved up substantially since 2017 (the last time we published a similar report), showing how much traction there has been on the topic in the last four years (see Exhibit 327 and Exhibit 328).

EXHIBIT 327: **Bernstein high case from autos team has 44% EV fleet penetration by 2040 (low case is ~20%)**



Source: Bernstein Auto team estimates (2021+) and analysis

EXHIBIT 328: **The high case is in line with BNEF; notably all long-term estimates have risen dramatically in recent years**

Source	EV % of 2040 Fleet	*2017 estimates*	Note
Bernstein high	44%	*37%*	US Fleet
Bernstein low	22%	*8%*	US Fleet
BP	38%	*6%*	Global Fleet
Exxon	23%	*10%*	Global Fleet
BloombergNEF	42%	*33%*	US Fleet
EIA	23%		US Fleet (stock share)
OPEC	13%		Global Fleet
IEA	7%*		Global (2030)

*By the IEA Stated Policies Scenario

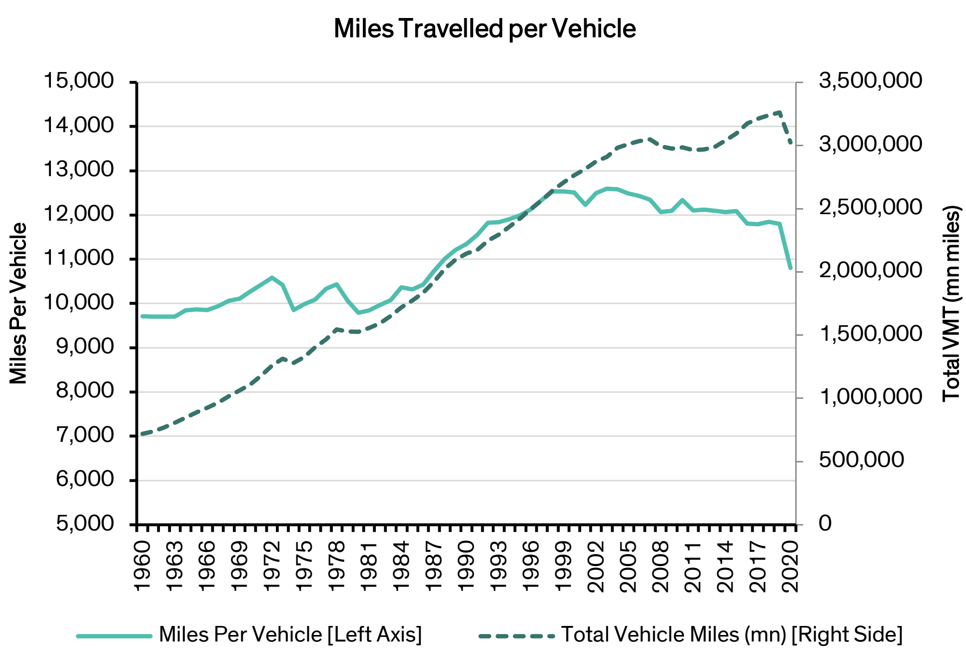
Source: BP Energy Outlook, Exxon Energy Outlook, Bloomberg, EIA, OPEC, World Energy Council, and Bernstein estimates and analysis

We consider all vehicles to be in the following four categories:

- **Traditional ICEs:** ICEs make up the vast majority of the current fleet, using gasoline or diesel as fuel.
- **HEVs:** Vehicles that rely on gasoline as the main fuel source, but featuring both an IC engine and an electric motor to power the car.
- **PHEVs:** A mix of gasoline and rechargeable battery powers these vehicles.
- **EVs:** Think Tesla — a fully EV with no need for gasoline; powered solely through a rechargeable battery.

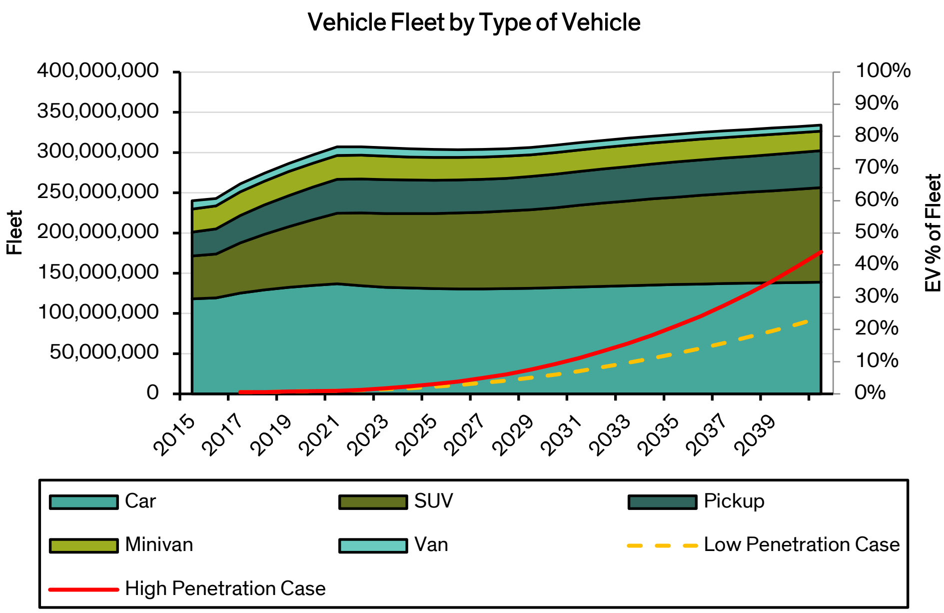
Exhibit 329 shows that even though miles traveled per vehicle in the US has been flat to down over the past two decades, the addition of new cars on the road has led to a long-term CAGR of 0.9% in vehicle miles travelled (VMT), on which we base our projections.

EXHIBIT 329: **Average miles driven per vehicle has been flat, but more vehicles on the road has led to a 0.9% CAGR in total VMT over the last 10 years excluding 2020, which we project forward**



Source: Federal Highway Administration (FHWA), and Bernstein analysis

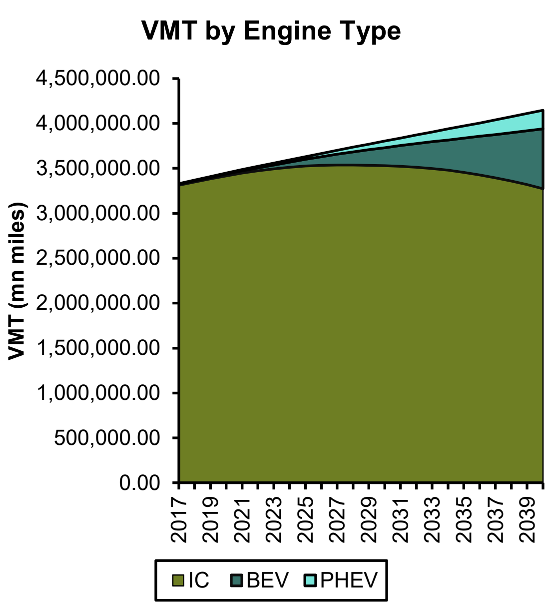
EXHIBIT 330: **Vehicle fleet by type and EVs as % of total fleet — EV CAGR to 2040 is 16% in the low case and 20% in the high case**



Source: IHS, AAA, FHWA, US Bureau of Transportation Statistics, US Census Bureau, and Bernstein estimates (2021+) and analysis

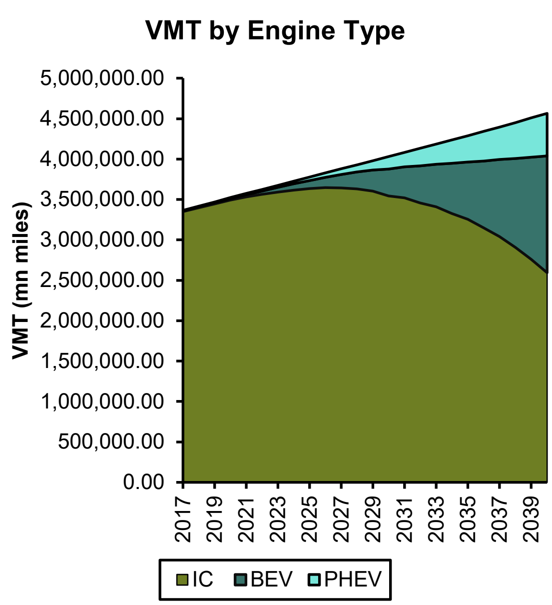
In Exhibit 331 and Exhibit 332, we show VMT by engine type; in the high case, VMT from ICE vehicles declined by -30% versus today; in the low case, it is -5%.

EXHIBIT 331: **In the low case, VMT by ICEs is not far below today's levels by 2040**



Source: IEA, and Bernstein estimates (2021+) and analysis

EXHIBIT 332: **In the high case, VMT from ICE vehicles fall by ~30%**



Source: IEA, and Bernstein estimates (2021+) and analysis

Finally, we review mileage for gasoline vehicles versus EVs. We find that on average, electric cars require only a quarter or so of the fuel to go 100 miles as a gasoline powered car; we convert the gallons needed to travel 100 miles to kWh using 34kWh/gallon of gasoline equivalent[68] (see Exhibit 333).

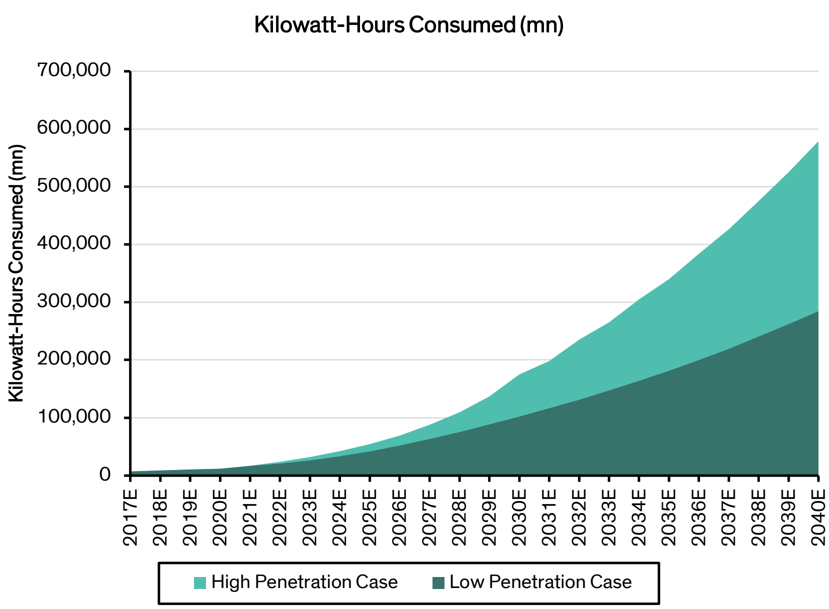
EXHIBIT 333: **When we convert gasoline fuel mileage into an equivalent kWh/100 miles, we find that EVs are 4x more fuel efficient than gasoline cars (34kWh to move 100 miles versus 149,000kWh to move 100 miles)**

Vehicle Class	Gal/100 mi	Total kWh/100 mi
Car		
Gasoline	4.43	149.2
Electric	-	34.1
Plug In Hybrid	3.87	182.9
Hybrid	2.06	69.4

Source: EPA, FuelEconomy.gov, Alternative Fuels Data Center, US Department of Energy, and Bernstein analysis

Combining the VMT breakdown and the mileage by fuel type yields the gallons of gasoline consumed along with the number of kilowatt-hours consumed. We forecast that EVs will require ~300-550 million kWh consumed, ~8-15% of today's generation (~4 trillion kWh) (see Exhibit 334).

EXHIBIT 334: **Kilowatt-hours ramp up as the fleet becomes electrified**

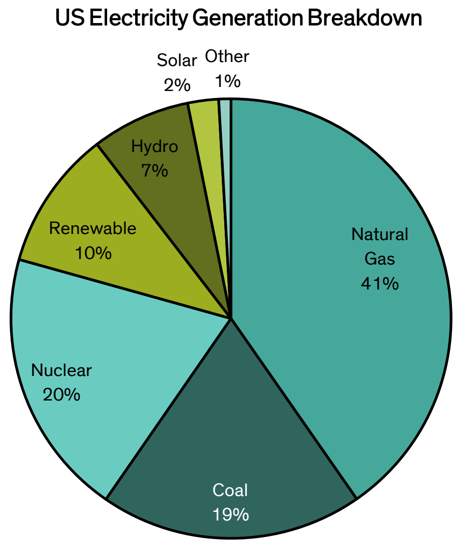


Source: IHS, AAA, Federal Highway Administration, US Bureau of Transportation Statistics, US Census Bureau, and Bernstein estimates and analysis

[68] US Department of Energy – Alternative Fuels Data Center Fuel Properties Comparison: https://www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf

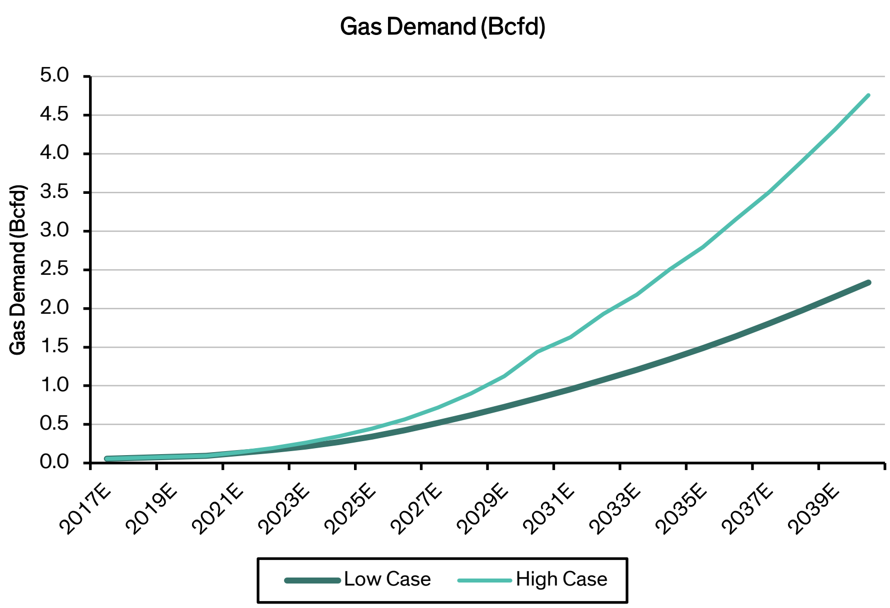
With natural gas driving almost 41% of electricity, we estimate this would ultimately require 2.5-5bcfd more natural gas (see Exhibit 335 to Exhibit 336).

EXHIBIT 335: **Natural gas drives ~40% of electric generation**



Source: EIA and Bernstein analysis

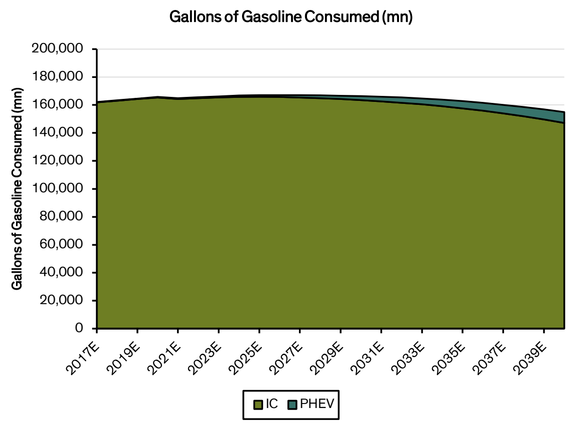
EXHIBIT 336: **Increase in gas demand from EVs would require ~2.5-5bcfd more gas (~4-6% of current total domestic consumption, or 3-5% inclusive of exports)**



Source: Bernstein estimates and analysis

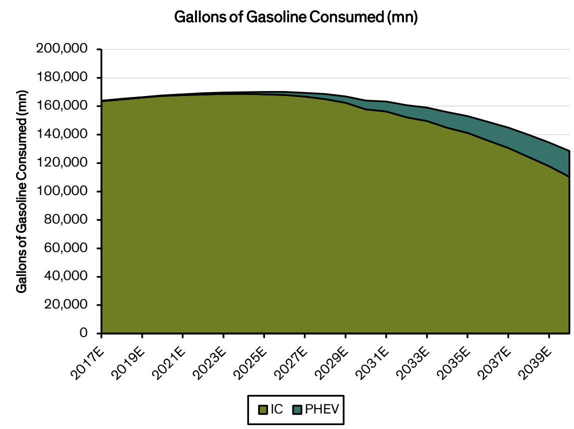
The effect on oil and gasoline demand is more pronounced, falling 10-20% by 2040 between the low and high cases (see Exhibit 337 to Exhibit 339).

EXHIBIT 337: **Millions of gallons/year of gasoline consumed falls in the low penetration case from 160 million gallons/year to 150 million/year by 2040...**



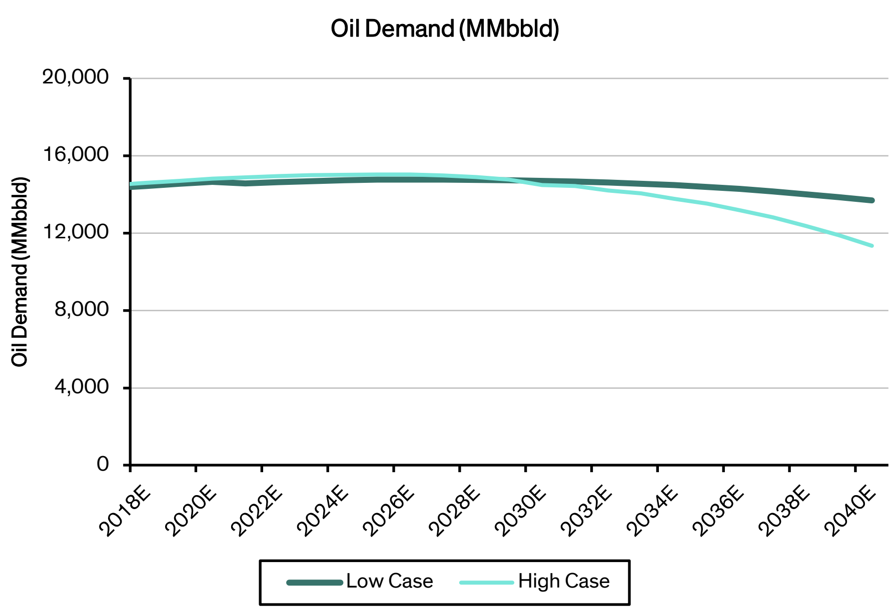
Source: Bernstein estimates and analysis

EXHIBIT 338: **...to 130 million gallons/year by 2040 in the high case**



Source: Bernstein estimates and analysis

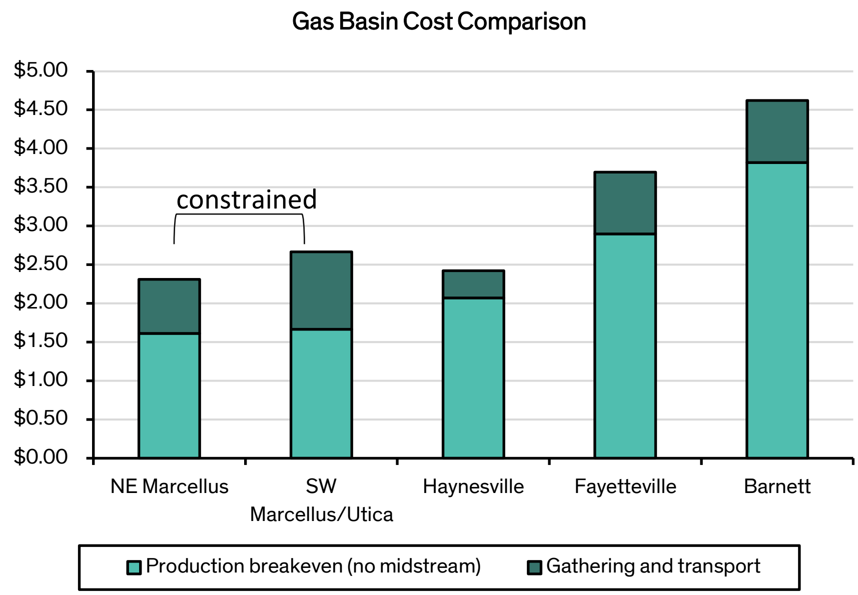
EXHIBIT 339: **Oil demand in the US would fall from 15mbd to 11.5mbd and 13.5mbd in the high and low case, respectively, if run pro rata across oil**



Source: Bernstein estimates and analysis

Oil is obviously a global market, so assumptions must be made about how this would impact US production, but there would almost certainly be a notable decline, given that US production is relatively high on the cost curve. This, in turn, would reduce associated gas production (free gas). If US gas demand is at least flattish with the new EV demand offsetting any losses in power due to renewables, it suggest higher natural gas prices and a return to the tier 2 basins on the margin, such as Barnett and Fayetteville (see Exhibit 340 and Exhibit 341).

EXHIBIT 340: **After associated gas, which is effectively free, Marcellus gas is constrained, suggesting that if gas demand stays flat but associated gas production falls, we will need to return to the tier 2 basins of Fayetteville and Barnett and gas price could rise**



Source: EIA and Bernstein analysis

EXHIBIT 341: **Total and Exxon are top producers in dry gas shales**

Barnett		Fayetteville	
Producer	Latest Gas Rate (mcfd)	Producer	Latest Gas Rate (mcfd)
Total	468,962	Flywheel Energy Production, Llc	628,628
BKV Barnett Llc	433,241	Merit Energy Co	157,260
ExxonMobil	314,475	ExxonMobil	136,140
Bedrock Energy Partners Llc	164,059		
Upp Operating Llc	161,126		
Blackbeard Operating Llc	147,884		
Fleur De Lis Energy	143,154		
Eagleridge Energy Llc	119,285		
EOG Resources	114,469		
Sage Natural Resources	70,959		
Other	139,788	Other	1,090
Total	**2,277,403**	**Total**	**923,117**

Note: EOG Resources is covered by the Bernstein.

Source: HPDI and Bernstein analysis

Finally, we have noted this a number of times,[69] but we do not think that gas midstream gets the relative credit it deserves compared to oil midstream, given how much more long lasting gas flows should be in the US.

INVESTMENT IMPLICATIONS

We continue to prefer gas and NGL midstream, and rate LNG, ET, EPD, and WMB Outperform.

[69] https://www.bernsteinresearch.com/brweb/ViewResearchStreamer.aspx?cid=3irFp0rAUQnhEV02mYvOrCMtdBx0q%2bKYSaPe49aTCbDnMJXCTRnm0MocevIHShi1

GREEN IS GOOD; SMART GREEN EVEN BETTER (PART 1): OPPORTUNITIES FOR UTILITIES & RENEWABLES

OVERVIEW

- **Electrification is key to decarbonize transport, industry, and buildings.** To decarbonize electricity (and produce green hydrogen), global renewables capacity should grow from 1TW today to more than 30TW by 2050. **The decarbonization of China's electricity supply is critical to determine how clean the electric revolution will be.** China is the largest end-user market for electric vehicles (EVs), accounting for 41% of global EV sales in 2020. The country is also a key hub for battery manufacturing, whose EV battery installation represented 44% of the globe last year. China's policy push for decarbonization is accelerating, as evidenced by the 14^{th} five-year plan. We expect the combined share of solar and wind in China's electricity supply to rise to 25% by 2030 versus 10% in 2020.

- **Flexibility in power to complement wind and solar generation will grow in importance,** and demand-side flexibility will play an important role. Uncontrolled EV charging could result in significant challenges for peak demand, whereas bi-directional flows from EVs to the grid (V2G) would be a source of valuable flexibility. The European Network of Transmission System Operators for Electricity (ENTSO-E) will push for this flexibility: "It is paramount to immediately begin the deployment of smart charging and, whenever viable, of V2G solutions."

- **Grid investments will increase** to replace assets, to integrate renewables, EVs, and heat-pumps, as well as to digitize the grid. The impact of EVs on grid investments will depend heavily on the degree to which flexible demand (via smart V1G or V2G charging) is utilized and the state of the existing grid. There is generally a lower constraint on the additional electricity demand from EVs. "The impact on peak demand (kW) is more critical, which happens in case of simultaneous power demand," according to the association of European Distribution System Operators (EDSO).

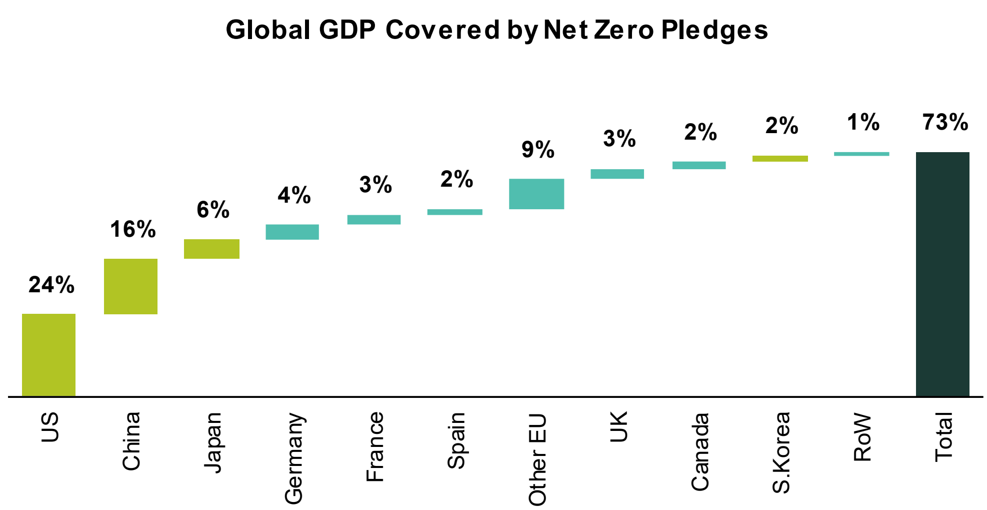
- **Charging — how utilities make money.** Utilities view EV charging as an opportunity complementary to their existing business models and are deploying charging infrastructure, with notable examples being Engie's EVBox, Enel's dominance in Italy, and E.ON's pan-European presence. EVBox and ChargePoint's business models show a way to growth and profitability.

EXECUTIVE SUMMARY

In this chapter, we look at the implications of electrification broadly and EVs specifically on the power sector. In the following chapter, we look at the infrastructure backbone required to support the electric revolution in more detail.

The Paris climate agreement calls for limiting global warming to well below 2°C above pre-industrial levels and the IPCC has catalyzed the new consensus that even a 2°C increase is likely too high and that warming should be limited to below 1.5°C to avoid a tipping point and the more extreme consequences of climate change. This will require reaching zero net emissions of CO_2 globally by mid-century. US President Joe Biden pledged climate change mitigation in his election campaign and China, Japan, and South Korea made new net-zero pledges. This means net-zero pledges now cover 73% of global GDP and encompass eight of the top 10 largest economies by GDP (India and Brazil being the exceptions; see Exhibit 342).

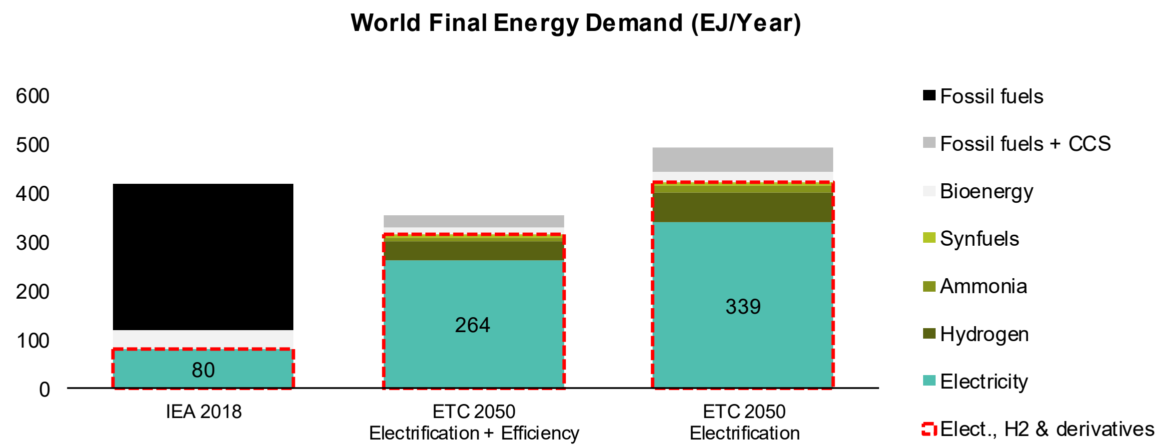
EXHIBIT 342: **73% of global GDP is covered by net-zero pledges**



Source: World Bank, Energy and Climate Intelligence Unit (ECIU), and Bernstein analysis

Limiting global warming to 1.5˚C and achieving net-zero carbon emissions by mid-century will require extensive electrification of the economy, energy efficiency gains, and hydrogen complemented by bio energy and carbon capture and storage (CCS). Electricity will directly meet between 68% and 74% of final energy demand in an analysis commissioned by the Energy Transition Commission — a green power sweep — and will likely play an important role in generating green hydrogen and derivative fuels which will account for a further 15-17% of final energy demand (see Exhibit 343).

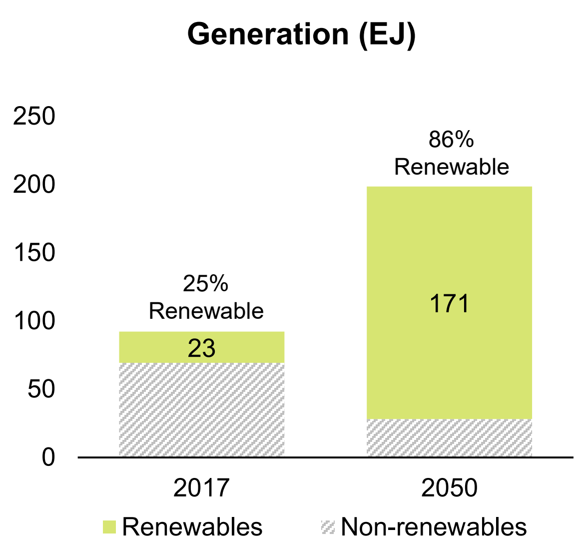
EXHIBIT 343: **Electricity and hydrogen (and derivative fuels) could account for 86-89% of world final energy demand**



Source: IEA estimates (2050) , SYSTEMIQ analysis for the Energy Transition Commission, and Bernstein analysis

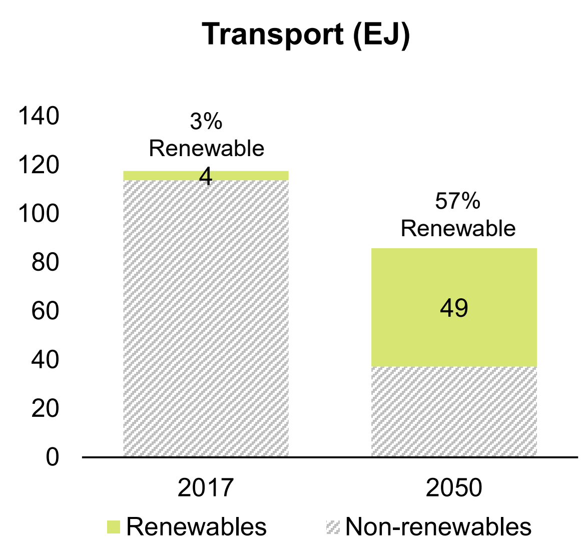
Electrification is key to decarbonize transport, industry, and buildings (see Exhibit 345 to Exhibit 347) and, therefore, power needs to become green as fast as possible (see Exhibit 344).

EXHIBIT 344: **Power sector must be green to enable decarbonization of other sectors**



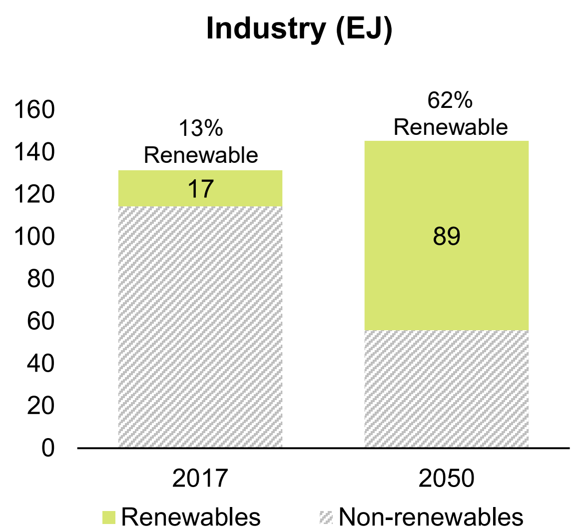
Source: IRENA 2020 ReMap data (2017) and estimates (2050) and Bernstein analysis

EXHIBIT 345: **BEVs mean 57% of transport power consumption could be powered by renewable electricity**



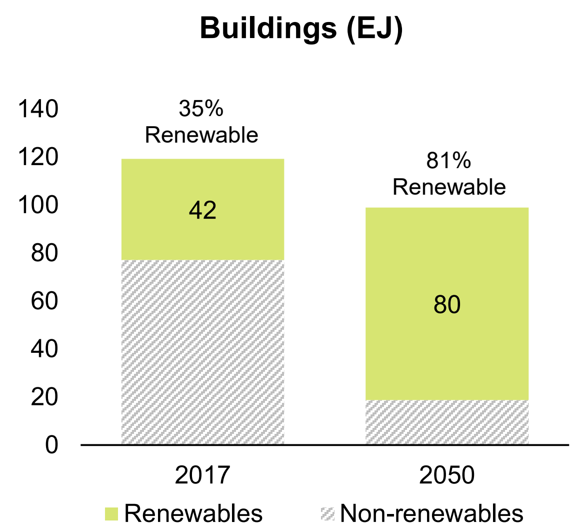
Source: IRENA 2020 ReMap data (2017) and estimates (2050) and Bernstein analysis

EXHIBIT 346: **Global industry could be 62% renewable**



Source: IRENA 2020 ReMap data (2017) and estimates (2050) and Bernstein analysis

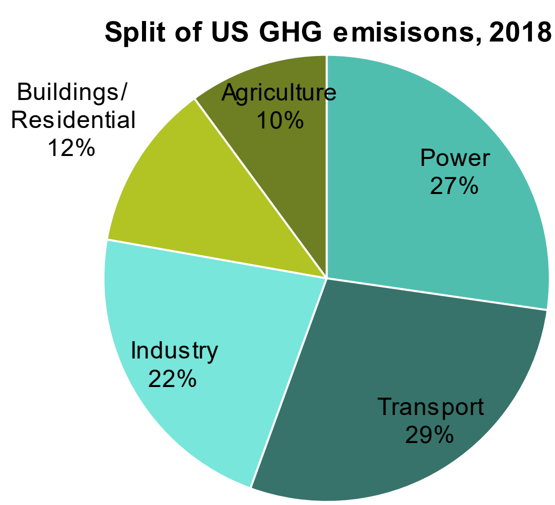
EXHIBIT 347: **Buildings could be 81% powered by renewable energy**



Source: IRENA 2020 ReMap data (2017) and estimates (2050) and Bernstein analysis

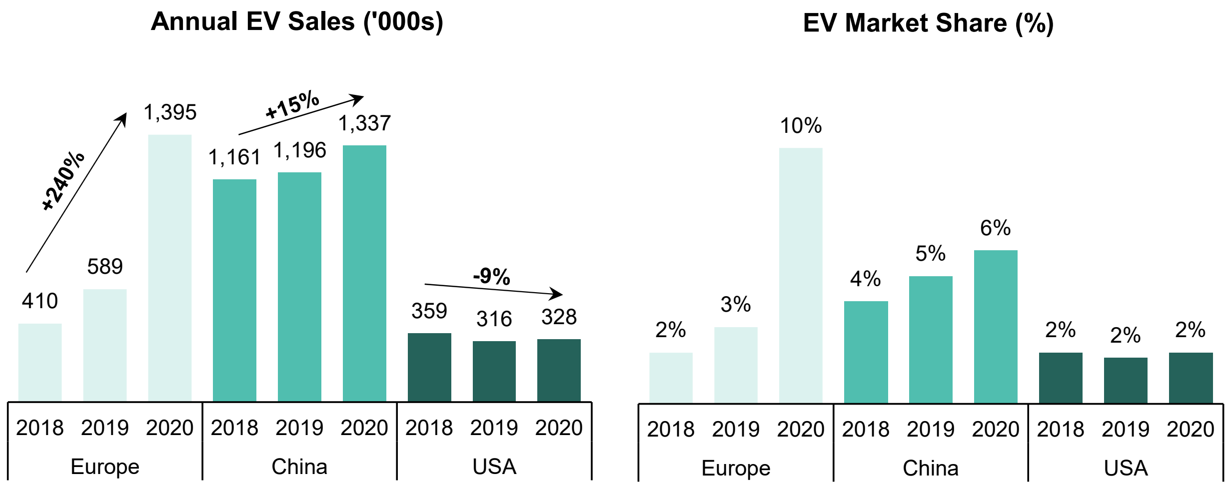
Transportation is an important focus area for decarbonization, accounting for ~29% of US CO2 emissions today (see Exhibit 348) and EVs are the most promising means to achieve decarbonization of large swathes of the transport sector. Momentum is increasing and over 2018-20 EV sales are up 240% in Europe and up 15% in China (see Exhibit 349). EV sales fell -9% over the same period in the US, but strong acceleration is likely under the Biden administration. European EV car sales stepped-up significantly in 2020, driven by entry into force of new passenger car CO2 targets under which automakers must reduce their overall fleet emissions to 95 gCO2/km in 2020-21 (for 95% of their car sales in 2020).

EXHIBIT 348: **CO2 emissions by sector**



Source: IEA and Bernstein analysis

EXHIBIT 349: **In 2020, the share of EV car sales stepped up in Europe, continued to grow in China, but remained at ~2% in the US**

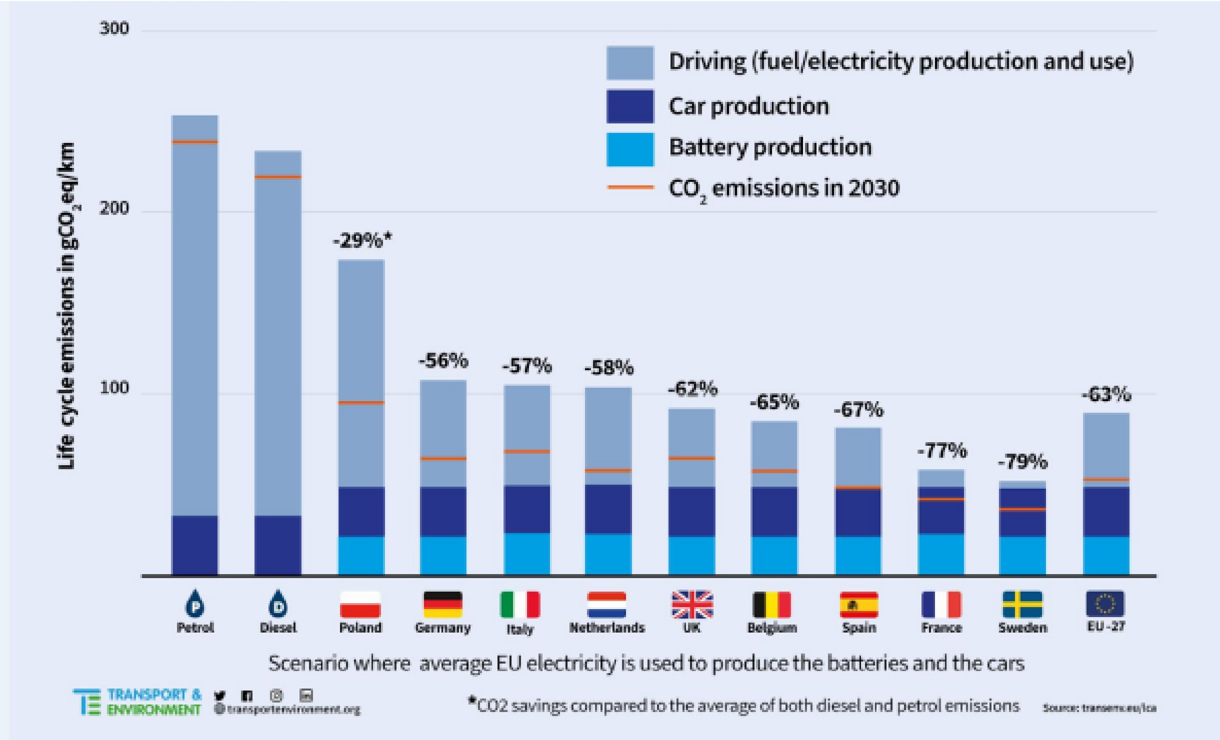


Source: EV-Volumes.com, Bureau of Economic Analysis, EV Box Group, and Bernstein analysis

Considering the entire lifecycle, including manufacturing and fuel extraction, an analysis[70] by Transport & Environment concluded that electric cars in Europe outperform conventional cars even when they run on carbon-intensive grids such as in Poland, where they are about 30% better than conventional cars. In the best case scenario (an EV running on clean electricity with a battery produced with clean electricity, e.g., in Sweden), EVs are already about five times cleaner than conventional equivalents. Over time, the carbon intensity of EVs will reduce as the grid decarbonizes from the phase-out of fossil fuels and addition of renewables — the EU's Green Deal modeling envisages a net-zero power sector by 2040 while the UK's net-zero strategy envisages a net-zero power sector by 2035. In addition to decarbonization, switching from an ICE vehicle to an EV **eliminates all toxic tailpipe pollution such as nitrogen oxides (NOx) and carbon monoxide (CO) and improves air quality (see Exhibit 350).**

[70] https://www.transportenvironment.org/sites/te/files/downloads/T%26E%E2%80%99s%20EV%20life%20cycle%20analysis%20LCA.pdf

EXHIBIT 350: **BEVs have a significantly lower emission footprint even considering life cycle emissions**



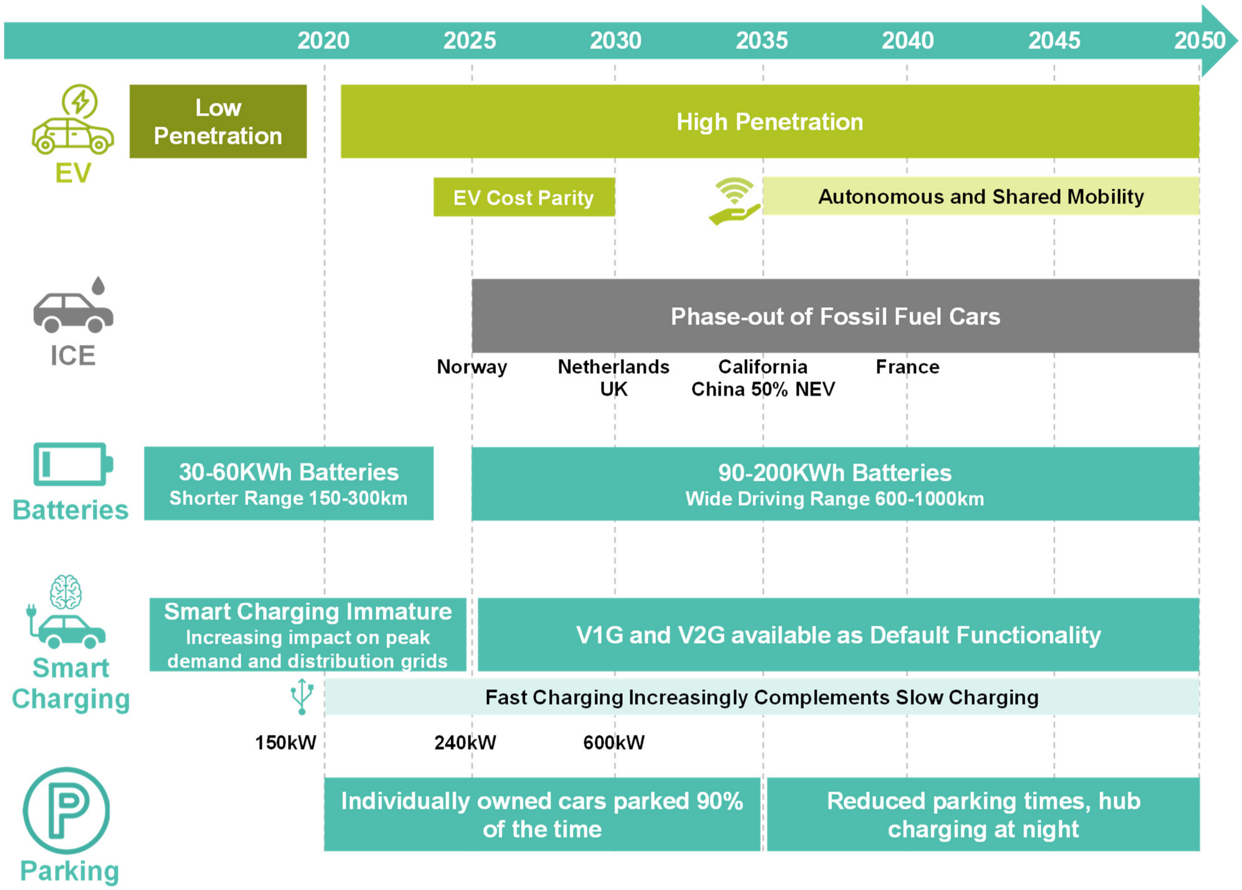
Source: Transport & Environment

We illustrate one possible industry evolution of EVs and related industries in Exhibit 351. Over the current decade, EVs achieve cost parity and reach high penetrations of PVs. Concurrently, countries begin phasing out sales of fossil fuel cars, with Norway being the earliest in 2025.

The emergence of larger batteries in the 90-200kWh range not only improves driving ranges up to 1,000km, but also significantly enhances grid flexibility if paired with smart charging. Under a V1G model, EV charging is controlled via incentives (or even direct control by DSOs) to avoid times of peak demand and to shift charging to periods of grid underutilization. Under V2G, EVs also act as a form of power storage for the grid and inject electricity during periods of high consumption needs and low generation.

By 2035, more forecasters such as IRENA expect autonomous mobility to begin taking off. Fewer cars will be privately owned (and parked 90% of the time) and more cars could be part of a high-utilization autonomous ride-hailing service using fast chargers to improve fleet utilization, increasing peak demand and grid reinforcement needs.

EXHIBIT 351: **Possible industry evolution of EVs, batteries, and charging behavior**



Note: Image credits: Flaticon (hosted on FlatIcon, images created by Photo3idea_studio, FreePik, SmashIcons)

Source: IRENA and Bernstein analysis

ACCELERATION IN EV POLICY AND COMPANY TARGETS

In the context of reducing emissions of the transportation sector, many countries have announced an outright ban on the sale of ICE cars at a certain point or set a timeline to achieve a fleet without ICEs (see Exhibit 352).

Governments have accelerated policy commitments toward zero carbon emission vehicles (see Exhibit 353), and set public charger targets (see Exhibit 354) and provided incentives (see Exhibit 355). Some of the latest proposals are:

- The EU has been urged by nine member states (led by Denmark and the Netherlands) to set a firm date for a total phaseout of new petrol and diesel PVs. According to Danish climate minister Dan Jorgensen, *"we have to accelerate the green transition of road transport and as legislators send clear signals to car manufacturers and consumers across the EU."* Furthermore, fuel economy regulations in the EU mandate a 37.5% fall in CO2 emissions by 2030. BNEF believes this indicates that at least 40% of PV sales would have to be either BEVs or PHEVs. Brussels is currently debating the possibility of increasing the CO2 reduction target to 60% by 2030 and setting a zero-emission target for vehicles by 2035.

- **China's** New Energy Vehicles (NEV) mandate has passed into legislation. It will encourage OEMs to increase zero-emission vehicles (ZEVs) to certain shares of revenues each year. This is 14% in 2021, 16% in 2022, and 18% in 2023. The country also has aspirational goals of 40% NEVs share by 2025 and 50% by 2035 (of which 95% are BEVs). China is also an EV30@30 signatory with aspirational goals of 30% sales share of EVs by 2030.

- **US**: Safer Affordable Fuel Efficient (SAFE) vehicles rule for 2021-26 mandates a 1.5% increase in the stringency of CO2 and CAFE emissions standards. Some states have set their own ZEV targets, with California issuing an executive order in 2020 requiring all PVs (cars and passenger trucks) sold in the state to be ZEVs by 2035. President Biden is pushing for a majority of vehicles manufactured in the US to be electric by 2030, as well as for all vehicles to be electric by 2040.

EXHIBIT 352: **Announced 100% zero emission vehicle (ZEV) sales targets and bans on ICE vehicles**

	2025	2030	2035	2040	2045	2050
Canada				●		○
Chile						○
China			●			
Costa Rica						●
Denmark		●				
France				●		
Germany						●
Iceland		●				
Israel		●		○		
Ireland		●				
Japan			●			
Netherlands		●			○	
New Zealand						○
Norway	●					○
Portugal				●		
Singapore		●				
Slovenia		●				
Spain				●		○
Sri Lanka				○		
Sweden		●			○	
United Kingdom		●				○
European Union						○

● ICE sales ban or 100% ZEV sales target
○ Fleet without ICEs

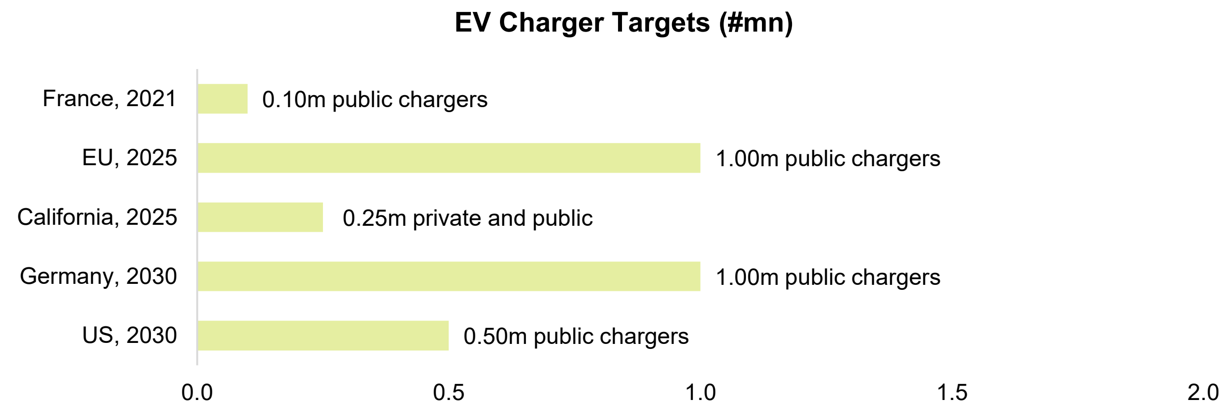
Source: IEA Global EV Outlook 2021 and Bernstein analysis

EXHIBIT 353: **Overview of selected recent country ZEV policies**

Country	Announced	Policy Measure
Europe		
European Union	**2021**	**Proposal** by 9 countries (Austria, Belgium, Denmark, Greece, Ireland, Lithuania, Luxembourg, Malta and the Netherlands) for EU-wide phaseout of sale of new petrol and diesel passenger vehicles.
	2020	**Ambition** of at least 30m ZEVs by 2030 and virtually all passenger and heavy commercial vehicles by 2050.
	2019	**Legislation:** A revision to the Clean Vehicles Directive was made specifying minimum public procurement levels for urban buses (33-65% by 2030) and trucks (7-15% by 2030). Starting from base CO2 emissions for new cars of 95g CO2/km in 2020, the standard will tighten by 37.5% over 2021-30.
France	**2020**	**Target:** Passenger vehicle stock targets of 500k PHEV, 660k BEVs and FCEVs and 170k BEVs and FCEVs by 2023. For 2028, there will be stock of 1.8m passenger PHEVs, 3m passenger BEVs and FCEVs. There will also be 500k light commercial BEVs and FCEVs.
Italy	**2019**	**Target:** By 2030, there will be 6m passenger LDVs stock (of which 4m BEVs). Electric cars will account for 6% of gross final energy consumption.
Spain	**2020 (all)**	**Target** of 5m electric passenger vehicles, buses and 2/3-wheel vehicles by 2030. **Ambition** of 5k-7k FCEVs stock by 2030. **Proposal** has been made to ban sales of CO2 tailpipe emitting passenger vehicles by 2040.
UK	**2020**	**Legislation:** Ban on the sale of ICE cars by 2030.
N. America		
USA	**2020**	**Legislation:** Safer Affordable Fuel Efficient (SAFE) vehicles rule for 2021-26 mandates a 1.5% increase in the stringency of CO2 and CAFÉ emissions standards.
	2016	**State of California:** Targets 1.5m ZEV stock by 2025, increasing to 5m by 2030.
	2020	**State of California:** Executive order requiring all passenger vehicles (cars and passenger trucks) sold in the state will have to be ZEVs by 2035.
Asia		
China	**2021**	**Legislation**: Fuel economy standard tightened to 4.6L/100km (WLTP) for passenger vehicles.
	2020	**Legislation:** New energy vehicles (NEVs) mandate encouraging OEMs to increase zero-emission vehicles (ZEVs) to certain shares of revenues each year. This is 14% in 2021, 16% in 2022 and 18% in 2023. **Target:** China targets NEVs to reach 20% share by 2025. **Aspirational goals** include 40% NEVs by 2025 and 50% by 2035 (of which 95% are BEVs).
India	**2017**	**Aspirational goal:** EVs to reach 30% share of passenger vehicles by 2030.
Japan	**2019**	**Legislation:** Fuel economy of passenger vehicles to improve 32.4% from 2016 in terms of well to wheel efficiency, which includes EVs and related grid electricity consumption.
	2018	**Target:** By 2030, battery-electric vehicles (BEVs) and petrol-hybrid electric vehicles (PHEVs) to reach 20-30%, hybrid electric vehicles (HEVs) 30-40% share, FCEVs 3% share of passenger vehicle sales.

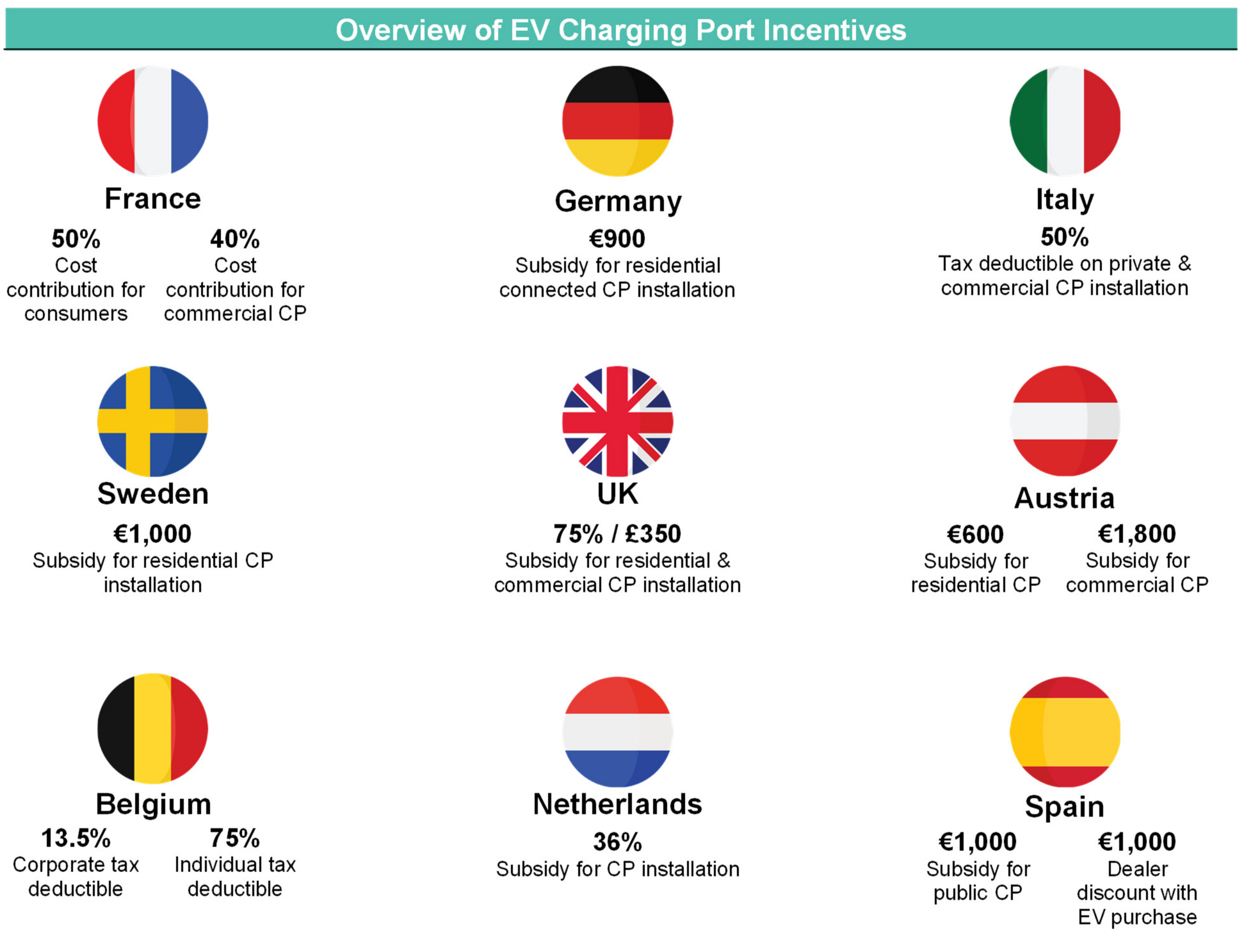
Source: IEA, country and state plans, and Bernstein analysis

EXHIBIT 354: **Country public charger targets**



Source: BNEF, country targets, and Bernstein analysis

EXHIBIT 355: **EV charging port incentives in Europe**



Note: Image credits — FlatIcon and RoundIcons

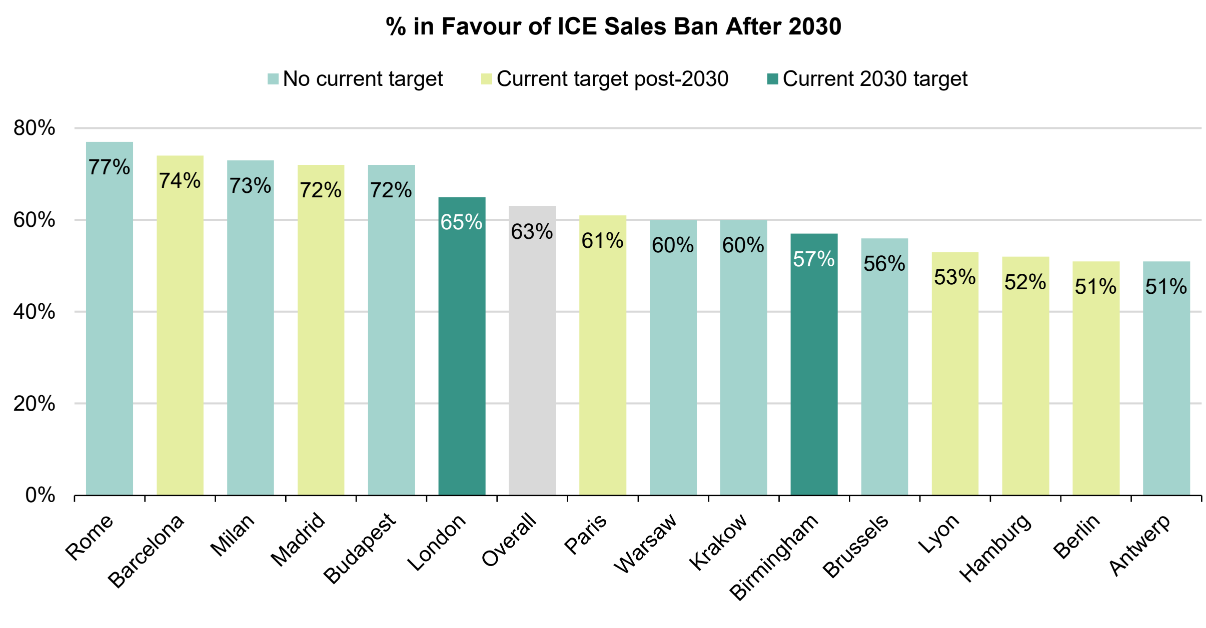
Source: Country plans and Bernstein analysis

Automakers are taking note of this inflexion point in regulatory and societal momentum, with several accelerating goals in 2021. In 1Q, Jaguar, Volvo, and GM announced a global phaseout of ICE vehicle sales by 2025, 2030, and 2035, respectively, while Ford announced an end to ICE sales in Europe by 2030 (with a 40% EV global target). This was followed by Fiat, which announced in June that it would only sell electric cars by 2030. Volkswagen has also announced a ban on the sale of ICE vehicles in Europe from 2035. EV Scope III emissions (via the supply chain and usage of the product by consumers) will fall 50% by 2035 versus 2019.

Many automakers have also announced net-zero targets which range over 2030-50. Rolls-Royce aims to make its own operations carbon neutral by 2030, with an additional goal of ensuring all its products and technologies will generate no carbon emissions by 2050. Ford recently provided greater clarity on its net-zero target and its pathway to 2050. By 2035, the firm targets a reduction in Scope I and II emissions (direct emissions from operations and indirect emissions from power consumed) by 76% by 2035 off a 2017 base year.

The policy drive toward EV adoption is supported by consumers as well. A recent survey (April 2021) indicates that a majority of citizens in 15 major European cities support a ban on ICE car sales after 2030 (see Exhibit 356). 63% of consumers in major European cities favor an ICE ban after 2030. Among the respondents who supported an ICE ban, 66% of those directly or indirectly infected by Covid-19 were in favor versus 56% of those who were never infected with Covid-19.

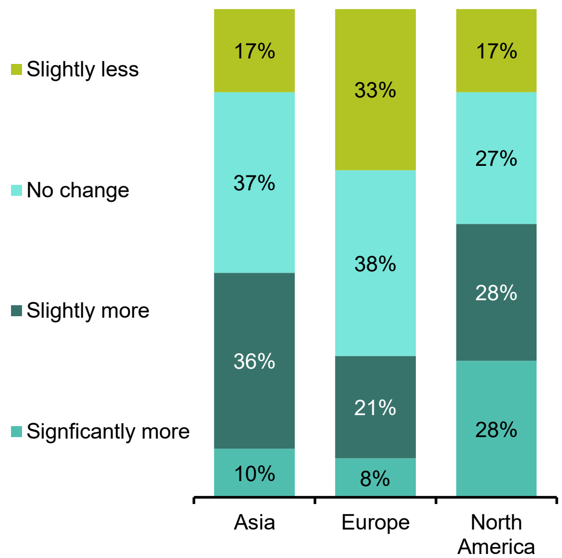
EXHIBIT 356: **63% of consumers in major European cities favor an ICE ban after 2030**



Source: Transport & Environment (data), city and national targets, and Bernstein analysis

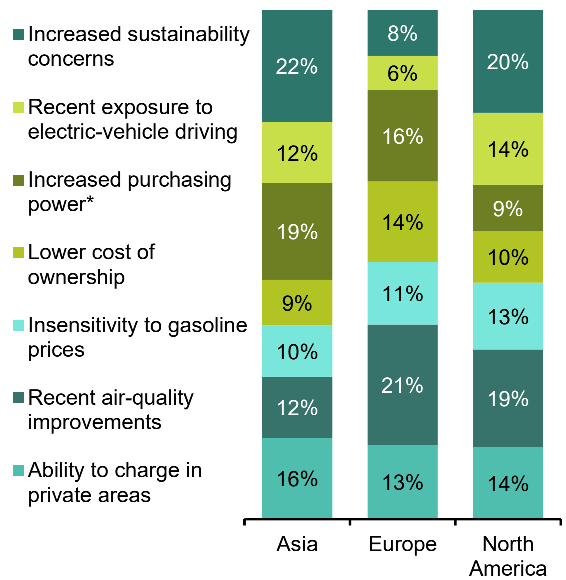
This result is mirrored by another survey by McKinsey that showed that air quality considerations were the biggest factor pushing people in Europe toward EVs and the second biggest factor in North America (see Exhibit 358). The survey has shown that over the course of the Covid-19 pandemic, public support for EVs has increased slightly (see Exhibit 357). The reasons given for this have also varied across regions — aside from the aforementioned air-quality considerations, in Asia and North America, increased sustainability concerns have driven the increase more than anything else, while increased purchasing power (including the impact of government incentives) have also driven increased support in Asia and Europe.

EXHIBIT 357: **Did Covid-19 change your interest in buying an electric/hybrid vehicle?**



Source: McKinsey and Bernstein analysis

EXHIBIT 358: **What are the top three reasons why you now consider electric/hybrid vehicles more?**



*Through government incentives

Source: McKinsey and Bernstein analysis

OPPORTUNITIES AND RISKS ACROSS THE UTILITY VALUE CHAIN

Electrification has been called "the greatest engineering achievement of the 20th Century" by the US National Academy of Engineering and will be a key enabler for the energy transition in the 21st century. This presents tremendous opportunities and risks for utilities across the value chain, which we highlight in Exhibit 359. Obvious beneficiaries of the electrification theme include:

- **Wind and solar** companies, which will build the foundations of future clean power mixes, accounting for 70-80% of capacity on average.

- **Flexibility** services, which will gain increasing importance as intermittent wind and solar increase their penetration of the generation mix. Dispatchable renewables such as storage or hydro will earn margins for production during periods of high demand but low wind/solar generation. Demand flexibility including EVs can play an essential role for grid operators both in terms of integrating renewables and future demand profiles, as well as minimizing or deferring capital investment.

- **Electricity networks.** The move to electrification will provide a boost to electricity network investments to connect new renewables, upgrade to allow bi-directional flows, to accommodate increased electricity demand, e.g., from EVs, and to digitalize.

- **Services companies'** upside includes the deployment of EV charging solutions.

In the following sections we deep dive into wind and solar, flexibility services, and EV charging as a business model for utilities. We outline high-level implications for electricity networks here and deep dive into this in the following chapter.

EXHIBIT 359: **Opportunities and risks of electrification across the value chain**

	Generation			Networks		Retail	
Climate change trends	**Wind/Solar**	**Short-term balancing** Hydro/ batteries/ flexible demand	**Gas/Nuke/ Coal**	**Electricity**	**Gas**	**Services**	**Supply**
Renewables	✓✓	✓	✗✗	✓			
Electrification	Demand, policy and cost to determine EV share ✓	✓		✓	✗✗	✓	
Efficiency/ demand shift						✓	
Green gas / hydrogen	✓				✓		
Carbon capture							
Trends	✓✓✓✓	✓	✗✗	✓✓	✗	✓	
Description	+ Growth & cost exceed expectation + Adequate margins + 70-80% of mix by 2050, plus green hydrogen	+ Flexibility & storage valuable long-term + In Europe price-taker	+ Coal "closed" + Nuclear a political debate/expensive + Gas for transition + Hydrogen/nuke/ gas+CCS for last 10-20% back up. Remuneration?	+ Investments needed in electricity to integrate renewables, replace aging assets and to digitize	+ Natural Gas falls 80% by 2050 partially replaced by hydrogen/ green gas + Tx transitions to hydrogen, Dx partially stranded	+ Energy efficiency services grow	+ Growth in de-mand + Margin pressure might offset growth

Source: Bernstein analysis

RENEWABLES WILL BE A CLEAR WINNER

BNEF's clean electricity and hydrogen pathway (CEHP) explores a potential *"trajectory toward a well-below-2-degrees-Celsius electricity-based energy system"* with electrification of end-use sectors and hydrogen decarbonizing the last mile. Under this scenario, global electricity demand could increase by ~2.5x to ~66 Peta-watt hours (PWh) by 2050 (see Exhibit 360). This energy demand is broken down by:

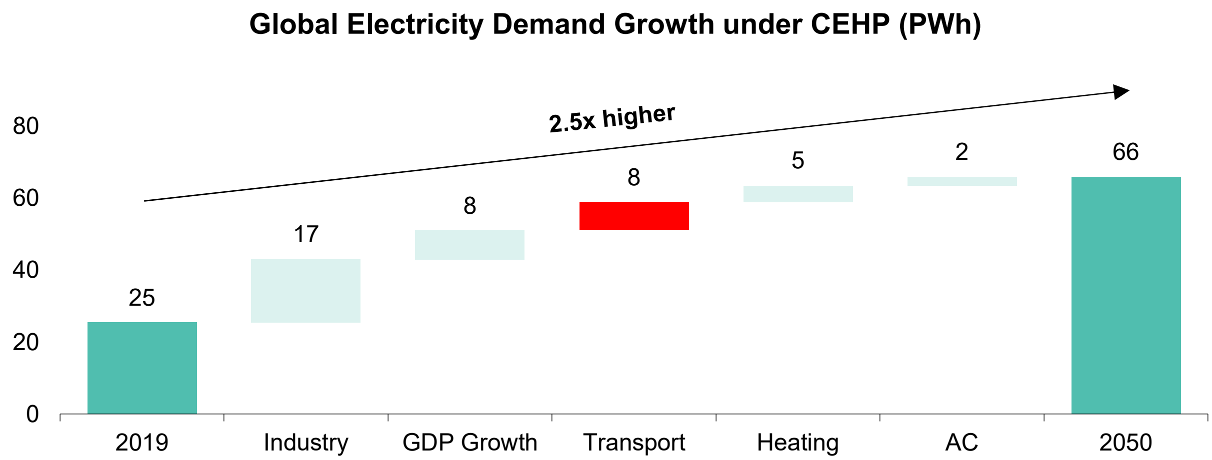
Industry, which accounts for an additional 17PWh of electricity consumption.

- Steel: Secondary steel production from recycled scrap utilizes electricity and could increase from a 27% share today to 50% by 2050. Remaining primary steel production is split 5% via molten oxide electrolysis (requiring electricity) and 95% via direct reduction with hydrogen.
- Aluminum is already primarily electric via electrolysis of aluminum oxide.
- Cement is challenging to convert to electricity because of the lack of high-temperature electric processes. BNEF CEHP assumes 30% electrified, 30% hydrogen, and the remaining unallocated.
- Petrochemicals could see 30% of capacity electrified by 2050, given independent studies have shown electricity could be cost-effective if power costs are below US$25/MWh. The remaining 70% of capacity could be converted to hydrogen.
- Pulp and paper is easily electrified, given it utilizes a low-temperature heating process. 75% could be electrified and 25% via hydrogen.

Transport, which could account for an 8PWh increase in electricity demand if 80% of vehicles are electrified by 2050. The only exceptions would be commercial/long-haul vehicles where electrification does not reach beyond 50%. This is because trips at shorter distances <400km could potentially be electrified, but longer trips will likely require a fuel-based solution such as hydrogen.

Buildings, which would contribute 7PWh in electricity demand growth by 2050. Heating will require 5PWh additional power as electric heat pumps dominate in countries with milder climates, particularly those that do not already have established gas networks. Air conditioning demand doubles to ~4.7PWh, resulting in power demand growth of ~2.4PWh.

EXHIBIT 360: **Global electricity demand could increase by a factor of 2.5x by 2050**

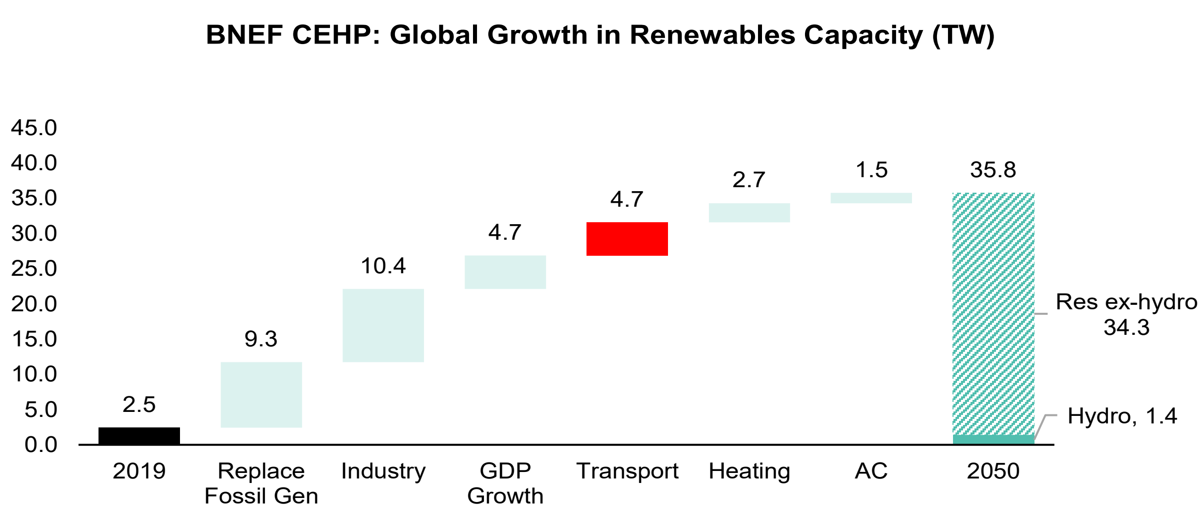


Source: BNEF CEHP Scenario estimates (2050) and data (2019), and Bernstein analysis

To be green, both electricity and hydrogen are expected to be generated from renewable resources to a large degree. Considering the recent momentum in green hydrogen and policy commitments such as net-zero pledges from the US and China or early reduction targets in Europe, more than 30TW of renewables capacity by 2050 is now possible in our view, of which 5TW can be allocated to transport decarbonization.

We breakdown the additional capacity in BNEF's CEHP scenario in Exhibit 361. Overall, we estimate that ~24TW of additional renewables capacity will be necessary to meet demand growth and that ~9TW will be necessary to decarbonize the power industry and replace existing fossil generation. This implies a >14x increase (versus 2019 base) in renewables capacity to ~36TW by 2050, of which ~34TW will be renewables (ex-hydro) and ~1.4TW will be hydro.

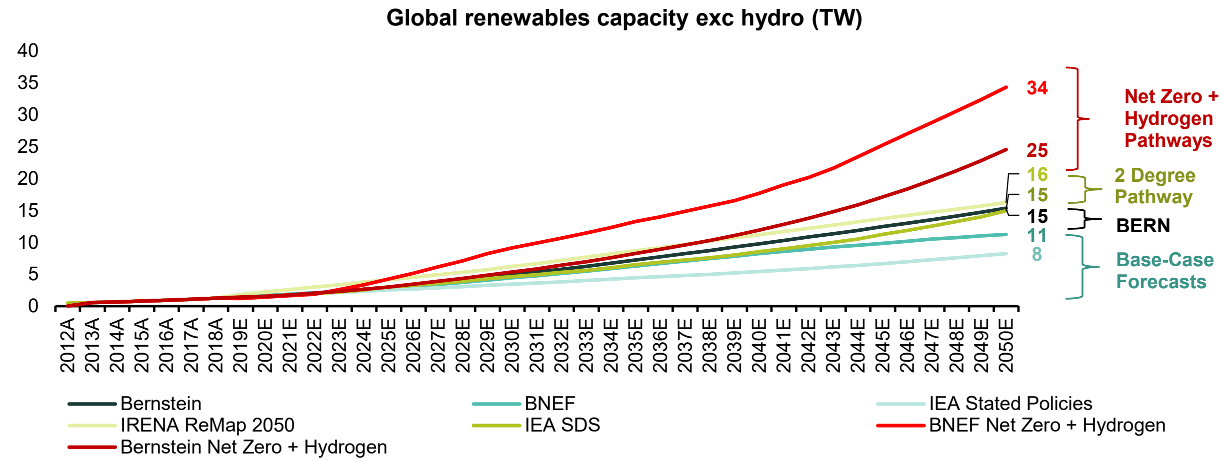
EXHIBIT 361: **>14x increase in total renewables capacity**



Source: BNEF CEHP Scenario estimates (2050) and data (2019), and Bernstein analysis

Estimates for renewables capacity by 2050 range from 8TW to 34TW, depending on climate change mitigation ambition levels and pathways (see Exhibit 362).

EXHIBIT 362: **Hydrogen will likely significantly boost renewables rollout**



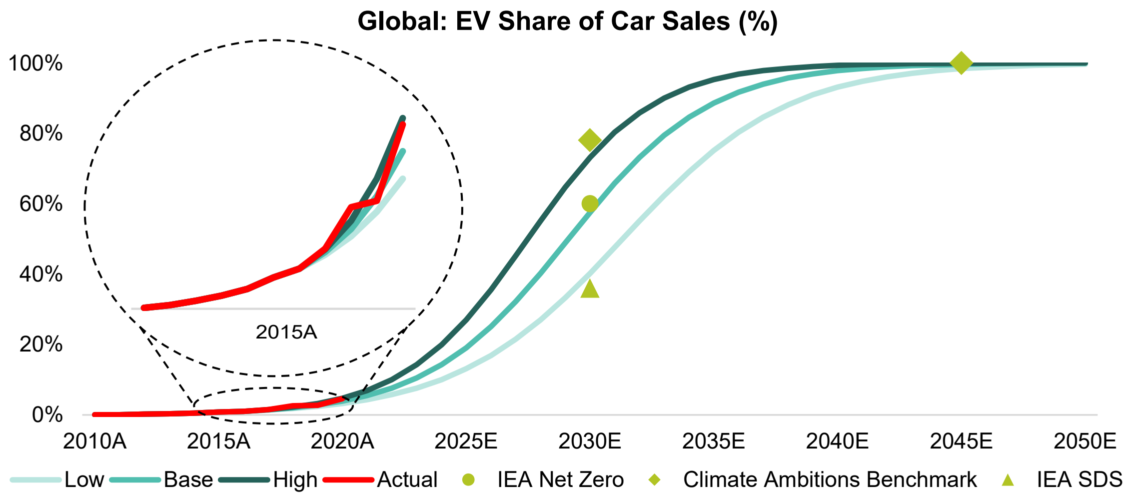
Source: IEA estimates, IRNEA estimates, BNEF data and estimates, and Bernstein estimates and analysis

EV electricity demand will likely rise at an exponential rate and could account for 24% of total demand by 2050. EVs are rapidly reaching cost parity and oftentimes running costs could even be on par or lower than ICE vehicles because of lower lifetime fuel costs offsetting higher initial purchase cost.

In Exhibit 363, we show an extrapolation of EV share of global car sales utilizing similar methodology to studies conducted by University College London on behalf of the We Mean Business Coalition. We show sensitivities for emergence rates of 30% (low case), 35% (base case), and 40% (high case). This is compared to historical EV market share growth at ~41% CAGR since 2015.

Our global net-zero base case suggests ~58% share of EVs of global car sales versus the IEA Net Zero scenario's projections of 60%. By 2045E, all car sales are electric, in line with the Climate Ambitions Benchmark. Reaching IEA SDS targets of limiting *"temperature rise to below 1.8 °C with a 66% probability without reliance on global net-negative CO2 emissions"* can be met with an emergence rate of 30%.

EXHIBIT 363: **Global EV sales could reach 60% of total car sales by 2030E**

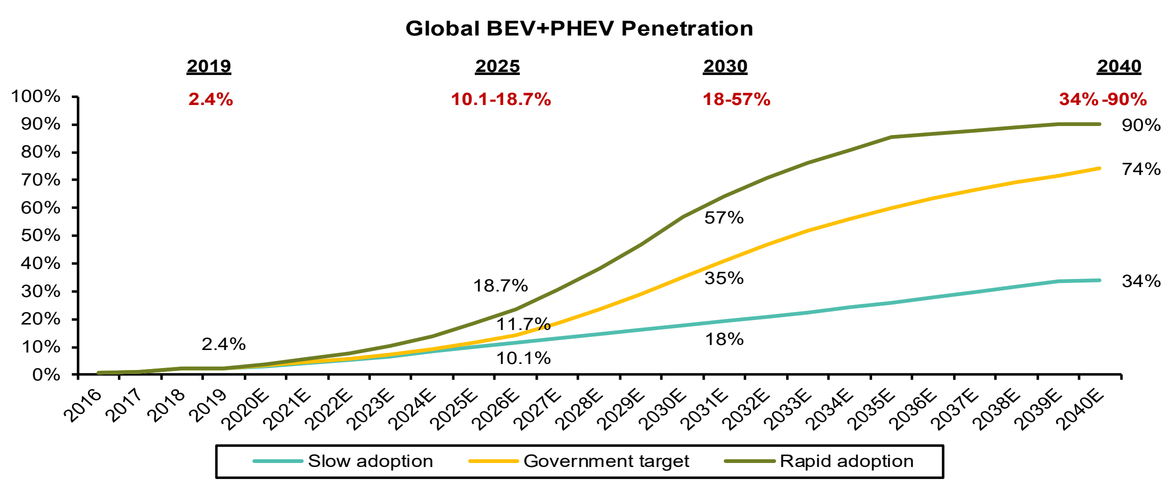


Methodology credits: University College London, We Mean Business Coalition. Electric car share of sales. Historical values over 2005-20. Total sales of electric cars for 2005-19 from IEA Global EV Outlook (IEA, 2020c), Statistical Annex, Electric Car New Registrations (BEV and PHEV) by country. Total sales of passenger cars for 2005-19 from OICA (OICA, 2020a), Sales Statistics, New Passenger Car Registrations. 2020 electric car sales and total car sales calculated based on Irle (2021) and IEA (2020b). Share calculated from these data. S-curve projections start from 2015 values. Saturation point of S-curves set at 100%.

Source: IEA Data, University College London Methodology, and Bernstein estimates and analysis

Exhibit 363 highlights modeling to reach net-zero targets from various forecasters. Exhibit 364 shows pathways from an industry standpoint from Bernstein's Global EV and Energy Storage team. Reaching the IEA Net Zero scenario target would be consistent with the **"rapid EV adoption"** case. Bernstein's analyst Toni Sacconaghi, who covers Tesla, additionally writes: "Realistically, we think the trajectory of EV uptake will likely fall between Global EV team's rapid adoption case and government target base case (~35% in 2030, ~75% in 2040 — see Exhibit 364). As such, we forecast EVs to account for 15% of total auto sales in 2025, 40% in 2030, and 75%+ by 2040."

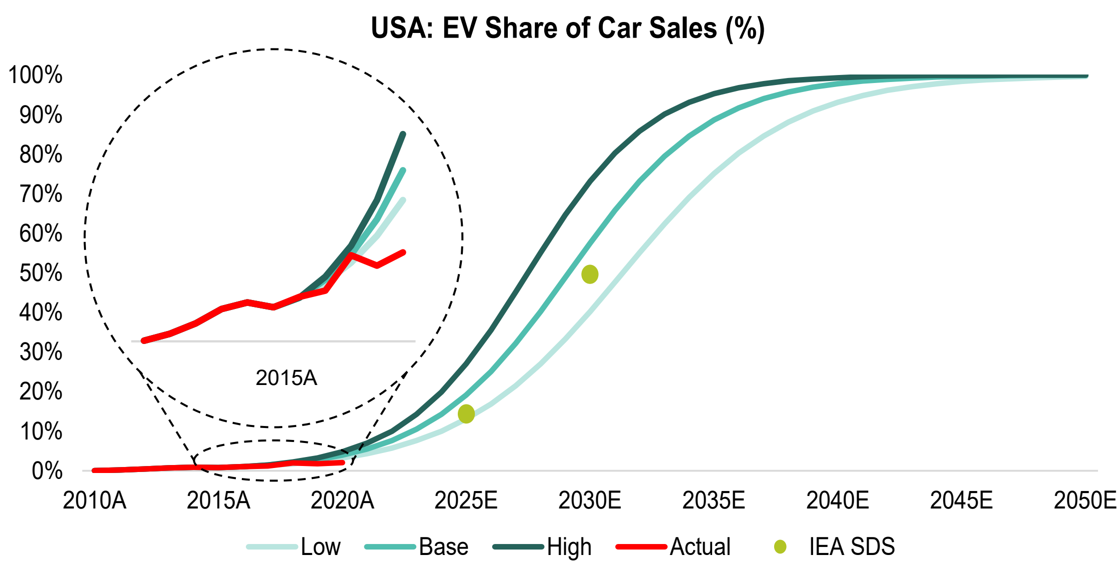
EXHIBIT 364: **Global Energy Storage and EV Team: Updated EV demand projections (2020)**



Source: SNE Research, and Bernstein estimates (Global Energy Storage and EV team) and analysis

Utilizing a similar methodology as before, we show that reaching IEA SDS targets in the US would require emergence rates to remain between 30% and 35% per year (see Exhibit 365).

EXHIBIT 365: **US EV sales could reach 60% of total car sales by 2030E**

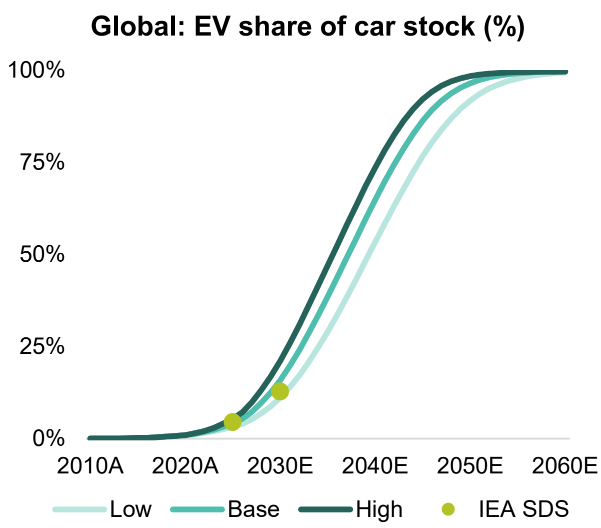


Methodology credits: University College London, We Mean Business Coalition. Electric car share of sales. Historical values over 2005-20. Total sales of electric cars for 2005-19 from IEA Global EV Outlook (IEA, 2020c), Statistical Annex, Electric Car New Registrations (BEV and PHEV) by country. Total sales of passenger cars for 2005-19 from OICA (OICA, 2020a), Sales Statistics, New Passenger Car Registrations. 2020 electric car sales and total car sales calculated based on Irle (2021) and IEA (2020b). Share calculated from these data. S-curve projections start from 2015 values. Saturation point of S-curves set at 100%.

Source: IEA data, University College London Methodology, and Bernstein estimates and analysis

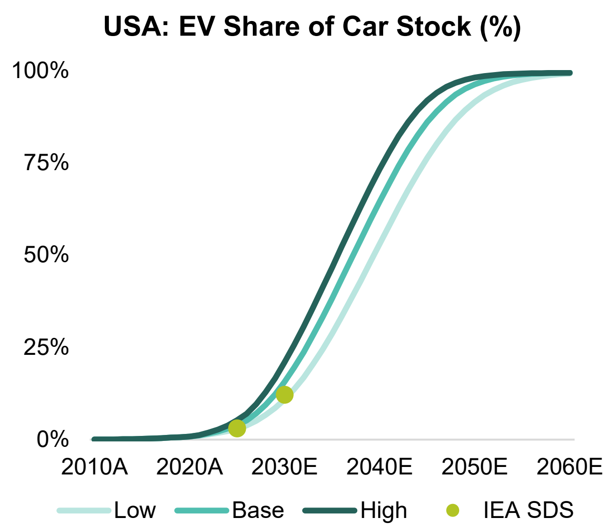
Assuming a global "scrapping-age" for PVs of 17 years (compared to scrapping age estimates of between 13 years and 17 years in the US and 13.9 years in the UK), this implies a rapid acceleration in EV share of global car stock from around 2030E to 2045E. In our net-zero base-case scenario, global EV share of car stock increases from ~15-16% in 2030E to more than ~90% by 2047E and with similar figures for the US. Our forecasts are consistent with IEA SDS scenario projections in 2030E. Overall, this implies a coming acceleration in EV electricity demand which could start around the turn of the decade and which will remain sustainable over more than two decades (see Exhibit 366 and Exhibit 367).

EXHIBIT 366: **Global EV shares are poised for rapid acceleration from the turn of the decade...**



Source: IEA data, and Bernstein estimates and analysis

EXHIBIT 367: **...and a similar picture is true of the US**

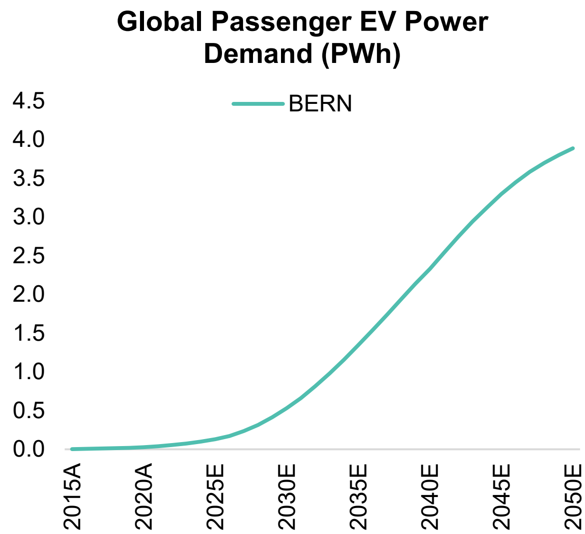


Source: IEA data, and Bernstein estimates and analysis

We translate this emergence of (passenger) car sales into an increase in electricity and renewables capacity demand. Power consumption will likely fall in the future as battery weight reduces and EV engineering improves. Overall, we assume that fuel economy improves from ~0.2kWh/km historically to ~0.15kWh/km by 2040E. For comparison, the Tesla Model III has been shown to be able to achieve ~0.12kWh/km, although these have been under specific test and temperature conditions and actual usage is likely higher. This translates to an additional power demand of ~3.9PWh by 2050E (versus BNEF's forecast of ~3.8PWh) and requiring ~1.6TW of additional renewables capacity (see Exhibit 368 and Exhibit 369).

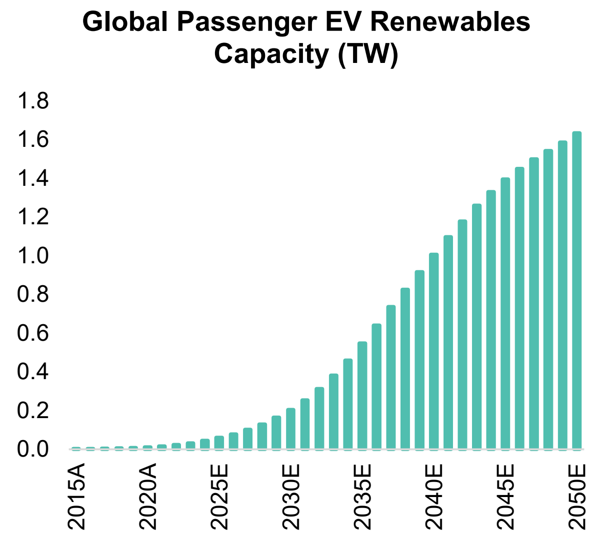
We show PV power demand (outlined in red (black line in print copy) in Exhibit 370) in the context of power demand from other ground vehicle types. BNEF released a new net-zero scenario (NZS) in 2021 which explores a possible trajectory that could bring the global vehicle fleet to zero emissions by 2050 whereupon road vehicles account for ~24% of global electricity demand. Similar to our projections, it forecasts a rapid acceleration in EV stock beginning from the turn of the decade and which is sustained until around 2050E: EV stock increases from ~218 million in 2030E to ~1.35 billion by 2050E. This results in a rapid acceleration in electricity demand for vehicles, which increases from 0.9PWh in 2030E to >8PWh by 2050E.

EXHIBIT 368: **We forecast private passenger EV power demand to rise to just under 3.9PWh by 2050E**



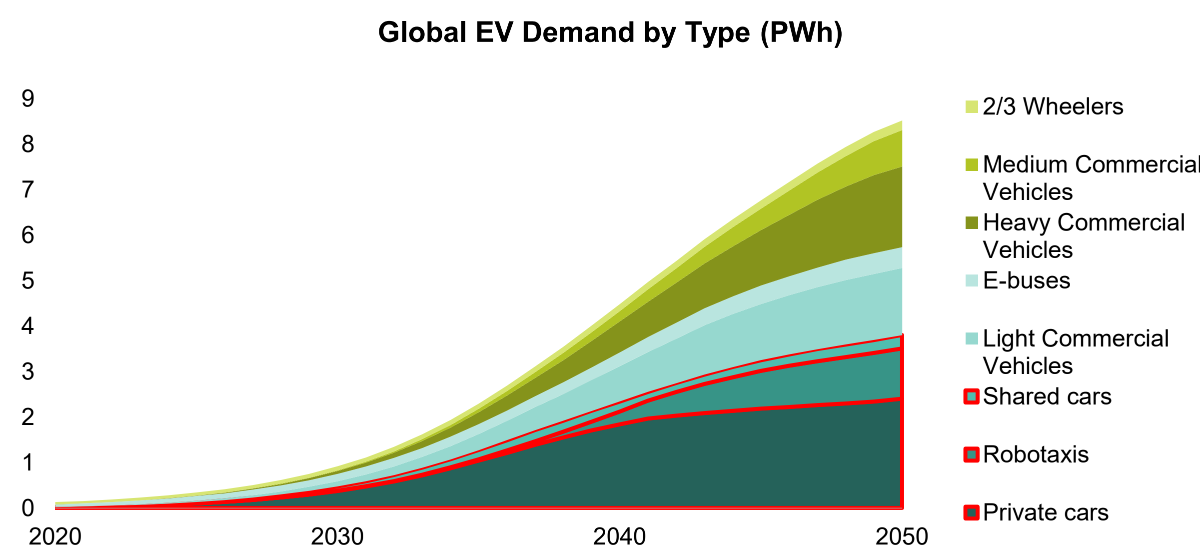
Source: BNEF CEHP, and Bernstein estimates and analysis

EXHIBIT 369: **This could require ~1.6TW of renewables capacity**



Source: BNEF CEHP, and Bernstein estimates and analysis

EXHIBIT 370: **EV power demand will likely rapidly ramp up and see two decades of strong growth**



Source: BNEF CEHP scenario estimates (2020+) and Bernstein analysis

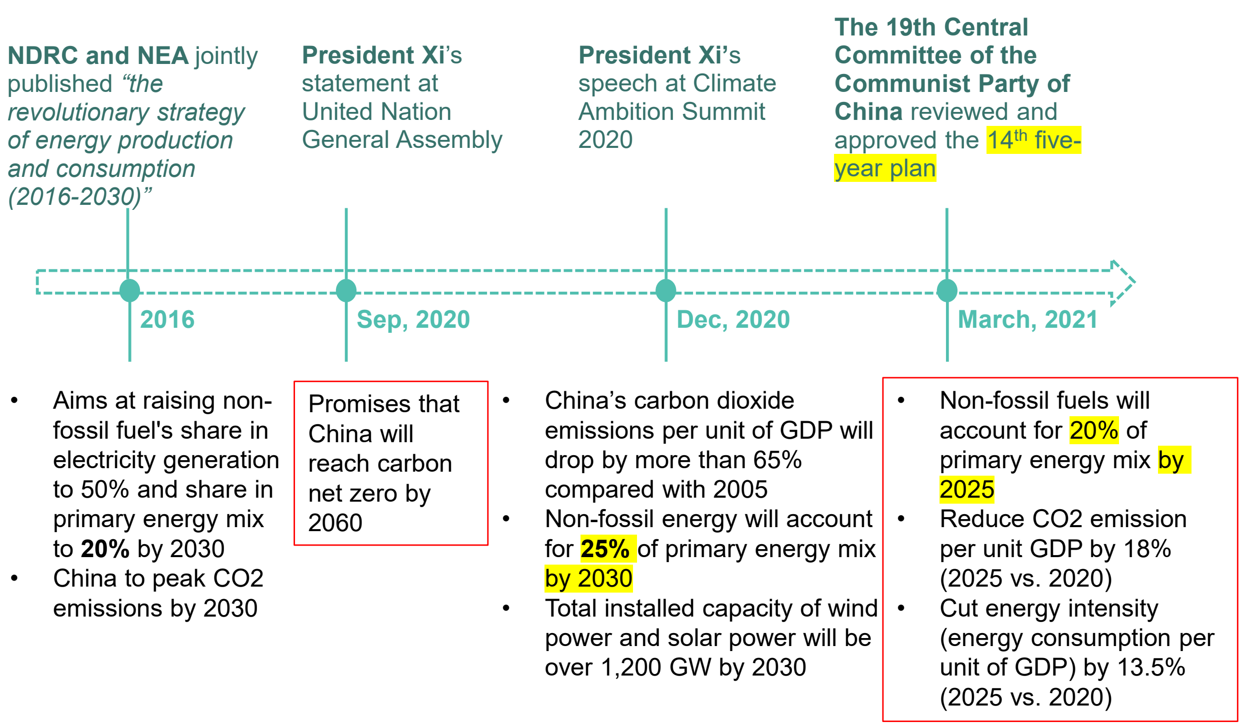
CHINA IN-DEPTH: RENEWABLES POTENTIAL FROM DECARBONIZATION AND EVS

China is the largest end-user market for EVs, accounting for 41% of global EV sales in 2020. The country is also a key hub for battery manufacturing, whose EV battery installation represented 44% of the globe last year. As a result, the decarbonization of China's electricity supply is critical to determine how clean the Electric Revolution will be. Developing renewables is a pre-requisite for EVs and making the Electric Revolution truly green. In this section of the chapter, we focus on the decarbonization of China's power supply.

THE POLICY PUSH FOR DECARBONIZATION IS ACCELERATING

Decarbonization is accelerating in the 14th five-year plan period (2021-25). Non-fossil fuels are targeted to account for 20% of the primary energy mix by 2025. This brings the previous target set for 2030 (per the "Strategy for Energy Production and Consumption Reform 2016-2030," published in May 2017) ahead by five years. This is also on track to achieve what Chinese President Xi Jinping committed to at the Climate Ambition Summit on December 12, 2020 where non-fossil fuels will account for a 25% share of the primary energy mix by 2030 (see Exhibit 371).

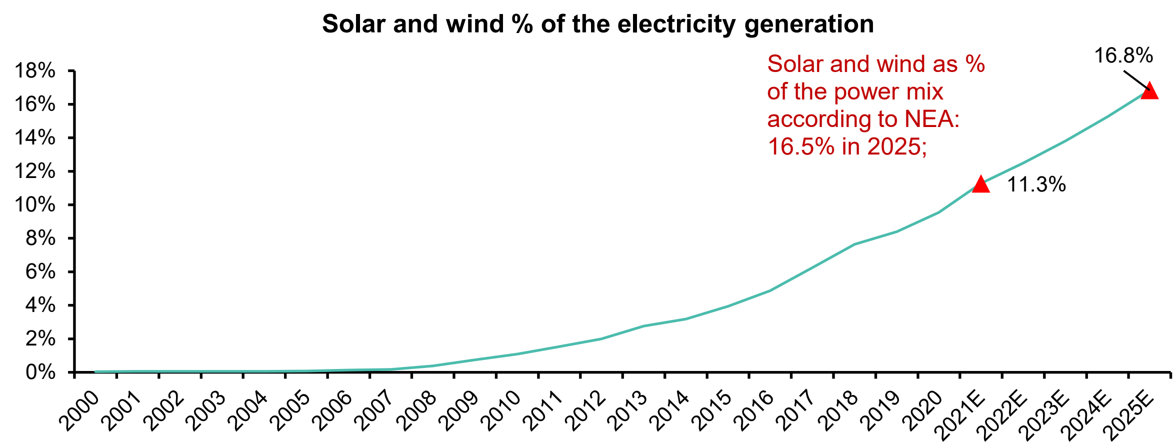
EXHIBIT 371: **Policy update on renewables**



Source: NDRC and Bernstein analysis

The National Energy Administration (NEA) proposed 2025 targets for solar and wind for the first time in April 2021: solar PV and wind will make up 16.5% of total power consumption in 2025 versus 11% in 2021. Incrementally, this increases clarity of solar and wind capacity growth. Our forecasts (16.8% in 2030 and 11.3% in 2021) are in line with NEA's targets (see Exhibit 372).

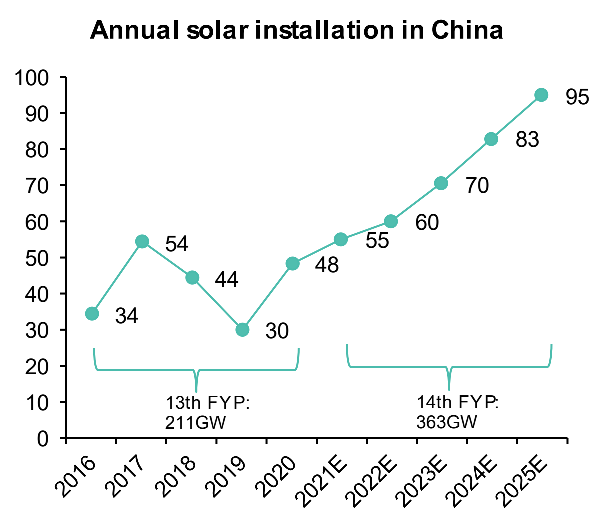
EXHIBIT 372: **Solar and wind will contribute 16.5% of China's electricity supply in 2025 versus 11% in 2021, according to NEA; our forecasts (16.8% in 2030 and 11.3% in 2021) are in line with NEA's target**



Source: BP Statistical Review, and Bernstein estimates and analysis

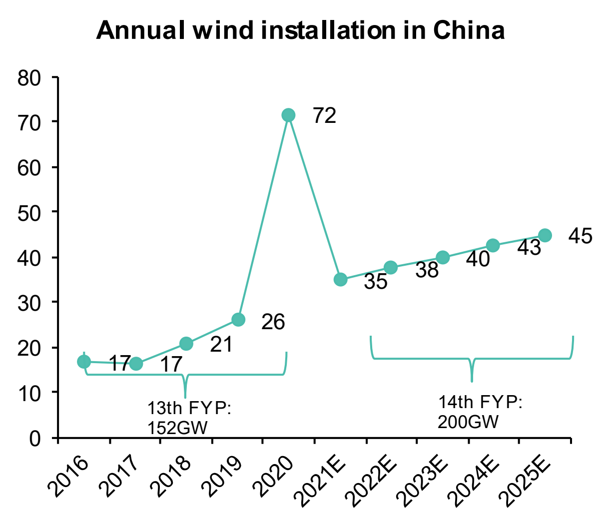
In the 14th five-year plan period (2021-25), we expect 363GW of solar capacity to be added versus 211GW in 2016-20 (see Exhibit 373). For wind, we expect 200GW of wind capacity to be added in 2021-25 versus 152GW in 2016-20 (see Exhibit 374).

EXHIBIT 373: **We expect 363GW of solar capacity addition in 2021-25 versus 211GW in 2016-20**



Source: Haver, and Bernstein estimates and analysis

EXHIBIT 374: **We revise up our forecast of wind capacity addition in 2021-25 from 175GW to 200GW**



Source: Haver, and Bernstein estimates and analysis

We believe state-owned enterprises (SOEs) will account for the majority (about three-fourths) of renewable capacity additions in 2021-25 (see Exhibit 375). Based on the targets of renewable capacity additions during the 14^{th} five-year plan published by major SOEs, they will in total add more than 413GW during 2021-25, which means the annual renewable installation of SOE will be more than 82GW in the next five years, accounting for 75% of our forecast of solar and wind capacity additions (563GW, comprised of 363GW of solar and 200GW of wind).

EXHIBIT 375: **Annual renewable installation of SOE will be more than 82GW in the 14^{th} five-year plan**

Company	14th FYP target (GW)	Annual installation (GW)
Huaneng	80-100	16-20
Three Gorges	75	15
Datang	Renewable (non-hydro) installation plan will not be lower than other SoE; expect to be 75-100GW	15-20
China Energy Investment	120	24
State Power Investment Corporation	Install 28GW in 2020-2025; reach 45GW total installed capacity by the end of 2025	5.6
CGN	>40GW total installed capacity by the end of 2025; ~20GW installation during the 14th FYP	4
Huadian	>15	>3
Total	**>413**	**>82**

Source: Company announcements and Bernstein analysis

THE CLEANER POWER MIX TARGET RESULTS IN SECULAR GROWTH OF SOLAR AND WIND

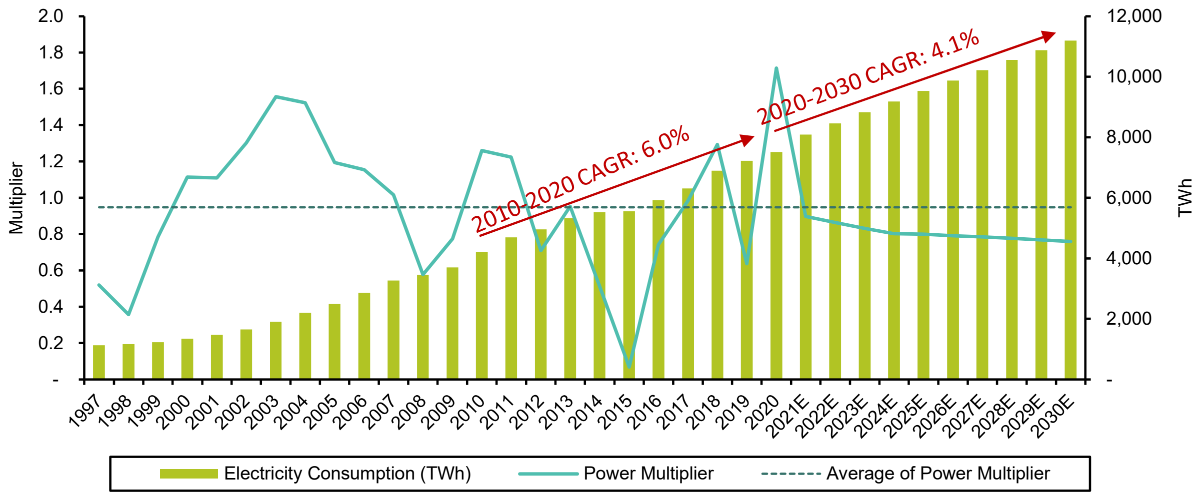
In 2020, China in total consumed 7,511TWh of power and we expect power consumption to rise to 11,000TWh in 2030, representing a CAGR of 4.1% during 2020-30 versus 6.0% in 2010-20 (see Exhibit 376).

According to the NEA, renewables (hydro, solar PV, wind, and biomass) will account for 40% of Chinese power consumption in 2030 and non-hydro renewables (solar PV, wind, and biomass) will account for 26% of Chinese power consumption in 2030. Given that biomass only accounts for ~1% of power mix, the NEA's target on non-hydro renewables' share in the power mix is effectively a target set for solar and wind. We expect solar and wind will contribute ~25% of the electricity supply in 2030 versus 10% of total power generation in 2020.

Chinese President Xi Jinping said at the Climate Ambition Summit on December 12, 2020 that total installed capacity of solar and wind will be over 1,200GW by 2030. While some have mistakenly used the 1,200GW of solar and wind capacity as the guidance of 2030 installation targets, we find 1,838GW of total installed solar and wind capacity by 2030 is required to reach the NEA's targets. Solar total installed capacity is expected to grow at a

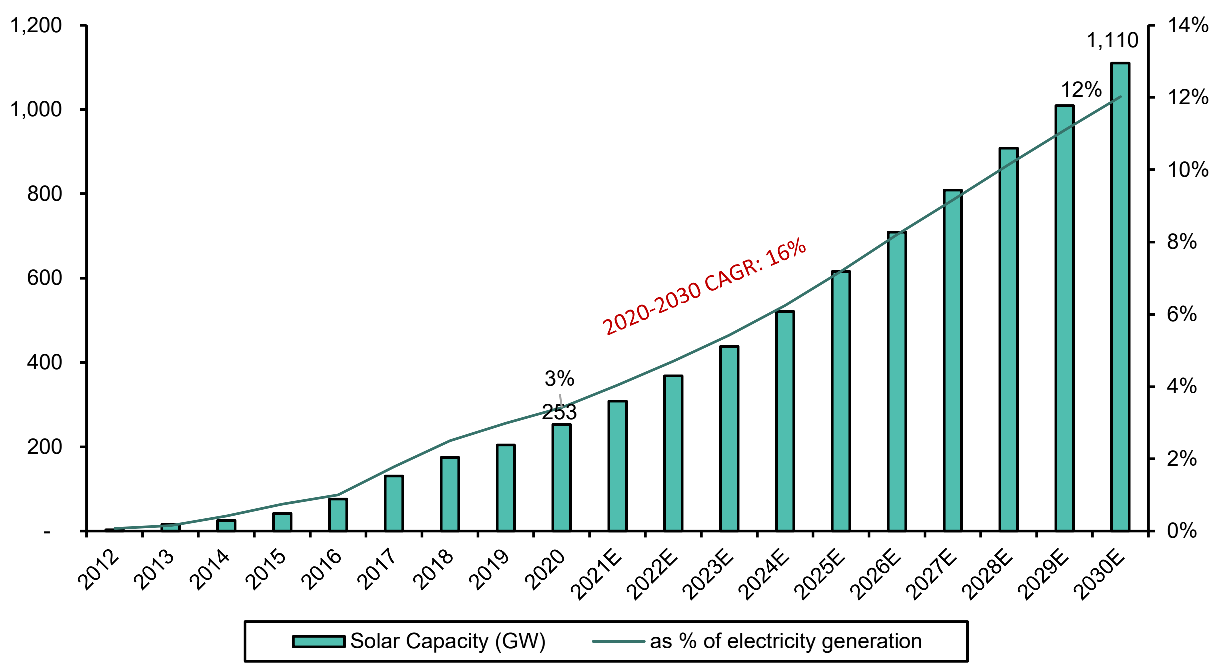
16% CAGR from 2020 to 2030 (see Exhibit 377). For wind, the total installed capacity is expected to grow at a 10% CAGR from 2020-30 (see Exhibit 378).

EXHIBIT 376: **We estimate China's electricity consumption will reach 11,000TWh in 2030**



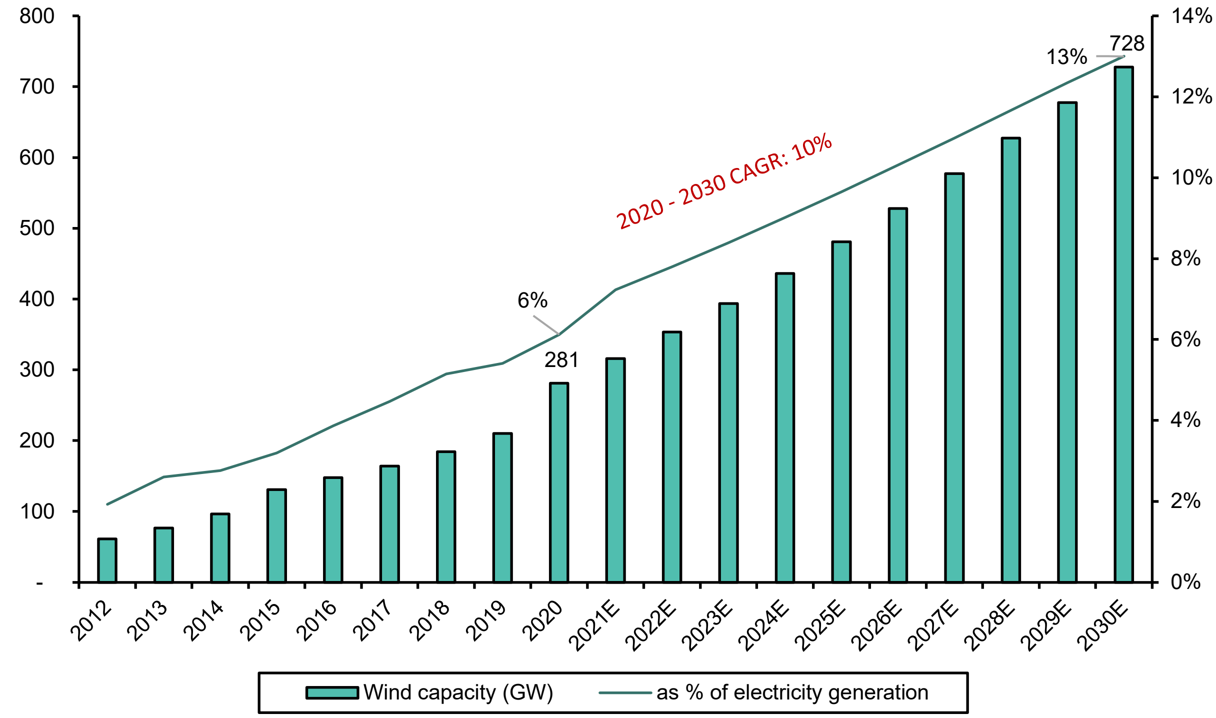
Source: China Electricity Council, Haver, and Bernstein estimates and analysis

EXHIBIT 377: **Solar total installed capacity is expected to grow at a 16% CAGR over 2020-30**



Source: BP Statistical Review, and Bernstein estimates and analysis

EXHIBIT 378: **Wind total installed capacity is expected to grow at a 10% CAGR over 2020-30**



Source: BP Statistical Review, and Bernstein estimates and analysis

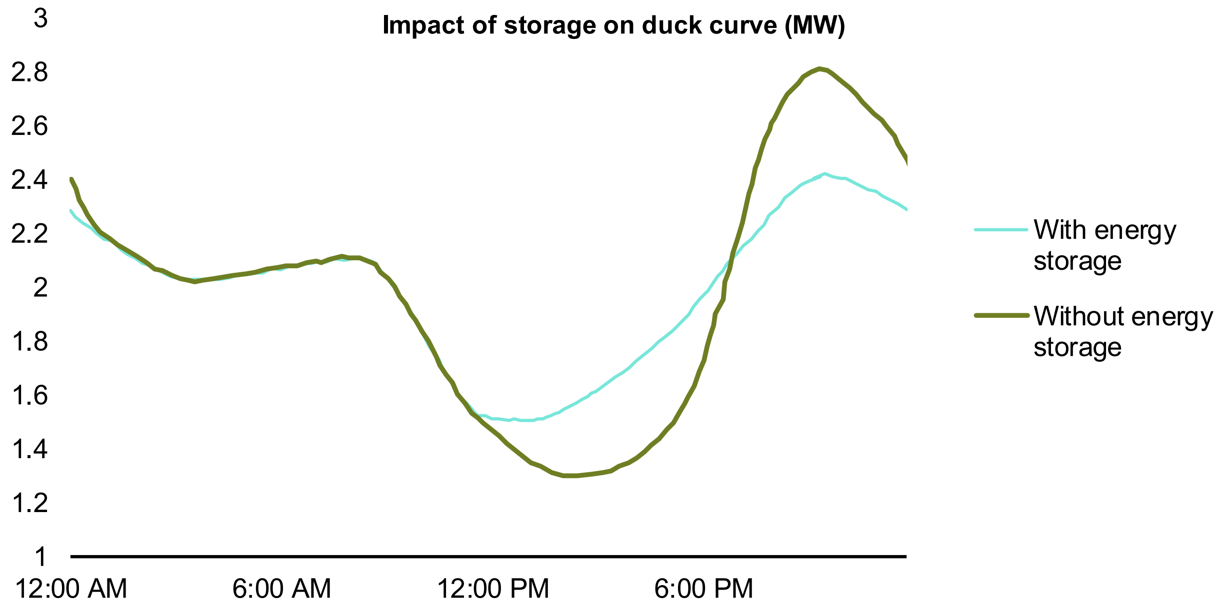
FLEXIBILITY — UNDERAPPRECIATED POTENTIAL

Diurnal demand patterns with morning and evening peaks may not be well aligned with renewables, particularly solar PV power generation in the middle of the day. There are a number of supply side levers that can be used to match the demand profile, such as battery storage, a change in generation mix to higher shares of wind, or technology progress in solar PV such as trackers to broaden generation profiles.

Net load curves (as shown in Exhibit 379) are one way to show flexibility needs in the system to complement wind and solar PV power generation: wind and solar generation output has been deducted from total demand and the net load curve represents load that needs to be provided from other flexible or dispatchable technologies. In a region where high amounts of solar are being netted during the middle of the day, this curve is sometimes referred to as the duck curve — representing the profile of a duck.

One option is batteries. With meaningful amounts of solar, there is a steep ramp within 2-3 hours where other generation resources need to ramp up to serve a typical evening peak demand when solar is not available. The value of additional solar diminishes at the middle of the day and peak demand in the evening remains high. 4-8 hour battery storage systems are very valuable and can shift solar from the middle of the day to the evening peak and, thus, limit curtailment, reduce peak demand, and soften ramping.

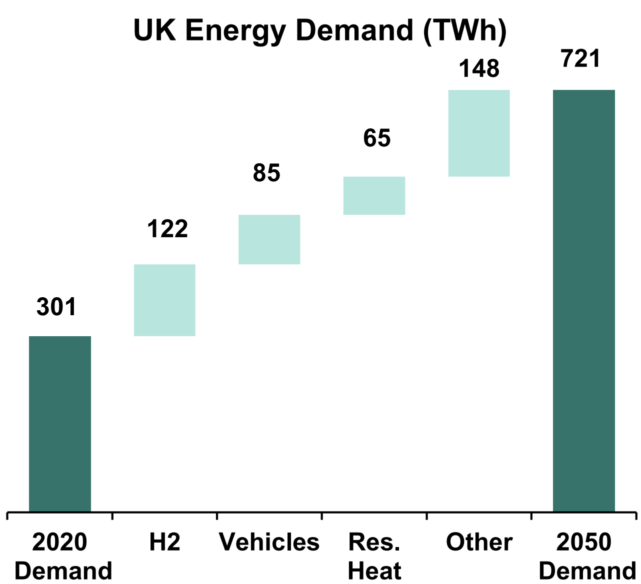
EXHIBIT 379: **Four-to eight-hour battery storage systems can shift solar from the middle of the day to the evening peak and, thus, limit curtailment, reduce peak demand, and soften ramping**



Source: Sunverge (2015) and Bernstein analysis

Another option is demand side flexibility. The bulk of electricity demand growth for the energy transition to 2050E will come from hydrogen production, EVs, and residential heat (delivered via heat pumps), all of which could be very flexible (see Exhibit 380).

EXHIBIT 380: **Future electricity demand will be flexible**



Source: CCC 6th Carbon Budget estimates (2050) and Bernstein analysis

Demand response will play an essential role for grid operators both in terms of integrating renewables and future demand profiles, as well as minimizing or deferring capital investment. In 2021, ENTSO-E, the pan-European association representing 42 electricity transmission system operators across 35 countries, released a position paper stating demand response will be "*a crucial solution to limit the need for additional peak capacity when renewable production is scarce, and prevent grid overloads (especially at local level).*"

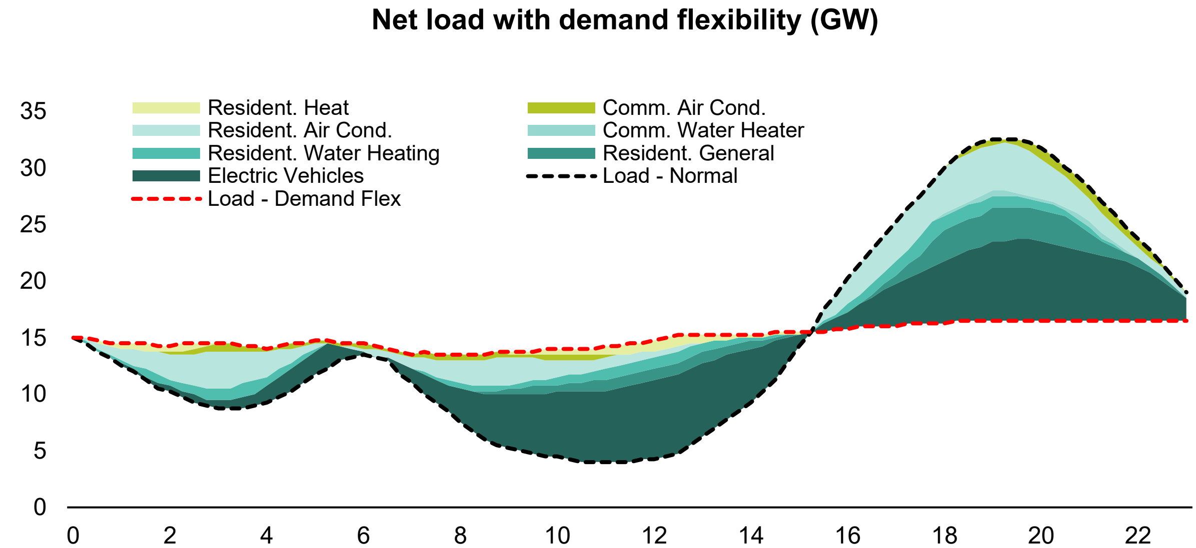
Digitization and smart grids will continue to improve speed and flexibility of demand. Traditional demand modification measures have been employed by system operators for years, e.g., increasing pricing during periods of likely high grid stress. However, digitization will result in a step change in capabilities by enabling smart control and communication technology, which modifies consumer loads in real time in response to market signals (e.g., changing renewables generation levels).

Exhibit 381 illustrates how demand flexibility including EVs could contribute meaningfully to managing the net load profile.

- **Water heaters:** In the US, water heating is the second-highest load energy use after space temperature control. Electric heaters work on a typical on-off cycle: water fills the tank, which is heated by resistance elements in the heater. When the temperature reaches the desired level, a thermostat turns the heater off, whereupon the water is stored until it is used. When hot water is used, it flows from the tank which is replenished with cold water, restarting the cycle again. As a result of this on/off cycle, the water heater has two main peaks — morning and evening. A smart water heater can avoid this cycle and shift load away from times of peak usage. At the midday generation peak, water can be heated to higher temperatures of 76°C, allowing for much more energy to be stored. When water is drawn from the heater in the evening, extremely hot water is mixed with cold water to reach the desired temperature without needing to turn on the electric resistance bands.

- **Space heating/cooling:** Load can be shifted by turning heat pumps or air conditioners on or off ahead of periods of expected high load. High thermal mass materials can act as a "temperature battery" keeping the building comfortable for longer periods of time while reducing energy costs. The higher the thermal mass, the more energy is required to alter the temperature of the material. For instance, in a hot country, air conditioners could draw out the stored energy in a thermal mass. For several hours later, the thermal mass reabsorbs energy from the house, keeping temperatures comfortable.

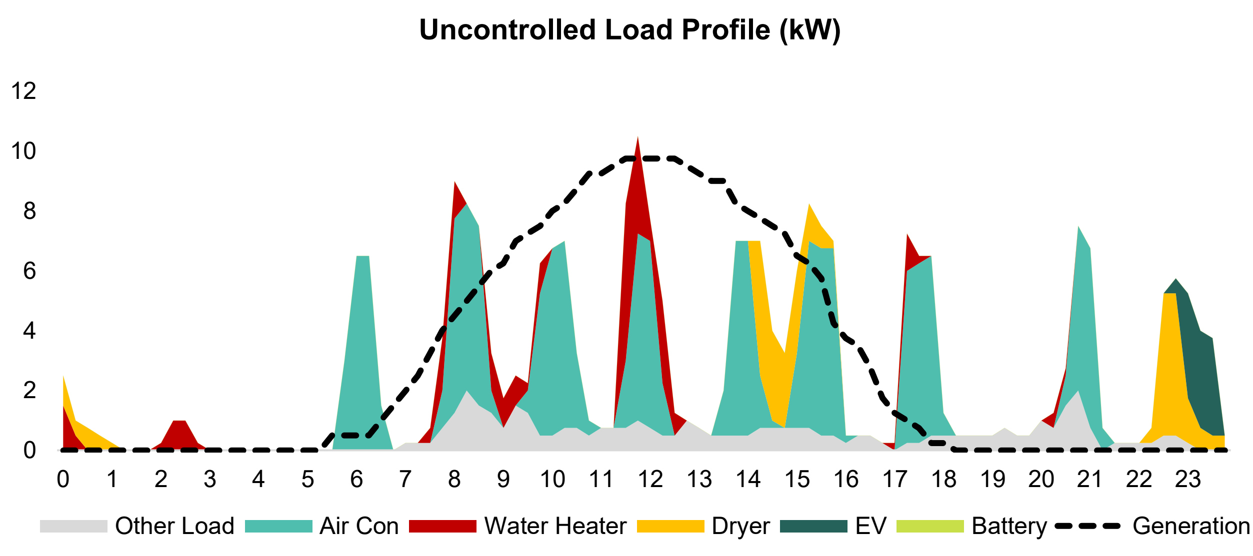
EXHIBIT 381: **Demand response flattens net load and reduces congestion**



Source: RMI estimates (all data) and Bernstein analysis

Exhibit 382 illustrates an uncontrolled load profile for a simulated home in Hawaii. Solar generation results in a peak in overall generation during mid-day. However, this is not matched with demand peaks in the late afternoon when temperatures peak and in the evening when families return home.

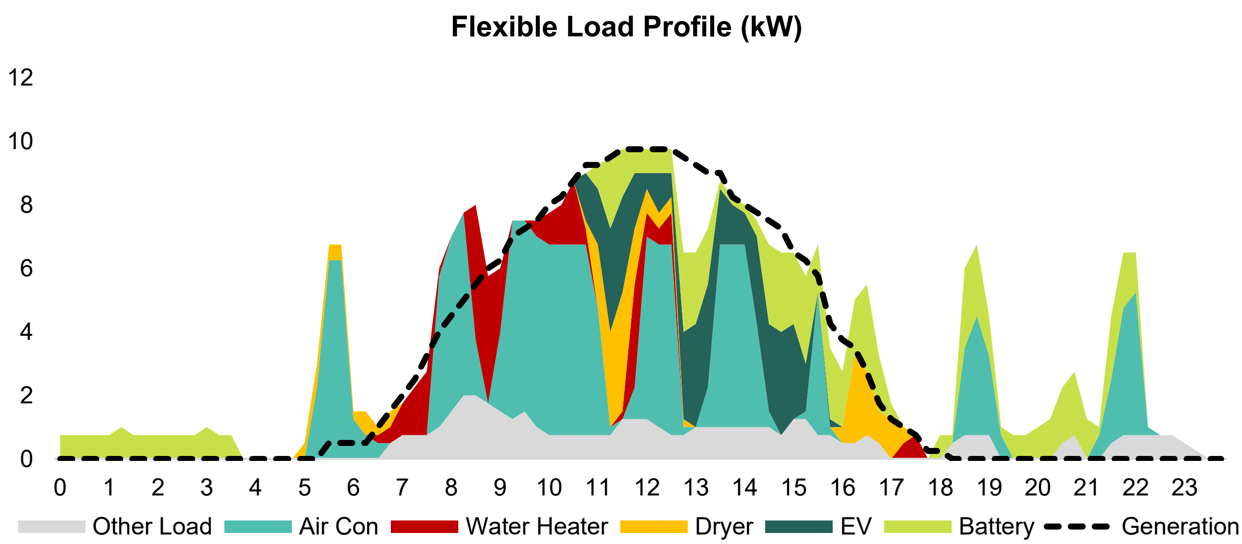
EXHIBIT 382: **Uncontrolled load profile**



Source: RMI estimates (all data) and Bernstein analysis

Smart energy efficient houses of the future will boast technologies that will substantially modify demand to coincide with peak generation (see Exhibit 383) without the loss of service quality. As discussed in detail earlier in this chapter, batteries and personal EVs could be left unused 90% of the time and could utilize flexible charging (V1G) and power injections to the grid at times of stress (V2G). Better building insulation and/or thermal storage with ceramic blocks will provide greater scope for the phasing of heat pump warming cycles. Ice storage could allow air conditioning load to be shifted to the mid-day generation peak. Water heaters could intelligently start running at noon.

EXHIBIT 383: **Flexible load profile**

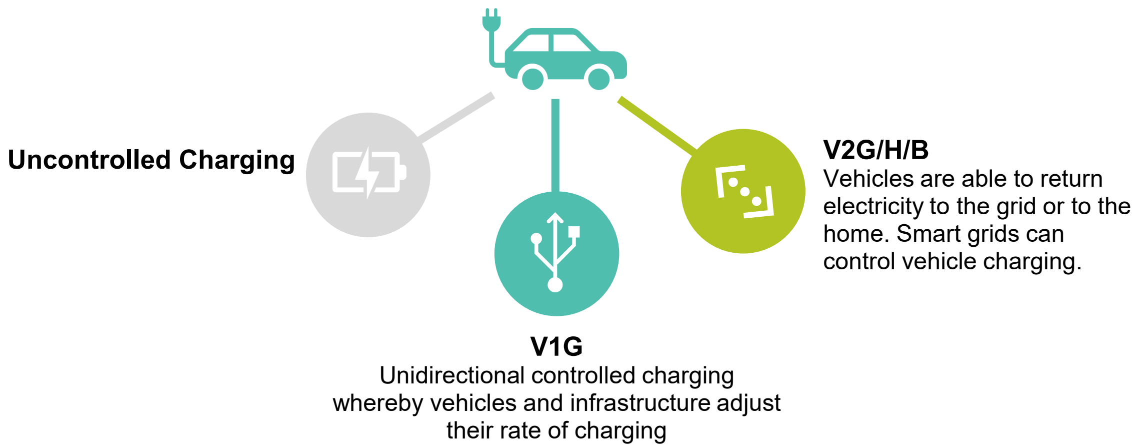


Source: RMI estimates (all data) and Bernstein analysis

EV CHARGING CAN PROVIDE FLEXIBILITY

Unregulated, uncontrolled, and uncoordinated charging could result in significant increases in peak loads should EV owners plug in their cars at the same time, especially during evening peaks. This could result in system instability such as voltage drops and power losses, as well as reduce the lifespan of grid components such as transformers and cables due to increased overloading. These issues could be solved via controlled unidirectional charging (V1G) and, in the best case, bi-directional flows from EVs to the grid (V2G), or to supplement electricity consumption of residential houses or buildings (V2H/B) (see Exhibit 384). According to ENTSO-E's position paper on EV integration, *"it is paramount to immediately begin the deployment of smart charging and, whenever viable, of V2G solutions."*

EXHIBIT 384: **Overview of EV charging models**



Source: Bernstein analysis

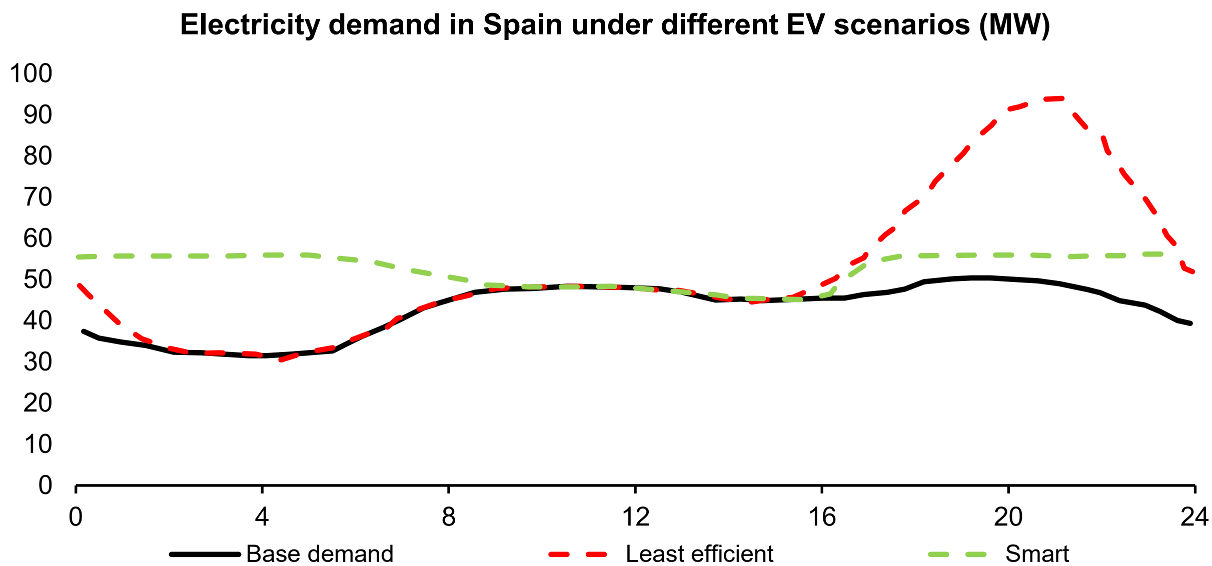
V1G: Unidirectional controlled charging

EV charging can be advanced or delayed based on cost, renewable content, or demand-supply constraints. For example, EV charging could be timed during mid-day when solar supply is at its peak or during the night when wind generation is high and non-EV demand is low.

Exhibit 385's black line shows current electricity demand profile in Spain. By 2050, with 70% smart charging and EVs, the future smart demand curve would look very different from today and from uncontrolled charging. Even by 2035, a part of this could already play out.

So far, V1G rollout has been accepted by EV drivers. Typically, only 2-3 hours of charge time is necessary per day, while the car is parked for 10 hours or more (e.g., at work) or overnight at home. Companies are also accelerating their offering of smart EV charging solutions; e.g., EDF launched a joint venture in 2019 with Nuvve operating across the UK, France, Germany, Belgium, and Italy, and which will increase adoption of V2G services while enhancing current V1G service offerings. Enel X offers EV charging stations across Italy, Spain, the US, the UK, and Latin America, and its new JuiceBox Level 2 station offers smart charging services tailored by consumer segment (residential, SME, and large enterprises).

EXHIBIT 385: **With "smart" (off-peak) charging, peak demand remains unchanged (Spanish example)**



Source: Red Electrica estimates and Bernstein analysis

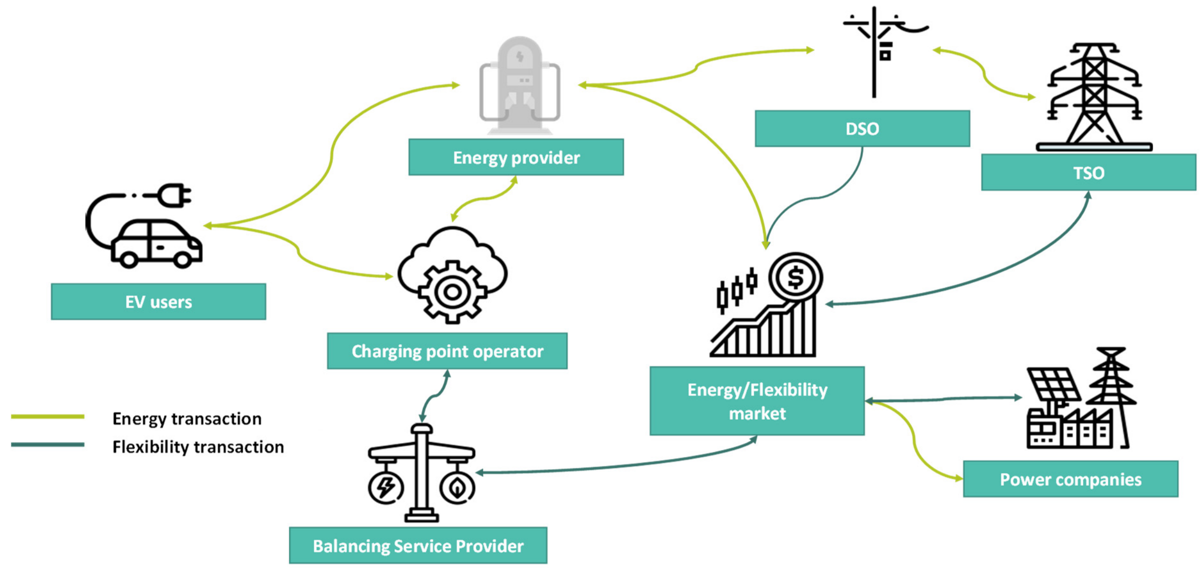
V2G/H: Bi-directional charging

Bi-directional charging is an even smarter solution wherein EVs not only receive energy from the grid but can also send electricity from their batteries to their grid or to a building. Within a closed system, vehicles could supplement power consumption at home or at a building (V2H/V2B), indirectly reducing grid peak loads. So far, these projects are relatively limited although some vehicle manufacturers such as Hyundai, Kia, and Volkswagen have announced that some of their cars will have V2H/B capability within the next few years.

Vehicles can also directly inject electricity to the electric grid (V2G), and this is expected to become an important tool for TSOs to reshape power demand and reduce grid congestion. ENTSO-E's policy paper recommends achieving this via a combination of increasing EV charging at offices and parking spaces, implementation of time-of-use tariffs, as well as charging management by aggregators. Other benefits include the reduction in renewable energy curtailment as well as lower fossil fuel generation during periods of peak demand coupled with low renewables generation.

Aggregator examples include the Equigy project backed by a consortium including Terna, Tennet, SwissGrid, and APG that works as a balancing platform which links ancillary markets with aggregators. When aggregated, EVs are a battery on wheels and could access flexibility and balancing revenue streams (see Exhibit 386 and Exhibit 387).

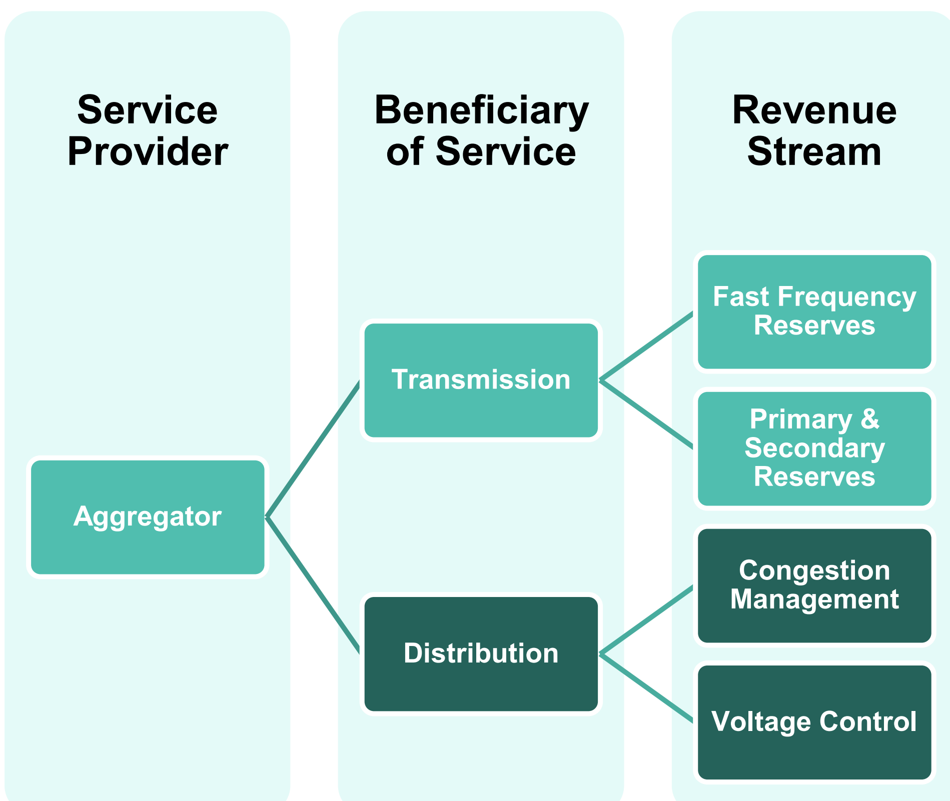
EXHIBIT 386: **Flowchart of the services and charging value chain**



Note: Image credits — FlatIcon (hosted on FlatIcon, images created by Photo3idea_studio, FreePik, SmashIcons)

Source: ENTSO-E and Bernstein analysis

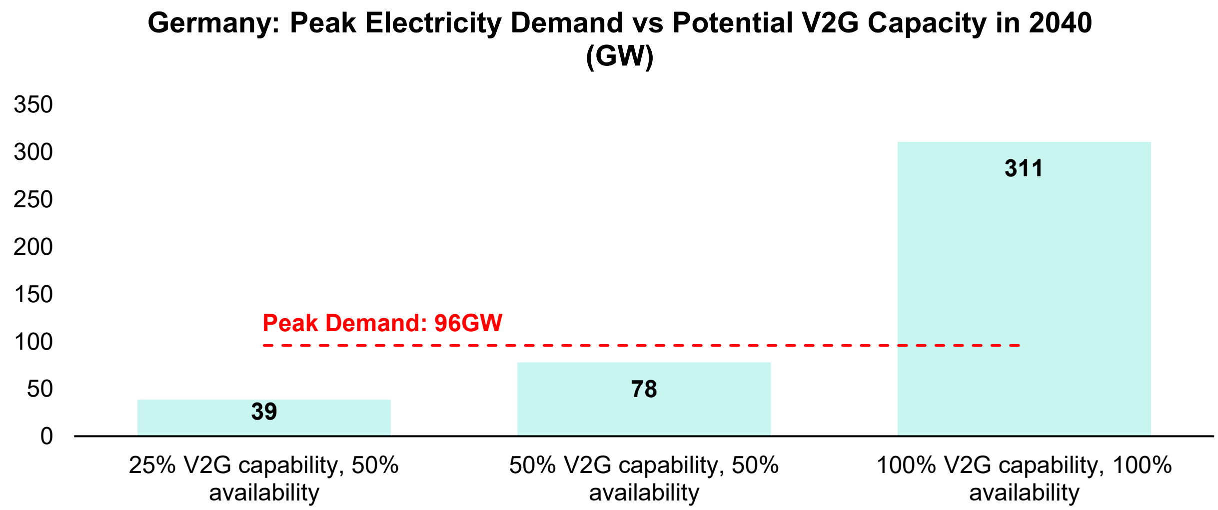
EXHIBIT 387: **When aggregated, EVs are a battery on wheels and could access flexibility and balancing revenue streams**



Source: Bernstein analysis

Exhibit 388 illustrates the impact V2G could play on Germany in 2050. If just 25% of EVs are V2G capable and only half are available, this would lead to the provision of 39GW of capacity or ~40% of peak demand of 96GW. In an extreme case, if the entire EV fleet is V2G capable and 100% available, this could lead to a potential maximum provision of capacity of 311GW or more than 3x peak demand.

EXHIBIT 388: **V2G could provide a significant portion of German peak energy demand**



Source: BNEF estimates (all data) and Bernstein analysis

ELECTRIC NETWORKS ARE "CENTRAL TODAY AND ESSENTIAL TOMORROW"

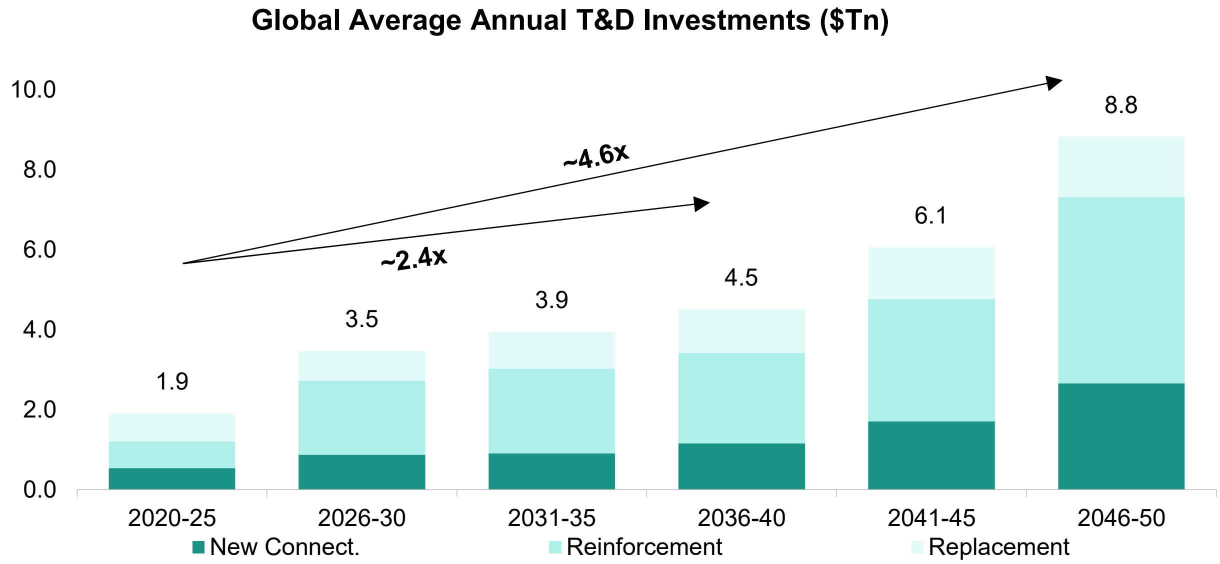
Electricity networks will serve as the backbone of the energy transition and, in the words of Enel's CFO, *"an infrastructure that is already central now will become essential tomorrow."* There will be significant need for investments (see Exhibit 389).

Replace aging assets. For instance, in Europe, most of the T&D grid was built over 1950-70 and investments are needed for replacing assets as well as maintaining and improving the quality of the infrastructure to minimize outages/interruptions to customers. Global investment spend could increase from ~US$0.7tn annually over 2020-25 to ~US$1.5tn by 2046-50.

New connections investments could quintuple from ~US$0.5tn p.a. over 2020-25 to ~US$2.7tn p.a. over 2046-50 in order to connect distributed renewables like onshore wind and solar (distribution networks) or large centralized renewables like offshore wind as well as inter-connecting different regions within a country and across countries, to make best use of renewable resources (transmission networks).

Grid reinforcements capex could increase from ~US$0.7tn over 2020-25 to ~US$4.7tn over 2046-50. This will be necessary to integrate EVs and heat pumps to accommodate a spike in residential loads and load from charging infrastructure, as well as to digitize the grid and make it smarter. The increasingly complex landscape requires a more sophisticated technological infrastructure to accommodate decentralized renewables, EVs, or heat pumps and manage two-way flows.

EXHIBIT 389: **Rapid acceleration in grid investment**



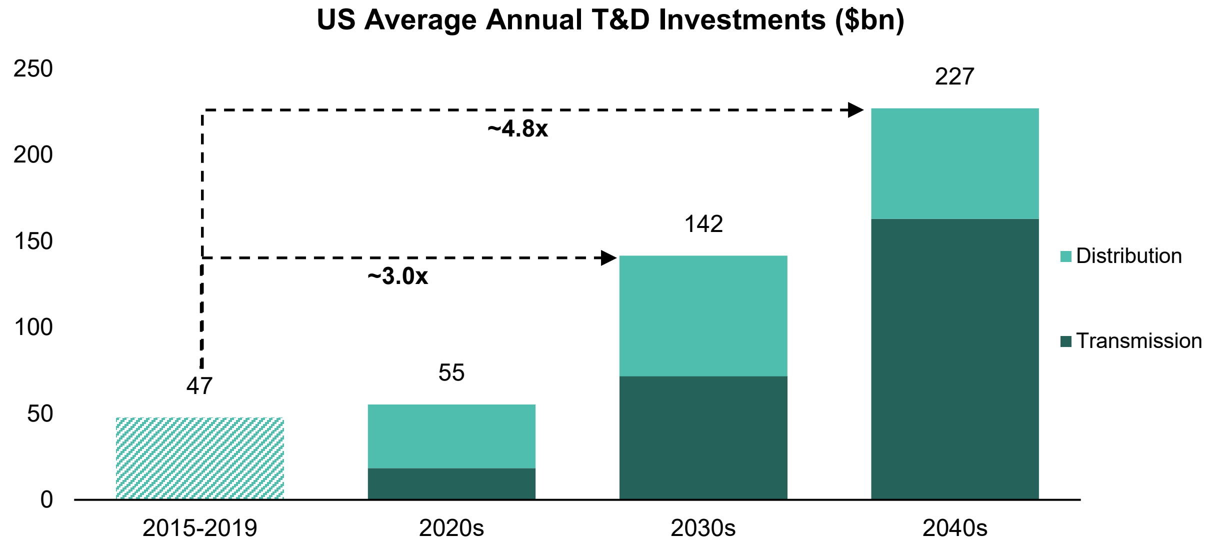
Source: BNEF CEHP scenario estimates (all data) and Bernstein analysis

The overall split between distribution and transmission investments will likely be relatively country-specific and dependent on local needs as well as the current state of the network.

On a global basis, BNEF expects distribution grids to grow in importance over the coming decades as a result of a need to connect smaller power plants which could be located closer to demand. BNEF expects the median size of power plants could shrink to 158MW by 2050 — a reduction by a factor of 6 — as a result of higher shares of wind and solar: *"By mid-century, distribution grids make up 63 percent of annual investment, up from 52 percent in 2020."*

On the other hand, Princeton expects US T&D spend to be skewed toward transmission in the US. Given the size of the country, high-voltage lines will be needed to transport electric power from areas with abundant renewables resources to population centers (e.g., from the Great Plains wind belt to cities in Texas). We expect US T&D investments to triple or quadruple (see Exhibit 390).

EXHIBIT 390: **US investments in networks are expected to rise to 3x by the 2030s**



Source: Princeton Net Zero America Project estimates (2021+) and data (2015-2019) and Bernstein analysis

SMARTER GRIDS AND CHARGING WILL BE THE FIRST PORT OF CALL

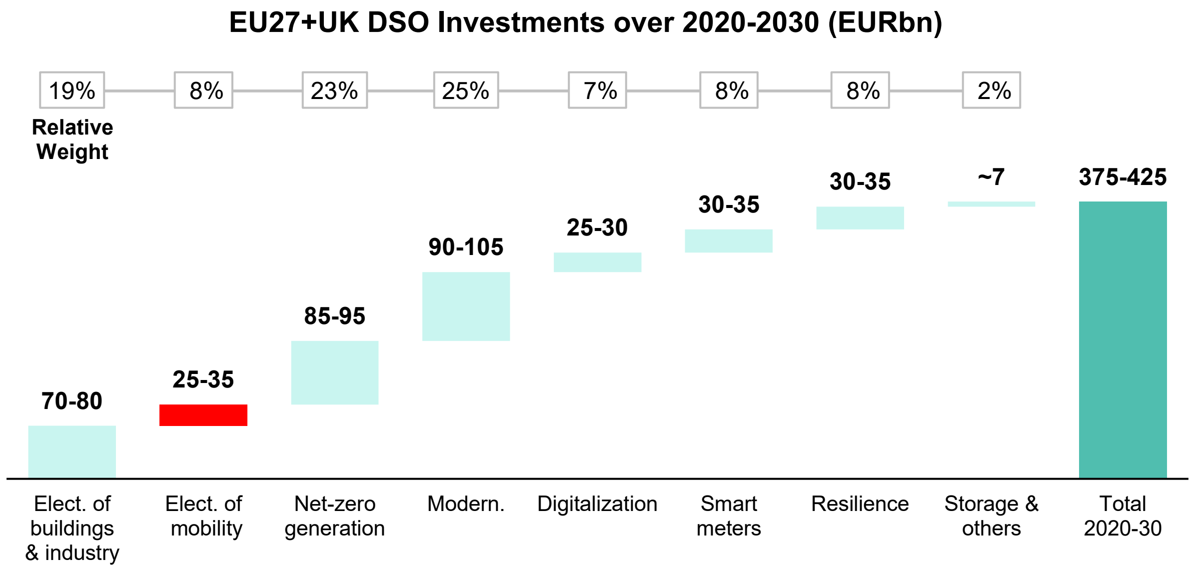
Networks operators are targeting smart grids and charging as the first port of call in integrating EVs rather than traditional grid investments. According to ENTSO-E, demand response will be a crucial lever to *"avoid, limit or postpone"* expensive grid reinforcement costs by shifting demand to periods of low grid utilization.

The low and medium-voltage grid will likely be the most impacted by EV charging. The association of European Distribution System Operators (EDSO) estimated in its position paper on mass adoption of EVs that *"traditional grid reinforcements can be between four and ten times more costly than smartening the grid."* Based on a study of 10 DSOs, EDSO expects a 50-70% increase in electric distribution grid investment growth over 2020-30 (versus historical trends) across the EU27+UK, but EVs will play a small part, accounting for just 8%.

The impact of EVs on grid investment needs will depend heavily on the degree to which flexible demand (via smart V1G or V2G charging) is utilized and the state of the existing grid. This is because there is generally a lower constraint on the additional electricity demand from EVs — rather the bigger issue is grid congestion, which can be ameliorated with demand flexibility. *"The additional EV demand (kWh) can be handled with the existing grid capacity. The impact on peak demand (kW) is more critical, which happens in case of simultaneous power demand,"* according to EDSO.

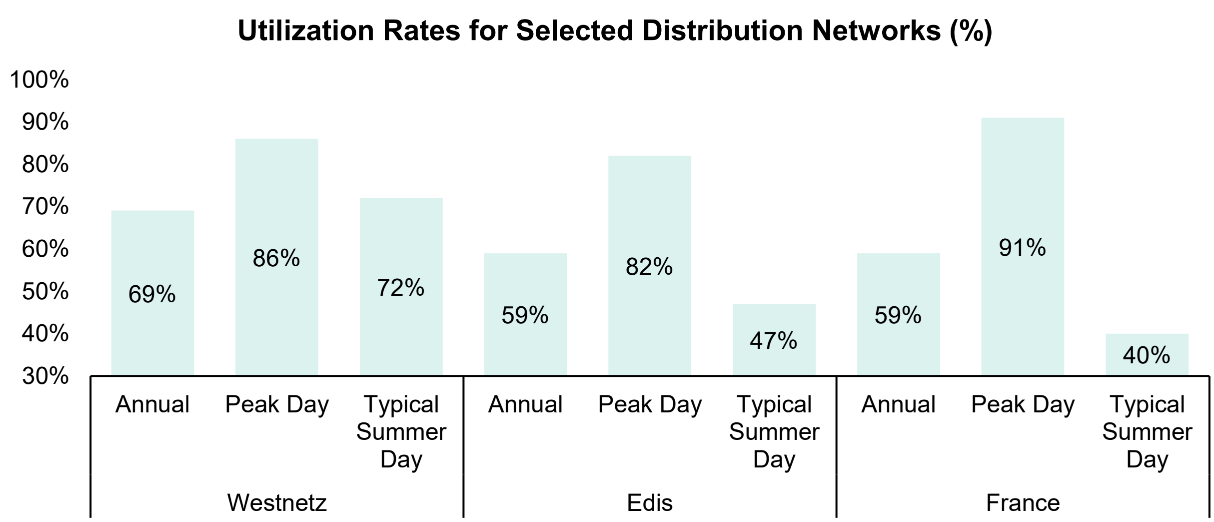
Other studies concur with these findings. The Regulatory Assistance Project argues that if all European PVs were converted to EVs today, the resulting ~20% increase in electricity demand would be substantial but theoretically manageable by the existing electricity grid. Basing its study on France and the Westnetz and Edis distribution grids in Germany, it found that annual utilization is low at between ~60% and ~70% on an annual basis (see Exhibit 392). Utilization rate was defined in the study as the *"ratio of actual versus the maximum power flow over a network over a specified period."*

EXHIBIT 391: **Electric mobility could account for ~8% of total EU27+UK DSO investments over 2020-30**



Source: EDSO estimates (all data) and Bernstein analysis

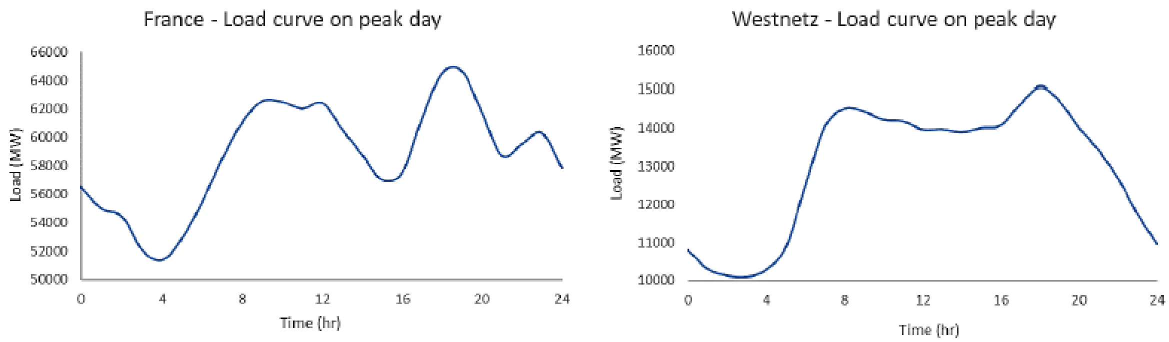
EXHIBIT 392: **Utilization rates imply capacity exists for EV charging**



Source: Regulatory Assistance Project data and Bernstein analysis

Furthermore, even on peak days with the highest grid utilization during the year, there is significant variability in loads, implying the possibility that more load could be added during off-peak hours. For instance, in France there was a 13GW differential between the highest and lowest load during the day (see Exhibit 393).

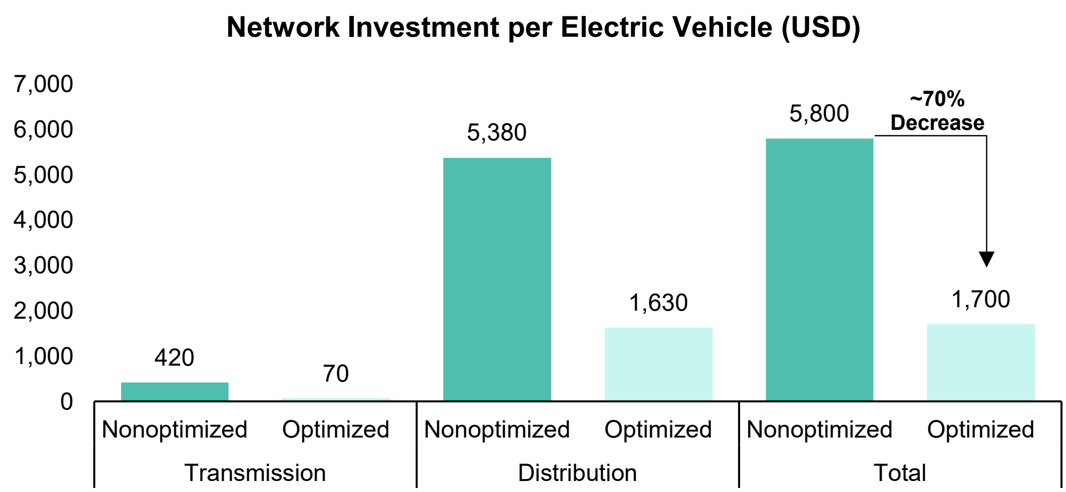
EXHIBIT 393: **Load curves on peak days for the French medium-voltage network and Westnetz's distribution network**



Source: Regulatory Assistance Project data

The quantum of networks investment reduced or deferred by smart charging is substantial. Boston Consulting Group estimates that under an optimized scenario with 50% of charging occurring during off-peak hours, and public and private charging infrastructure strategically located in areas with lower grid congestion, the overall cost of networks investment per EV could fall by ~70% (see Exhibit 394).

EXHIBIT 394: **Network investment costs could decline by ~70% per EV if optimized charging is used**



Source: Boston Consulting Group estimates and Bernstein analysis

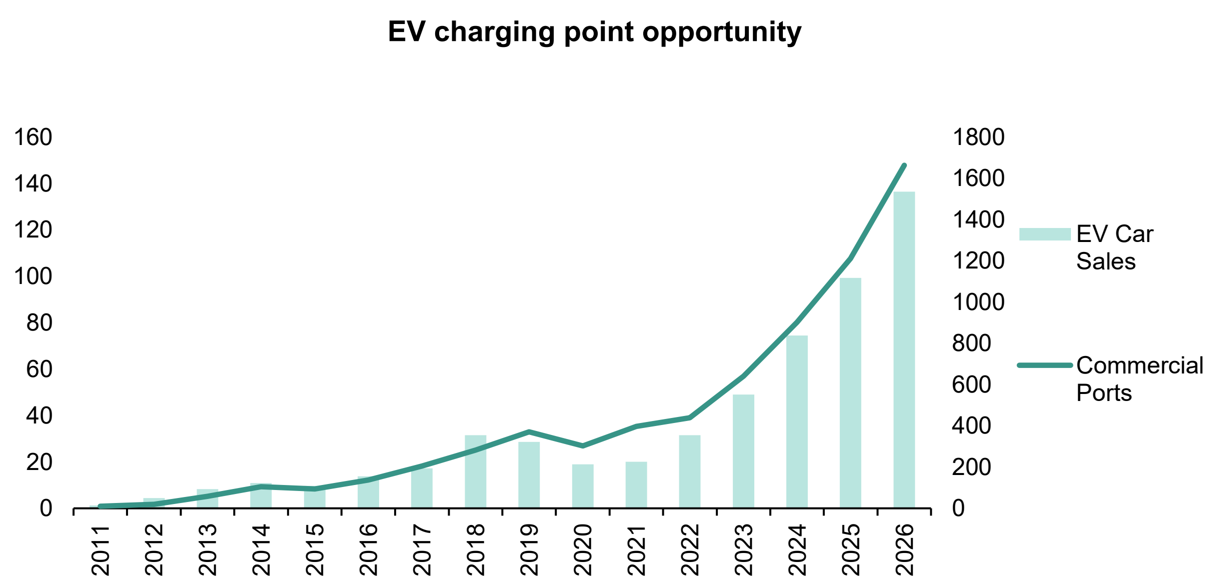
That being said, there will be large differences in investment need from one distribution network to the next, implying that the need for investments will be on a network by network basis. The Clean Energy Ministerial's 2020 report argues that countries like France and Sweden, which have already reinforced their grids to meet peak winter electrical heating demand, may have more spare grid capacity to integrate EV demand. In contrast, *"countries reliant on gas networks for heating (e.g., the United Kingdom and the Netherlands), distribution networks may not be designed for such high electricity loads locally."*

EDSO's original 2018 position paper on EVs argued that the potential for conventional grid investments will largely be in areas with aging grids and which already need reinforcement. *"However, conventional grid investments can still remain a viable option for certain LV networks that might anyways need reinforcements even without considering the uptake of electric vehicles (weaker rural networks or urban networks in the oldest districts of cities which were electrified first)."* In 2021, it released a new paper on smart grids, which largely re-affirmed its view that load flexibility could minimize investment needs, albeit with the caveat that there *"is still uncertainty about its potential impact"* which *"will depend on the development of regulation and markets."*

CHARGING AS A SERVICE — HOW WILL UTILITIES MAKE MONEY?

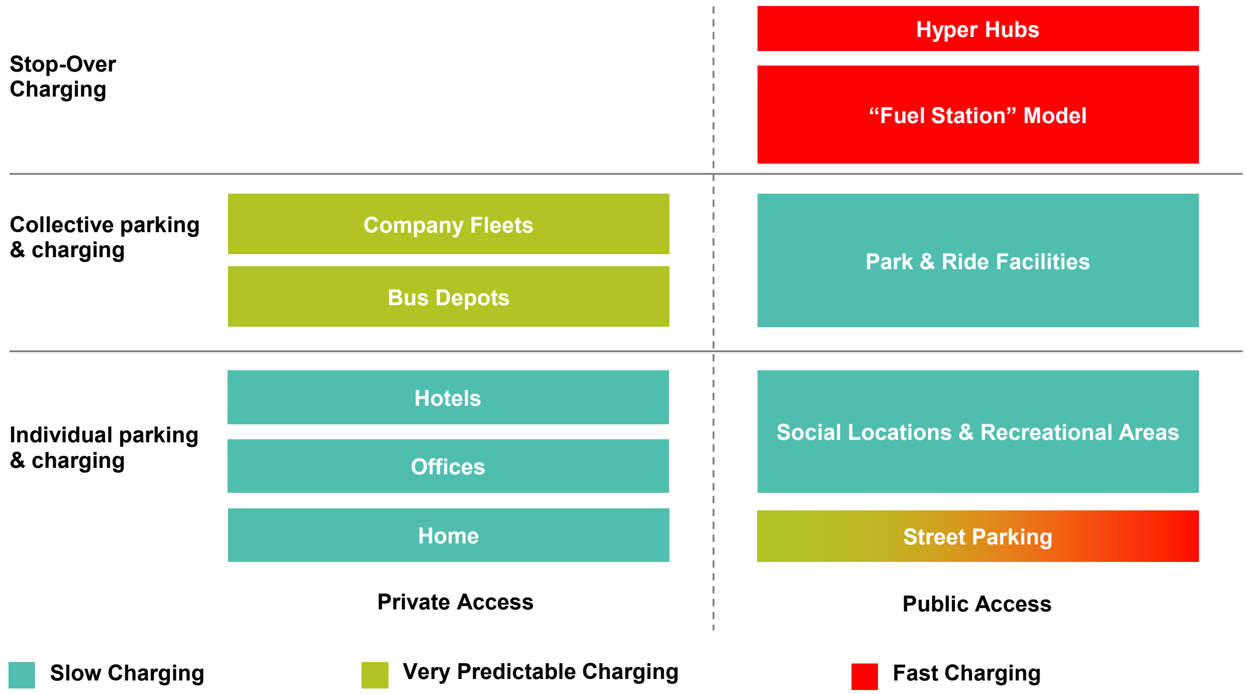
The increasing penetration of EVs will drive the growth of the EV charger market and related services. ChargePoint expects EV charging infrastructure growth to track closely the growth path of EV car sales (see Exhibit 395) across the three main applications of individual parking and charging, collective parking and charging, and stop-over charging (see Exhibit 396).

EXHIBIT 395: **Growth of the EV charging opportunity**



Source: ChargePoint data and estimates (2021+) and Bernstein analysis

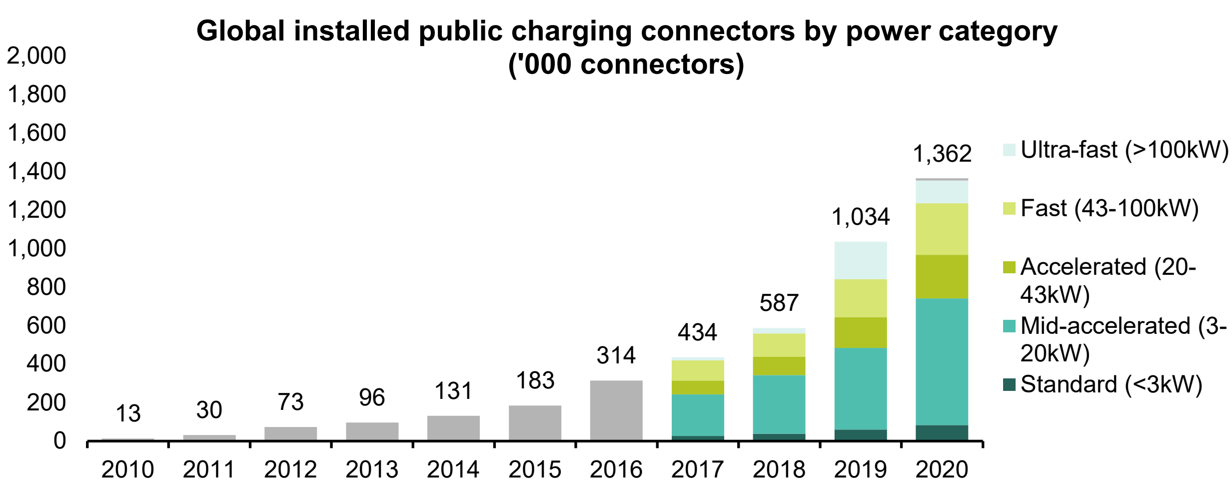
EXHIBIT 396: **Charging technologies by type**



Source: ENTSO-E and Bernstein analysis

This represents exponential growth from a very small base; EV chargers have grown by more than 100x over the past decade, but there are still only ~1.4 million EV chargers in service today (see Exhibit 397). Growth remains strong, and EV chargers grew 48% over 2019-20.

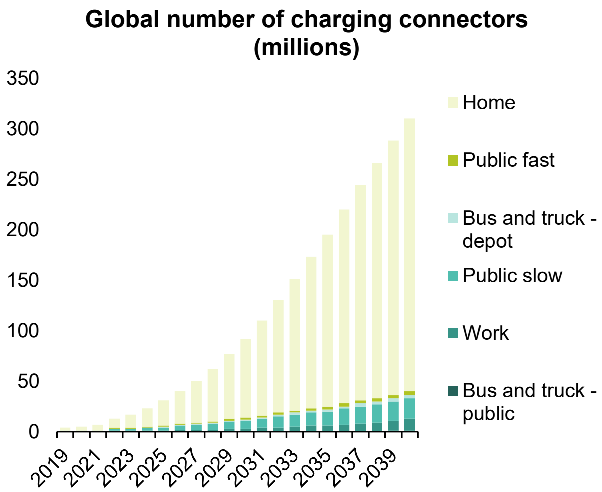
EXHIBIT 397: **Global installed public charging connectors are increasing at an exponential pace**



Source: BNEF and Bernstein analysis

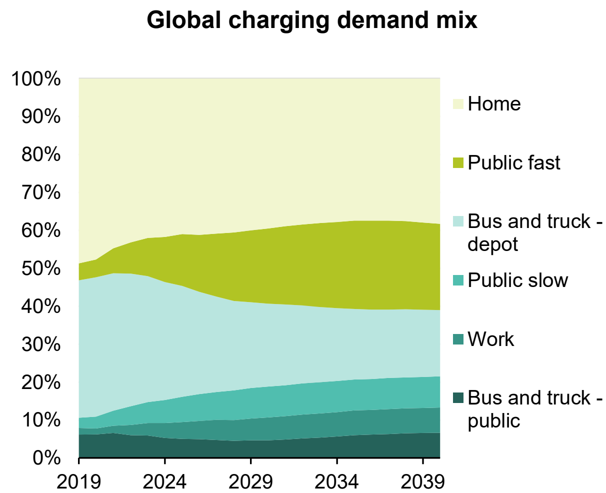
Global chargers are expected to increase to ~310 million by 2040E (see Exhibit 398), with home chargers representing the vast majority of connectors. In terms of charging demand, home charging is expected to represent ~38% of EV charging demand by 2040E as a result of an increasing trend toward public charging, which could grow to ~31% of total charging power demand by 2040E (see Exhibit 399).

EXHIBIT 398: **Global chargers could increase to ~310 million by 2040E**



Source: BNEF data and estimates (2021+) and Bernstein analysis

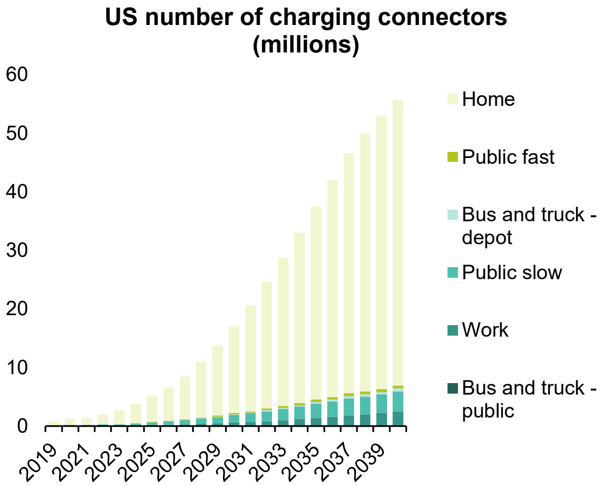
EXHIBIT 399: **Home charging will account for ~38% of EV charging demand by 2040E**



Source: BNEF data and estimates (2021+) and Bernstein analysis

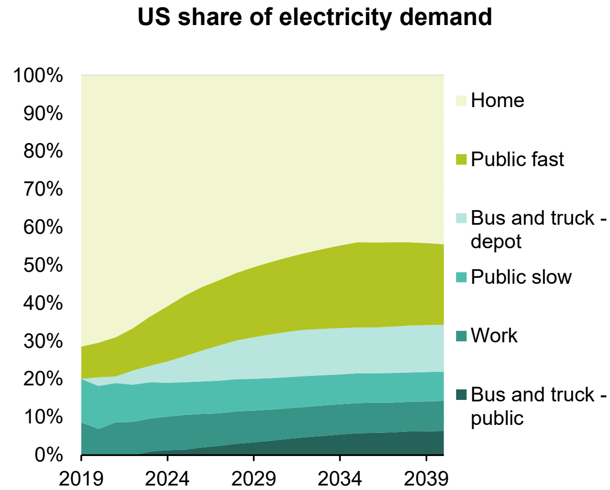
In the US, chargers could increase to ~57 million by 2040 (see Exhibit 400) and home charging demand could account for ~44% of total demand by 2050 (see Exhibit 401). BNEF expects the rise of *"autonomous vehicles from 2035 (to) quickly eat into the demand from shared and private vehicles"* and these vehicles could potentially rely more heavily on a network of public chargers needs. Fast public chargers could account for 21% of charging demand, while slow public chargers could account for a further 8%. For buses and trucks, most charging will likely occur at the depot initially (~12% of 2040E demand), although usage may shift toward public chargers as vehicle range improves (~6% of 2040E demand).

EXHIBIT 400: **Chargers could increase to ~57 million by 2040**



Source: BNEF data and estimates (2021+), and Bernstein analysis

EXHIBIT 401: **Home charging could account for ~44% of power demand by 2040**



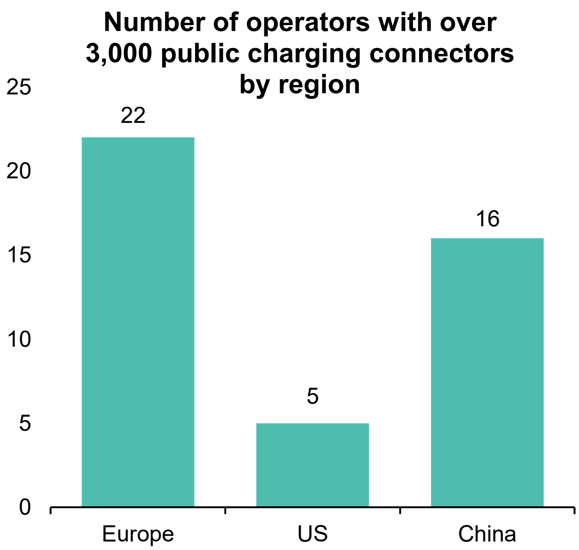
Source: BNEF data and estimates (2021+), and Bernstein analysis

COMPETITIVE LANDSCAPE OF THE EV CHARGING MARKET

The charging market is competitive in Europe with 22 companies counting 3,000 and more public charging connectors, with Germany, France, the Netherlands, and the UK leading in terms of charge points. The North American (US and Canada) market is much more consolidated with only five firms having more than 3,000 charging points (see Exhibit 402). If we consider only advanced fast-charging services, the number of large players in Europe shrinks from 22 to nine (see Exhibit 403).

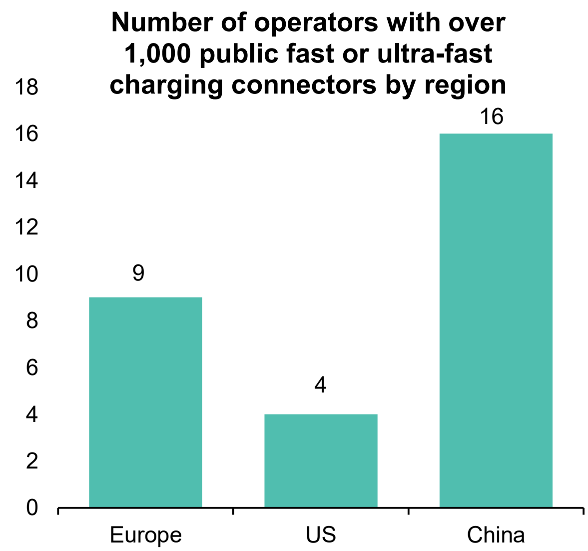
In terms of market share, the US is dominated by ChargePoint and Tesla, which together account for north of 60% of total market share; even the next largest player, SemaCharge, is 4x smaller than Tesla. By number, ChargePoint is by far the leader in North American public EV charging with 41,539 chargers (see Exhibit 405). Tesla is about half the size of ChargePoint with 20,860 chargers. However, half of Tesla's public EV charger stock is either fast or ultra-fast (43kW or greater) ,making the firm the largest fast-charging player by far in the US (see Exhibit 404).

EXHIBIT 402: **Large players by region**



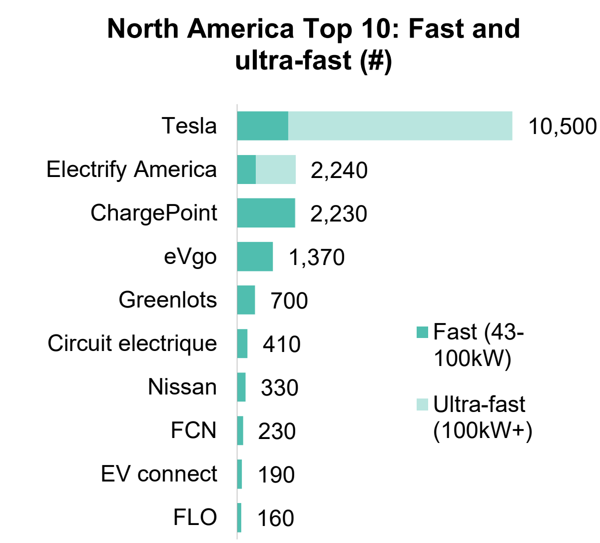
Source: BNEF data and Bernstein analysis

EXHIBIT 403: **Large fast-charging players by region**



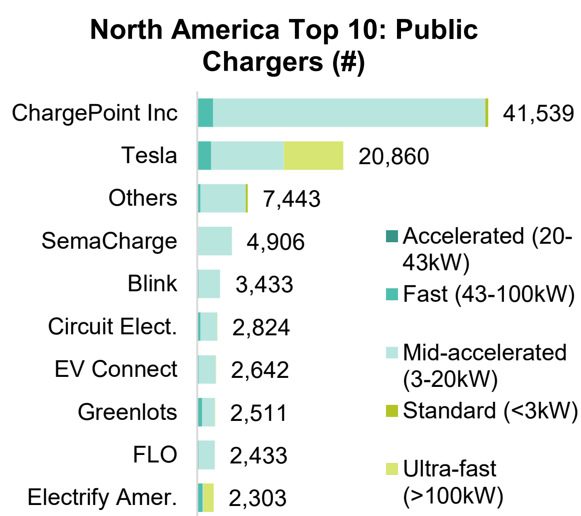
Source: BNEF data and Bernstein analysis

EXHIBIT 404: **Top 10 North American fast charging players**



Source: BNEF data and Bernstein analysis

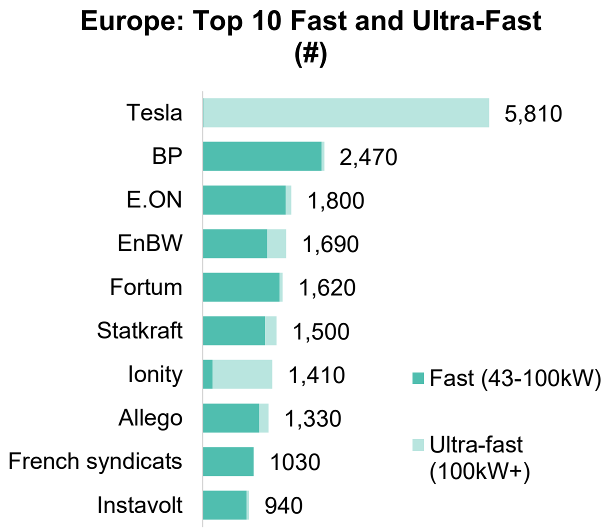
EXHIBIT 405: **Top 10 North American public charging players**



Source: BNEF data and Bernstein analysis

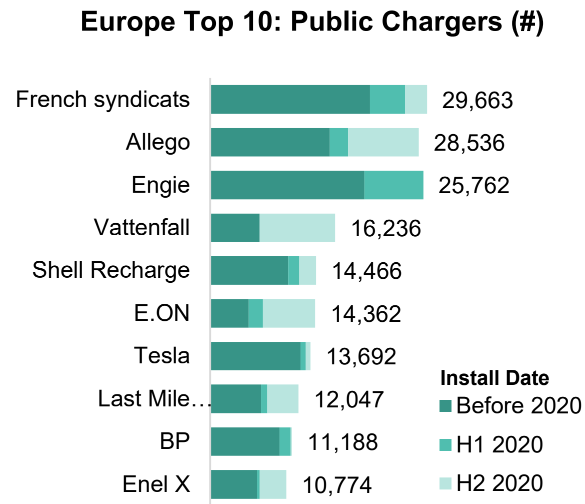
In Europe, the top 10 players include a French municipal syndicate, four utility companies, two pureplay operators, two oil & gas companies, and one automaker (see Exhibit 407). The top three public charging players are French syndicates (local authorities), Allego, and Engie/EVBox, which have a combined share of 24% in the public charging market. That being said, these firms largely utilize slow chargers and for the top 2 players (French syndicates and Allego), fast chargers only account for 4% of total EV charging stock (see Exhibit 409). Tesla remains the largest player in Europe for fast charging (see Exhibit 406).

EXHIBIT 406: **Tesla is top dog in European fast and ultra-fast charging**



Source: BNEF data and Bernstein analysis

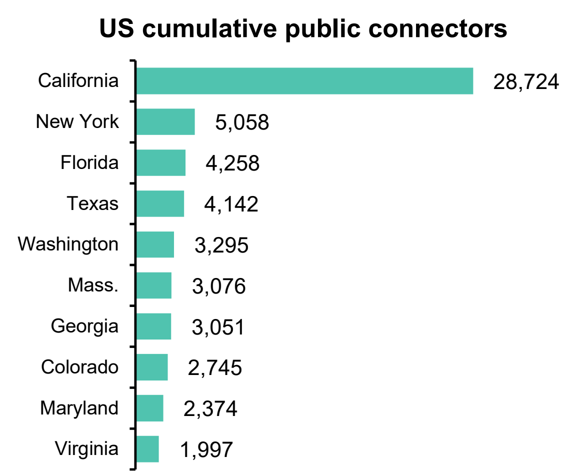
EXHIBIT 407: **French and Dutch companies, and local authorities dominate the top three spots**



Source: BNEF data and Bernstein analysis

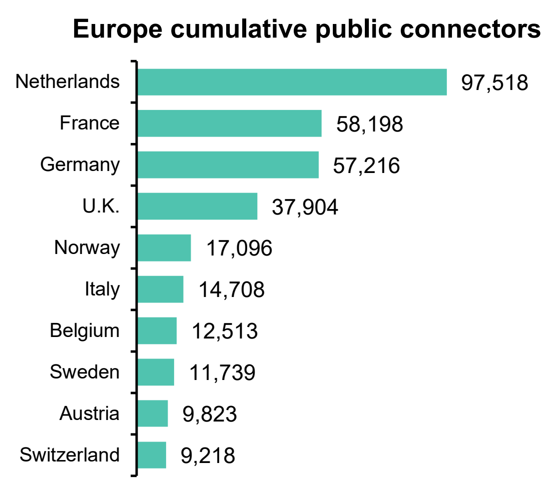
We break down the largest EV charging markets by existing infrastructure in the US (see Exhibit 408) and Europe (see Exhibit 409). In the US, California is by far the largest market and almost 6x larger than next largest market New York, reflecting the state's strong green credentials and ambitious targets of 1.5 million EVs by 2025 and all vehicles sold in the state to be net zero by 2035. In Europe, the Netherlands is the largest market and also has one of the most rapid ICE phaseout plans, with all new PVs to be zero-emission from 2030. France is the next largest market and has set concrete targets of 660,000 passenger BEVs by 2023 and 3 million passenger BEVs by 2028.

EXHIBIT 408: **California is by far the largest EV charging market in the US**



Source: BNEF data and Bernstein analysis

EXHIBIT 409: **The Netherlands and France are early EV charging adopters**



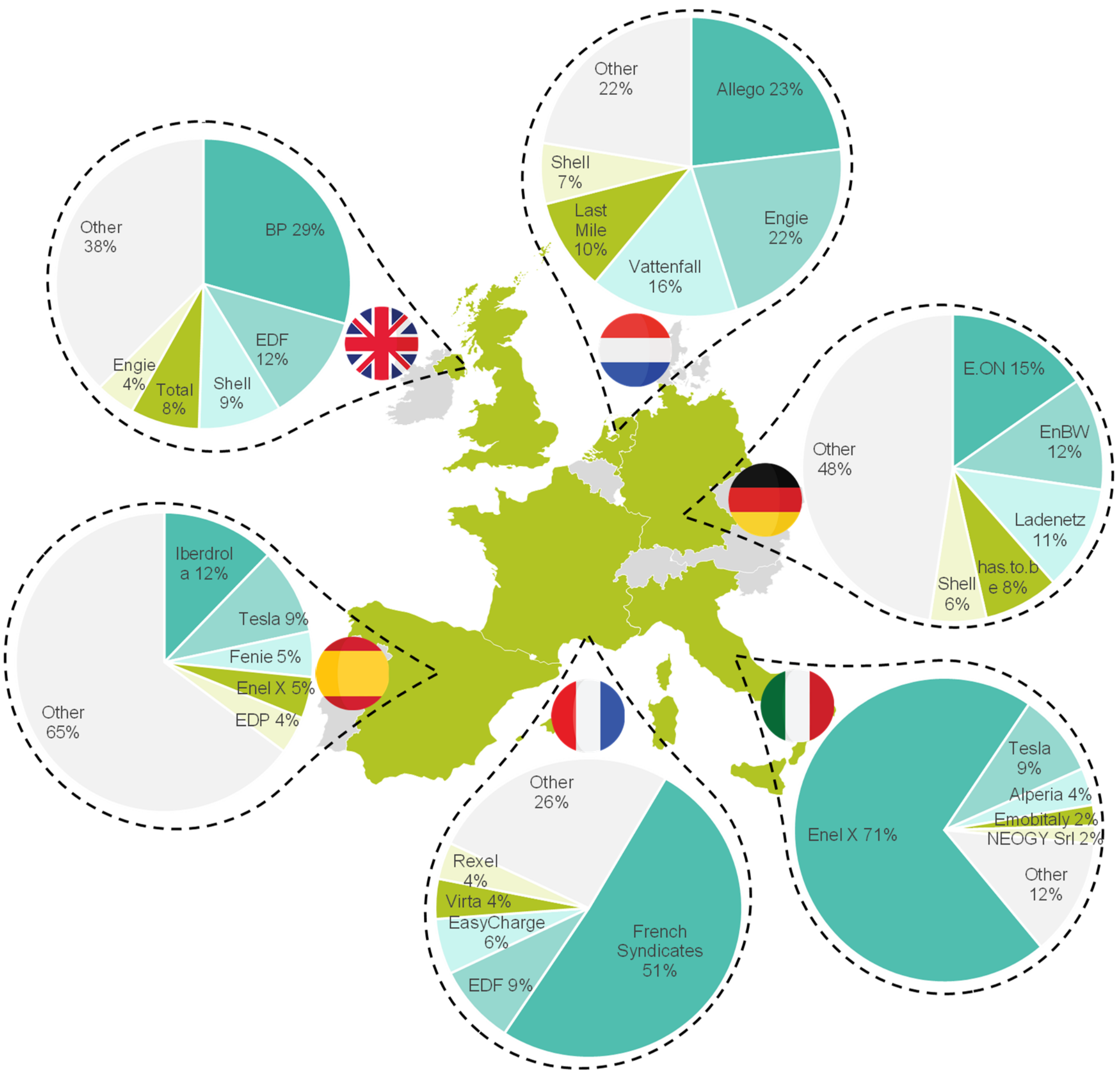
Source: BNEF data and Bernstein analysis

A country by country look reveals that European utilities have stayed close to home and are deploying charging infrastructure in countries where the companies also have other generation, network, or retail business (see Exhibit 410).

Italy is by far the most concentrated market, with Enel X the dominant player at 71% market share. This is followed by France, where local authorities account for 51% and the next largest player EDF accounts for 9%. The largest market, the Netherlands, has three main players Allego, Engie, and Vattenfall accounting for 61% of market share. Spain is fragmented, reflecting its nascent stage and smaller size with only ~8,000 public chargers today (compared to more than 97,000 in the Netherlands).

In the UK, BP, EDF, Shell, and Total account for 58% of the market, whereas in Germany the top spots go to E.ON, EnBW, and Ladenetz.

EXHIBIT 410: **Top five charging infrastructure players by country**



Note: Image credits — FlatIcon, RoundIcons, and PresentationGo.com

Source: BNEF data and Bernstein analysis

Utilities companies view EV charging to be an opportunity and a good fit for their supply segments, given their already existing customer base, installed power generation capacity, and network experience. We highlight targets from companies under our coverage and selected pureplays in Exhibit 411.

EXHIBIT 411: **Overview of EV charging targets for companies in our coverage and selected pureplays**

Company	Target	EV ($mn)
enel x	4 million charging points installed by 2030 (vs 175k in 2020)	
EDF	75,000 public chargers installed in Europe by 2022	
IBERDROLA	150,000 chargers by 2025 (Mainly in Spain)	
edp	40,000 chargers in Iberia by 2025	
ENGIE	1 million cumulative EVBox (subsidiary) charge ports shipped by 2023	**969** *(EVBox proposed SPAC Deal)*
e.on Drive	>36,000 chargers at present	
Fortum charge & drive	Owns 1,300 public charging points and operates an additional 1,400 charging points in Norway, Finland, and Sweden	
Volta (Not Covered by Bernstein)	>26,000 cumulative chargers by 2025	**~430**
ChargePoint (Not Covered by Bernstein)	Annual sales of ~425,000 chargers by 2026	**~9,500**

Source: Bloomberg EV data, company reports, and Bernstein analysis

Engie

Engie launched EV Solutions in November 2019 following the acquisition of ChargePoint Services Ltd, which has largely focused on the UK market to date. GeniePoint provides end-to-end solutions for charging, including hardware and backoffice software through its GeniePoint Network. GeniePoint, the charging point network of EV Solutions, is fully integrated with ENGI power supply to ensure it is from 100% renewable resources. Its charging network includes sites such as filling stations, supermarkets, workplaces, and public carparks. Engie's other activities include an Italian V2G project in partnership with Terna, developing new capacity at a logistics area, where V2G connections were built between the grid and a company fleet. The user can pay for the electricity with the GeniePoint App or an RFID card in advance.

Engie has a strong presence in charging point hardware through its subsidiary, EVBox, which it acquired in 2017. EVBox built the largest installed base of EV charging solutions, with more than 190,000 charge ports across 70 countries and is a leader in Europe. Its customers include fleet managers, utilities, CPOs, fuel/charging service providers, workplace/hospitality, and automotive companies. Engie is currently arranging a spin-off of EVBox.

Enel X

Enel X provides home and office EV charging station hardware (JuiceBox) and software (JuiceNet). It has a 12.5% stake in the JV Hubject, the world's largest cross-provider charging network, with over 270,000 EV charging points. Enel X is the only EVSE provider participating in wholesale energy markets and offers charging solutions to aggregate and manage EV load to maintain grid reliability. The firm created a 30MW virtual power plant in California through its subsidiary eMotorWorks in 2017. During the heat wave in August 2020 in California, Enel X provided 150MW-200MW of flexible load to grid from demand response customers and EV chargers.

EDP

EDP partnered with chargetrip to develop a routing engine that calculates the best route to a user's destination. EDP Commercial in March 2021 launched the EDP Electric Mobility card. EDP aims to reach 1,000 charging stations commissioned in 2021, and as of May 2021 has 900 commissioned and 500 operational. Charge points could grow to 40,000 by 2025. EDP also has a partnership with McDonald's in Portugal to install 100 fast charging points by the end of the year.

Iberdrola

Iberdrola has targeted 150,000 charge points in homes, companies, and on the public road network in cities by 2025. The firm is also investing in roadside ultrafast chargers and recently bought 1,000 fast chargers from Wallbox. The company aims to be able to provide ultra-rapid (350kW) charging stations every 200km, super-rapid (150kW) every 100km, and rapid (50kW), every 50km.

NextEra

NextEra's acquisition of eIQ Mobility in December 2020 highlights the firm's increased interest in e-mobility. eIQ is a leading provider of mobility planning solutions, which provides fleet and energy analytics with regard to optimal EVs and charging infrastructure use. According to eIQ, *"By joining NextEra Energy Resources, the eIQ Mobility platform and team will provide fleets a one-stop electrification solution, from vehicle selection and conversion planning, to the design and operation of resilient charging depots supported by clean energy."* NextEra also intends to utilize its push into energy storage as a differentiating factor and to provide energy storage planning services to clients. NextEra CFO Rebecca Kujwa recently commented that *"We believe that some of the real value-add that we are going to be able to provide to customers — that will differentiate us from the competition — is battery system management. This management system and optimization is going to be part of the secret sauce of our batteries."*

E.ON

With more than 36,000 charging points worldwide (mainly in Europe and the US), E.ON's EV charging unit E.ON Drive is one of the biggest charging network operators in Europe. Of these, 170 charging stations have an output of 50kW AC, which has a charging time of about an hour and E.ON's ultra-fast DC charging stations have a charging time of significantly less than half an hour. In Europe, E.ON Drive operates in 11 countries with strong market positions in Sweden, Germany, and Denmark and a growing position in Eastern Europe. E.ON also offers EV customers dedicated pricing plans. For example, in the UK, E.ON's Next Drive pricing plan for EV drivers, offers 100% renewable electricity and cheaper overnight charging. The tariff allows drivers to charge cars at a fixed price of 4p per kWh between midnight and 4am, potentially saving customers up to £188 a year. Outside off-peak hours, Next Drive is priced at 17.6p per kWh. Customers can use the free Next Drive app to "set it and forget it" and automatically schedule charging at the cheapest off-peak times and use the app to monitor energy use, costs, and savings of their at-home charging over time.

Fortum

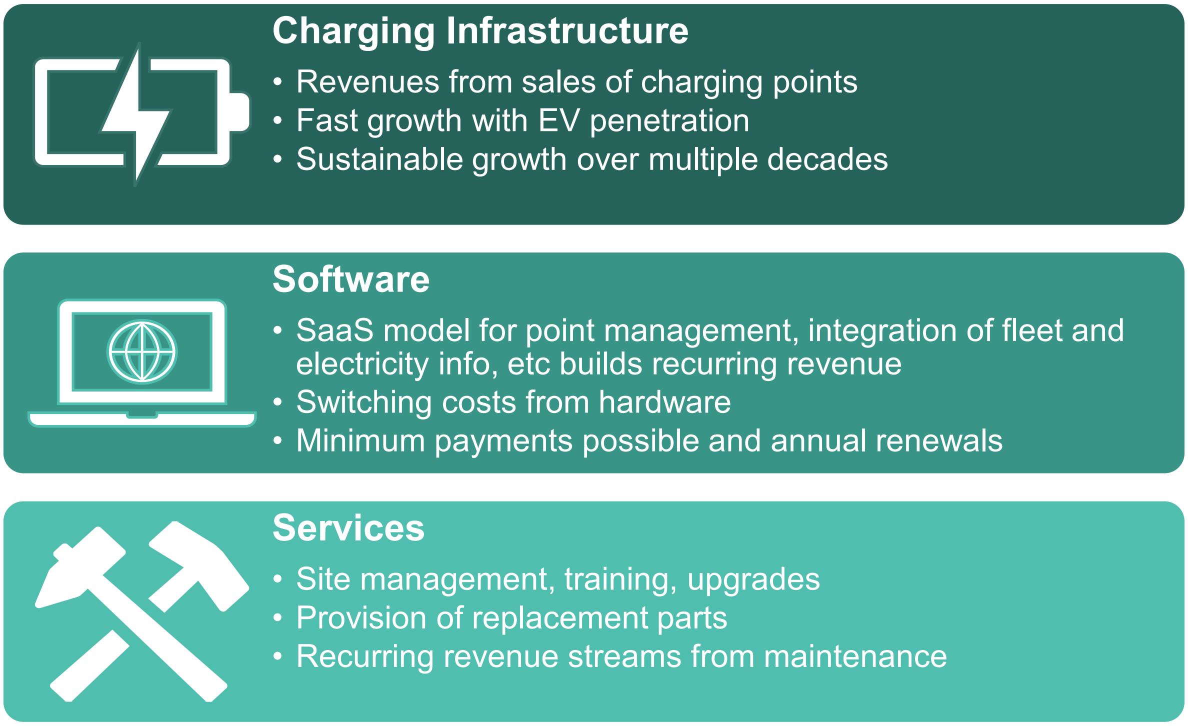
Fortum's EV charging unit, Fortum Recharge AS, owns 1,300 public charging points and operates an additional 1,400 charging points in Norway, Finland, and Sweden. Recharge is the largest charging point operator in the Nordics. In April 2020, Fortum sold a stake in Recharge to Infracapital, the infrastructure equity investment arm of M&G Plc, in order to grow speed-up charging infrastructure development and growth. After the transaction, Fortum's ownership in Recharge will be 37%. Fortum will continue to own and offer its leading mobility services for digital public charging, as well as home and destination charging services under its Charge&Drive and Plugsurfing brands. Fortum further continues to offer software as a service (SaaS) for operating electrical vehicles (EV) charging infrastructure networks and customer interfaces to other charging point operators.

HOW CAN UTILITIES MAKE MONEY IN EV CHARGING?

We summarize Engie's EVBox and ChargePoint's business models. EVBox and ChargePoint's core offering is the charging hardware and this is being complemented with a software and service package for different application and client segments such as home, commercial, and fleet (see Exhibit 412).

We highlight ChargePoint's product offering in Exhibit 413. The firm has positioned many of its software offerings, such as energy management and vehicle scheduling for commercial fleets, as SaaS to build recurring revenue streams. Subscriptions on an annual basis with software tied to ChargePoint's charging stations further builds customer stickiness.

EXHIBIT 412: **Possible revenue streams from EV charging**



Source: Bernstein analysis

EXHIBIT 413: **ChargePoint's product offering**

Source: ChargePoint

In Europe, EVBox has a similar approach, offering a full ecosystem of products and services customized for commercial and residential needs (see Exhibit 414). Many software services such as charging management platforms build recurring revenue.

EXHIBIT 414: **EVBox's product offering**

Source: EVBox

Charging points have become an established and profitable business model and Exhibit 415 and Exhibit 416 illustrate typical EV charger projects by EVgo. California projects receive incentives for EV charger purchases. In the state, typical projects would be 2,100kW or 4,175kW chargers where EVgo achieves a 35%+ unlevered IRR over seven years with a payback period of ~2.5 years. In other US states, typical projects of 2,100kW or 2,350kW chargers achieve ~30% unlevered IRRs over seven years and ~3.5 years payback period. EVgo believes that these IRRs are conservative because it believes that useful life of a charger is 10 years.

EXHIBIT 415: **Typical California project**

California Project	Year 0	Year 1 ►	Year 7
kWh Dispensed		155	705
Utilization		8.9%	22.9%
Revenue		**265**	**470**
OpEx		(180)	(290)
EBITDA		**85**	**180**
Net Capex	(260)		
Annual Cash Flow	(260)	85	180
Payback period		**2.5 years**	

Source: EVgo data and estimates (all data), and Bernstein analysis

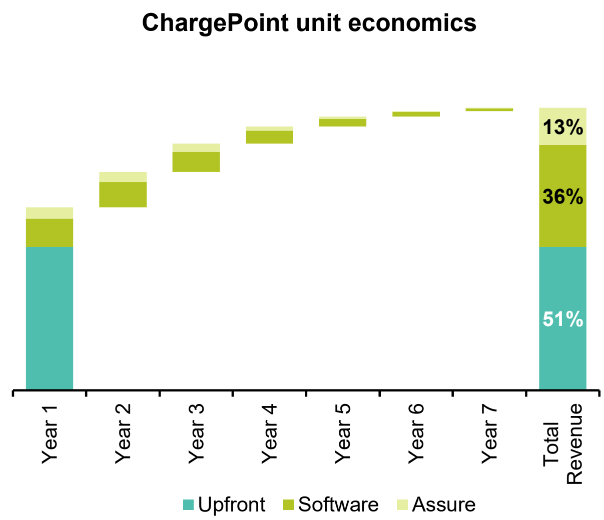
EXHIBIT 416: **Typical non-California US project**

Non-California Project	Year 0	Year 1 ►	Year 7
kWh Dispensed		145	545
Utilization		11.1%	23.7%
Revenue		**70**	**245**
OpEx	(10)	(50)	(95)
EBITDA	**(10)**	**20**	**150**
Net Capex	(165)		
Annual Cash Flow	(175)	20	150
Payback period		**3.5 years**	

Source: EVgo data and estimates (all data), and Bernstein analysis

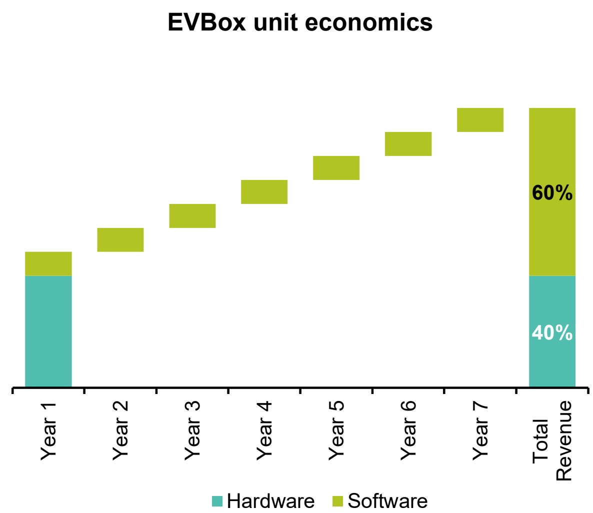
Exhibit 417 and Exhibit 418 illustrate the breakdown in revenues for typical EV chargers. Between ~40% and ~51% of an EV charger's revenue represents upfront costs for purchase of the charging point. The remaining 50-60% of revenue is recurring and comes from a combination of software sales, services (such as maintenance), and insurance.

EXHIBIT 417: **Upfront revenue is ~51% of total revenue**



Source: ChargePoint data and estimates, and Bernstein analysis

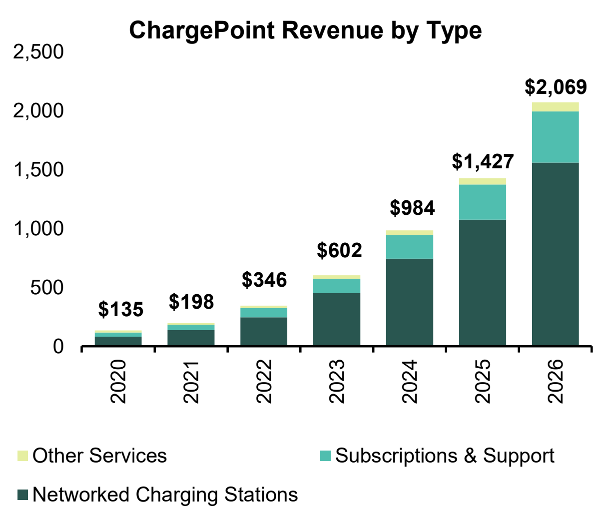
EXHIBIT 418: **Hardware revenue is ~40% of total revenue**



Source: EVBox data and estimates, and Bernstein analysis

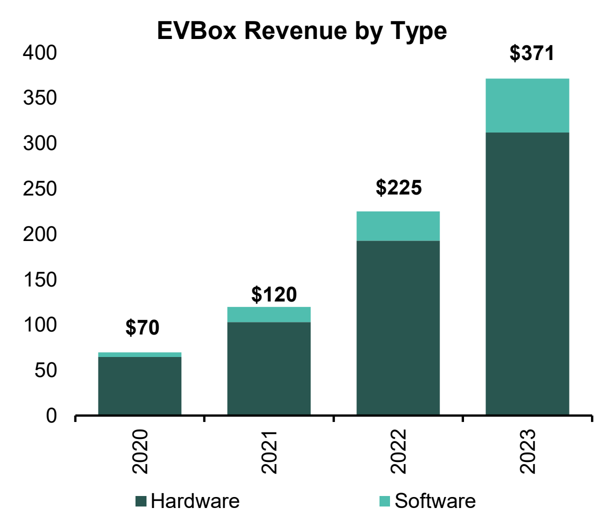
Revenue growth will be driven by charging point shipments/installations and complemented by subscription and support services (see Exhibit 419 and Exhibit 420).

EXHIBIT 419: **Recurring revenue is a growing share for ChargePoint...**



Source: ChargePoint data and estimates (2021+) , and Bernstein analysis

EXHIBIT 420: **...and for EVBox**



Source: EVBox data and estimates (2021+), and Bernstein analysis

Exhibit 421 and Exhibit 422 illustrate Chargepoint and EVBox's anticipated path to EBITDA breakeven.

EXHIBIT 421: **ChargePoint's expected financials**

ChargePoint	2020	2021	2022	2023	2024	2025	2026
Revenue	**135**	**198**	**346**	**602**	**984**	**1427**	**2069**
YoY Growth		46.7%	74.7%	74.0%	63.5%	45.0%	45.0%
Gross Profit	**33**	**62**	**124**	**225**	**400**	**591**	**878**
Gross Margin	24.4%	31.3%	35.8%	37.4%	40.7%	41.4%	42.4%
Total Operating expenses	**150**	**192**	**226**	**268**	**321**	**417**	**542**
Adjusted EBITDA	**(107)**	**(121)**	**(93)**	**(36)**	**86**	**178**	**340**
Adjusted EBITDA Margin	-79.3%	-61.1%	-26.9%	-6.0%	8.7%	12.5%	16.4%

Source: ChargePoint data and estimates (2021+), and Bernstein analysis

EXHIBIT 422: **EVBox's expected financials**

EVBox	2020	2021	2022	2023
Revenue	**70**	**120**	**225**	**372**
YoY Growth		71.4%	87.5%	65.3%
Gross Profit	**17**	**38**	**82**	**140**
Gross Margin	24.3%	31.7%	36.4%	37.6%
Total Operating expenses		**118**	**127**	**138**
Adjusted EBITDA		**(80)**	**(45)**	**2**
Adjusted EBITDA Margin		-66.7%	-20.0%	0.5%

Source: EVBox data and estimates (2021+), and Bernstein analysis

INVESTMENT IMPLICATIONS

The wind and the sun are the fuels of the 21st century, carried by electricity and hydrogen. This puts the electric power and renewables sector at the center of 21st century energy with a plethora of opportunities including renewables, electricity networks, and EV charging.

Companies exposed to renewables in our coverage include NextEra, Enel, EDP/R, Iberdrola, Engie, EDF, Ørsted, RWE, SSE, and Longyuan (all rated Outperform), and Endesa (rated Market-Perform).

Our coverage companies in the renewables supply chain poised to benefit from the electric revolution include those in the wind supply chain — Siemens Gamesa, Vestas, and Goldwind — and those in the solar supply chain — LONGi Green, Zhonghuan, and Daqo New Energy (all rated Outperform).

Companies with meaningful exposure to electricity distribution networks in our coverage include NextEra, Enel, EDP/R, Iberdrola, EDF, E.ON, National Grid, and SSE (all rated Outperform), and Endesa (rated Market-Perform).

The companies involved in EV charging infrastructure with some scale are NextEra, Enel, EDP/R, Iberdrola, EDF, and E.ON (all rated Outperform), and Fortum (rated Underperform).

GREEN IS GOOD; SMART GREEN EVEN BETTER (PART 2): DEEP-DIVE INTO GRID INFRASTRUCTURE BACKBONE

OVERVIEW

- **EV policy momentum continues to build:** In response to rising societal concerns on the impact of climate change, a number of countries/regions have put forward ambitious net-zero targets, which cover 51-62% of global emissions. Many countries have also announced an outright ban on the sale of ICE cars at a certain point.

- **Infrastructure enablers — public charging and grid backbone:** The two main infrastructure investments to enable EV rollout are a public charging network and upgrades to the electricity distribution grid to cope with the rise in peak charging demand. Across surveys, charging infrastructure is a top 3 concern for consumers as well as fleet owners, along with cost and range. As decarbonization ambitions continue to be tightened, the speed of infrastructure buildout will need to increase.

- **Public charging network, including fast chargers has been growing:** Although slow chargers still represent 88% of all public charging points in Europe, fast charging has grown much faster at a 137% CAGR since 2011. Globally, 1.3 million public chargers were deployed by 2020, of which 30% were fast chargers. We forecast the investment in public charging infrastructure of ~€90bn by 2050 to support mass EV rollout in Europe.

- **Grid impact and investments:** We expect electricity demand to increase by 25% when the entire car fleet is electric in Europe by 2050 and a further 5% by 2030. This impact is manageable, but will require grid upgrades to overcome thermal and voltage limitations in local grids. Fast and ultrafast charging networks will also need some dedicated infrastructure. By 2030, distribution grids in the EU-27+UK will likely require €25-€35bn (7-8% of overall spend) for integrating EVs. By 2050, we estimate distribution grid investments for EV integration to be €100-€185bn in Europe. Experts and network operators believe the grid would need to be strengthened when EV penetration reaches 15-30%, but the impact after this point could be non-linear. However, the costs of over-sizing network infrastructure are very low, as cable capacity accounts for just 8-10% of upgrade costs; over-sizing network infrastructure is a very low-regrets option.

- **EVs also present an opportunity for the grid, and upgrades requirements can be minimized through smart charging and Vehicle 2 Grid (V2G):** Smart charging systems (V1G) connect to the grid, and control charging rates and schedules to benefit the grid (and the user) by moving demand to off-peak/high renewables output hours.

Furthermore, bi-directional V2G charging can enhance these advantages by using the vehicle battery to supply power back to the grid. A recent real-world V2G trial in the UK has shown proven monetary benefits to EV customers as well as contributed to grid balancing.

DEEP DIVE ON GRID INFRASTRUCTURE BACKBONE

In this chapter, we deep dive into the infrastructure backbone (public charging and grids) required to support the electric revolution. In the previous chapter, "Electric Revolution: Green Is Good; Smart Green Even Better (Part 1): Opportunities For Utilities & Renewables," we looked at the implications of electrification broadly and EVs specifically on the power sector.

THE POLICY PUSH ON DECARBONIZATION IS ACCELERATING, INCLUDING SUPPORT FOR THE BAN OF ICE VEHICLES

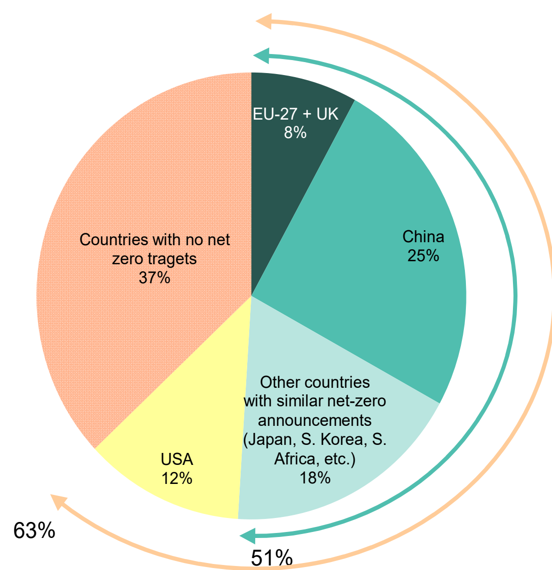
To limit global warming to 1.5°C, global emissions would need to fall by 45% from 2010 levels by 2030, reaching "net zero" by around 2050. In response to rising societal concerns on the impact of climate change, a number of countries/regions (see Exhibit 423) have put forward ambitious net-zero targets by 2050 or earlier, in line with the IPCC 1.5°C mitigation pathway. These international pledges cover 51-62% of global emissions (see Exhibit 424). With growing concern and acknowledgement of the issue at hand, along with a widening consensus that current pledges are likely to fall short of having an adequate impact, we expect further policy commitments will be made by various countries as part of the UN International Climate Conference — COP 26 in November 2021.

EXHIBIT 423: **Emerging net-zero commitments around the world**

Country/Region targets	Date to achieve target by	Formality
Net Zero targets adopted		
New Zealand	2050	Legislation
New York	2050	Executive order
UK	2050	Legislation
France	2050	Legislation
California	2045	Executive order
Sweden	2045	Legislation
Denmark	2050	Legislation
Norway	2030	Binding Agreement
EU	2050	Legislation (EU Green Deal)
Net Zero targets proposed		
Canada	2050	Proposed legislation
Chile	2050	Proposed legislation
Fiji	2050	Proposed legislation
Net Zero targets being considered		
China	2060	
Japan	2050	
South Korea	2050	
South Africa	2050	
Iceland	2050	
Switzerland	2050	
USA	2050	
Costa Rica	2050	

Source: CCC Net-Zero publication, ECIU, and Bernstein analysis

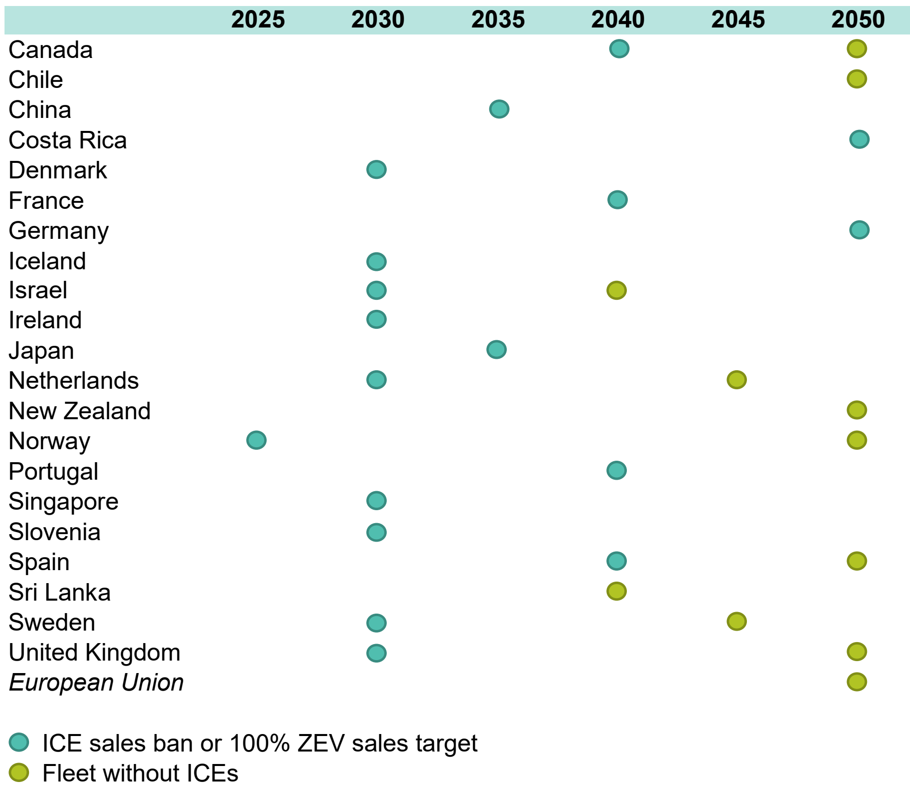
EXHIBIT 424: **Net-zero pledges cover 51-62% of global emissions**



Source: Climate Action Tracker and Bernstein analysis

In the context of reducing emissions of the transportation sector, many countries have announced an outright ban on the sale of ICE cars at a certain point or set a time line to achieve a fleet without ICEs (see Exhibit 425).

EXHIBIT 425: **Announced 100% zero emission vehicle (ZEV) sales targets and bans on ICE vehicles**



Source: IEA Global EV Outlook 2021 and Bernstein analysis

PUBLIC CHARGING INFRASTRUCTURE

The two main infrastructure investments that enable EV rollout are: (1) a public charging network and (2) upgrades to the electricity distribution grid to cope with the rise in demand from the electrification of transport. Additionally, personal chargers at home or work will also need to be installed. To the extent decarbonization ambitions are being tightened, the infrastructure buildout will need to happen faster. With the right policies to enable investments, the infrastructure rollout to support EVs would not be held back.

CHARGING INFRASTRUCTURE BASICS

In Exhibit 426, we show the classification of chargers by the speed of charging, assuming a 52kWh battery size. A normal single-phase AC charger with a power of <7.4kW will require more than seven hours to charge a 52kWh battery (Slow Charger), while a high-power DC charger with a power rating between 22kW and 50kW will require one to 2.4 hours (Fast Charger) and an ultra-high power DC charger with a >350kW power rating (Rapid Charger) will be able to charge a 52kWh battery in less than 10 minutes.

EXHIBIT 426: **Classification of chargers by speed of charging**

Category	Definition	Power (kW)	Time to get to full charge
1A	Normal single-phase AC	<7.4	>7 hours
1B	Rapid tri-phase AC	7.4 - 22	2.4 - 7 hours
2A	High power DC	22 - 50	1.0 - 2.4 hours
2B	High power DC	50 - 150	20 minutes - 1 hour
2C	Ultra-high power DC	150 - 350	10 - 20 minutes
2D	Ultra-high power DC	>=350	<10 minutes

Source: Eurelectric, Transport & Environment, and Bernstein analysis

There will be a place in the growing charger network for all types of chargers, depending on the use-case (see Exhibit 427). Family homes, residential locations, and workplaces are able to rely on slow, low-power charging (<22kW AC) as charging time is not a constraint. Chargers at "destinations" including business carparks and street parking can use low power charging as well as slightly faster AC and DC charging, while "on-the-go" chargers usually fall into two categories: slow street-side parking or public fast charging (up to 350kW DC) at retail stations. Lastly, commercial fleet owners may rely on all three types of charging, depending on their specific requirements. For revenue models associated with charging, refer to the previous chapter "Green Is Good; Smart Green Even Better (Part 1): Opportunities for Utilities & Renewables."

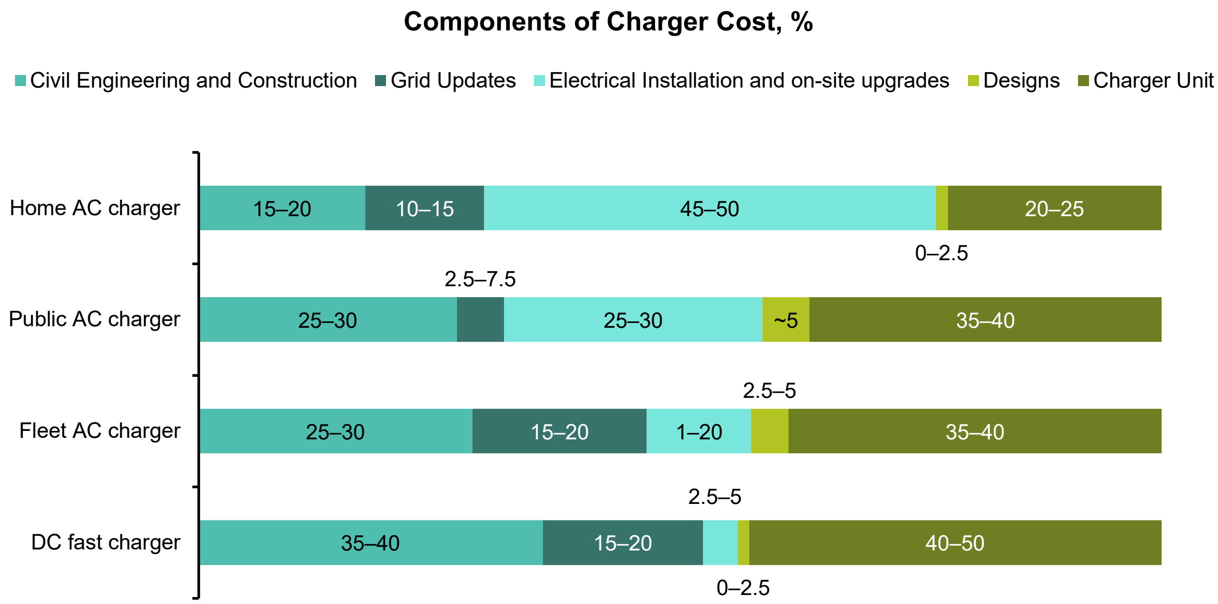
EXHIBIT 427: **Use-cases for EV charging, charging time, and infrastructure required**

Location	Single-family home Simple hardware offering for individuals; energy wholesale price but no markup	Multi-family home Simple offering with large volume potential; no/small markup	Workplace Midsize volumes with small B2B services markup, leading to stable cashflows	Destination Midsize to large volumes with medium energy-resale markup and dependent on utilization	On the go Midsize to large volumes with high resale markup but high required capex for DC chargers	Fleet depot Large volumes with stable cashflows; focus on services offered
Parking setup	Private	Private or shared	Shared	Public	Public	Private
Charging need	Multiple hours per day	Multiple hours per day	2-10 hours during work	<4 hours during visit	<1 hour on the go	Dependent on fleet management
Contractual party	End user	Real estate owner	Business owner	Business owner or municipality	Investor	Fleet Owner
Technology Required						
Wall box AC *(<22kW, 8-10hrs)*	●	●	●	●	●	●
Public slow AC/DC *(<22-50kW, 2-3hrs)*				●		●
Public fast *(50-350kW, <1hr)*					●	●

Source: McKinsey and Bernstein analysis

Depending on the type and use-case, the investment required to install a new charger can vary dramatically, from as low as US$400-US$1,000 for a low-power AC home charger, to US$2,400-US$5,000 for public AC chargers, to over US$30,000 for 50-150kW DC fast chargers. Of this, the charger unit itself can represent as little as 20% of the investment required for a new installation (see Exhibit 428).

EXHIBIT 428: **The charger unit itself represents as little as 20% of the total cost of charger installation, depending on the type of charger**



Source: McKinsey and Bernstein analysis

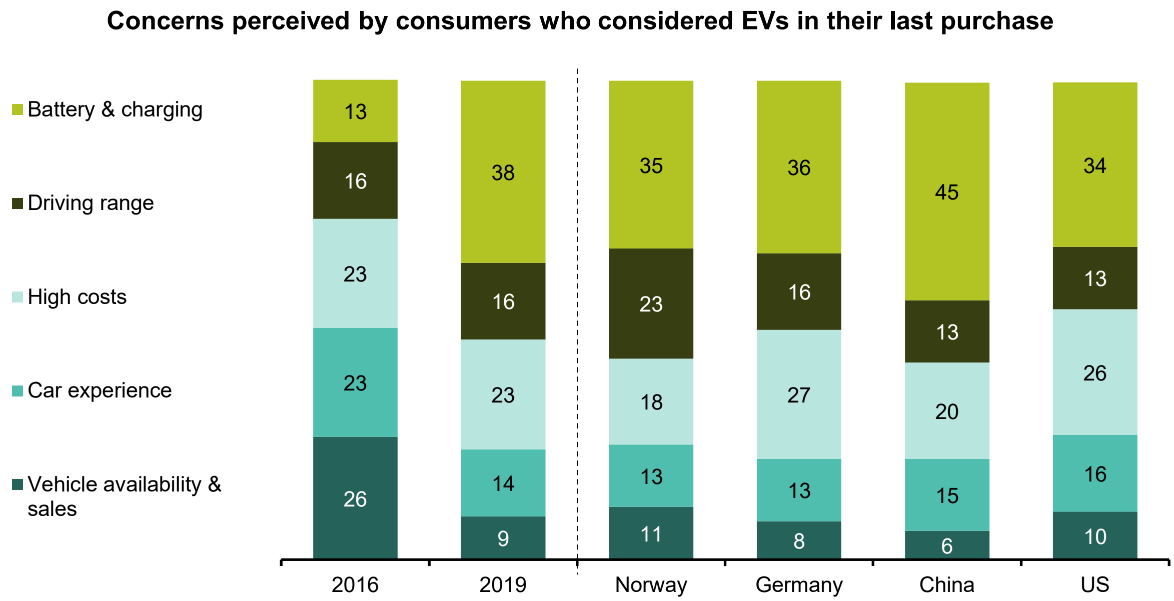
Civil engineering and construction costs are higher when retrofitting EV charging into existing buildings, but represent a significant hidden cost to charging that is often difficult to anticipate and can vary dramatically from case to case. Grid upgrades are of limited importance for the deployment of low-power AC chargers with a limited density. However, in the case of mass deployment of AC chargers (e.g., for fleet purposes) or for DC fast charging, grid upgrades are usually necessary and can represent up to 20% of the installation costs.

The final significant hidden cost is electrical installations that are not part of the charger unit itself, including panels, circuit breakers, new cables and wiring, and metering and power distribution upgrades. These costs typically vary the least between projects and, thus, are a very high proportion for the lowest-cost home AC charger installations, while representing much smaller proportions in the case of fleet AC charging and DC fast charging, where the overall costs are many times higher.

CONSUMER SENTIMENT ON EV PURCHASING DECISION AND ROLE OF CHARGING INFRASTRUCTURE

In the past, consumers ranked not having enough access to efficient charging stations as the third most serious barrier to EV purchases, behind price and driving range. However, now, with EV prices declining and driving ranges expanding, charging has become a higher barrier to adoption, as per a global consumer survey conducted by McKinsey (see Exhibit 429). There are and will be regional differences between reliance on at-home charging versus reliance on public charging versus work charging and these will change over time.

EXHIBIT 429: **With EV prices declining and driving ranges expanding, charging has now become the top barrier to adoption**



Source: McKinsey EV Consumer survey (2016 and 2019), and Bernstein analysis

Within charging, the key concerns of consumers have to do with speed of charging, availability of chargers, and cost of charging. Exhibit 430 shows the top concerns in key geographies.

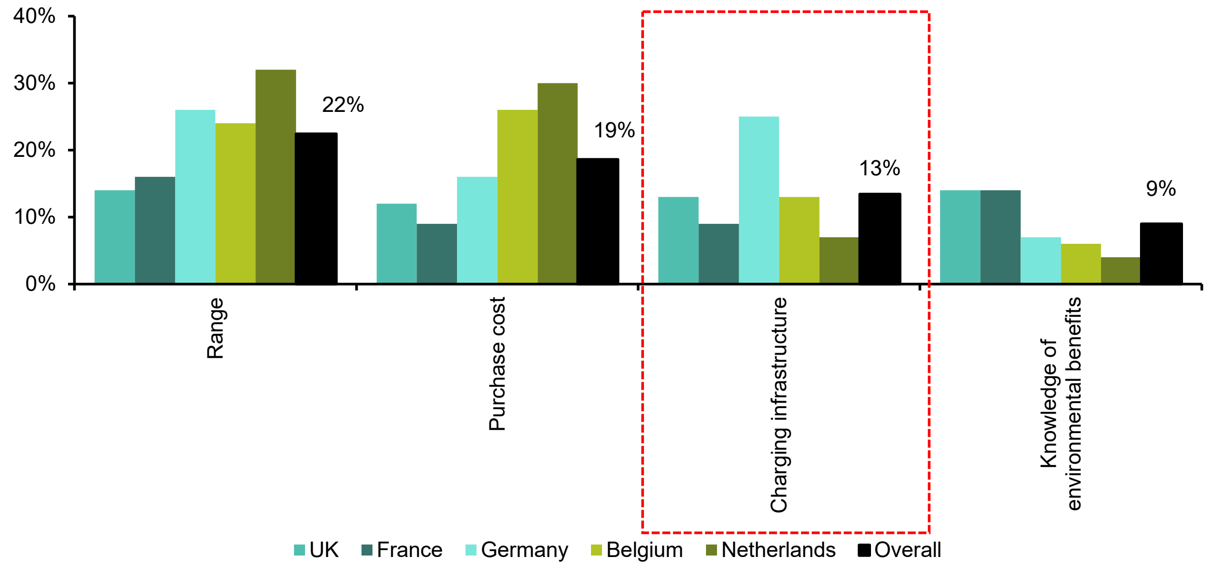
EXHIBIT 430: **Top concerns include speed of charging, availability of chargers, and the cost of charging**

	1st concern	2nd concern	3rd concern
Norway	Speed of charging	Availability of public chargers	Cost of charging
US	Speed of charging	Availability of public chargers	Managing battery charge
Germany	Cost of charging	Availability of public chargers	Breadth of public charger network
China	Chargers difficult to find	Speed of charging	Location of charging station

Source: McKinsey EV Consumer survey (2019) and Bernstein analysis

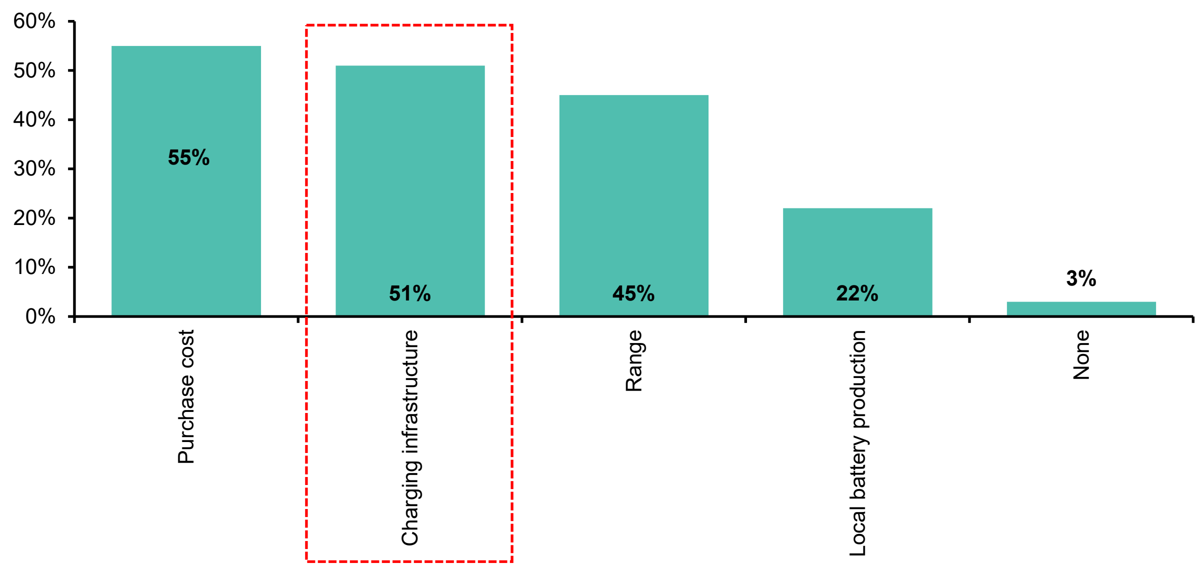
Within Europe, more recent surveys show the same three factors most affecting EV adoption: range, purchase cost, and charging infrastructure (see Exhibit 431). In the survey of city-dwellers (see Exhibit 432), range was understandably the least important of the three, as most inter-city journeys are already well within the range of most EVs.

EXHIBIT 431: **Percentage of drivers saying the most important driver for mass EV adoption would be...**



Source: Newmotion EV driver survey report 2021 and Bernstein analysis

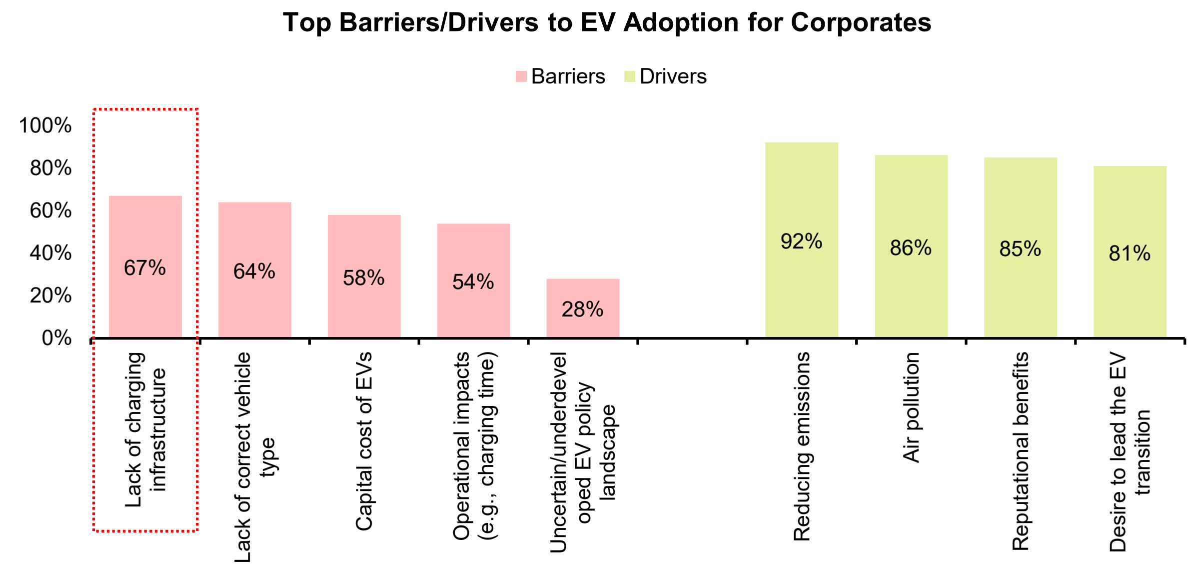
EXHIBIT 432: **Factors influencing the point at which emission-free cars will overtake the sale of ICE cars**



Source: Transport & Environment (April 2021) and Bernstein analysis

The Climate Group's EV100 initiative is a group of 110 companies involved in the EV value chain across 80 markets, representing 169,000 EVs and 2,100 charging sites. These companies see similar barriers to the general public (see Exhibit 433), with a lack of charging infrastructure, EV costs, and operational impacts (the specific example given is charging time, although range could be seen in a similar vein) among the most important barriers to adoption; in contrast to the general public however, the corporate sector suffers from a lack of commercial EVs. Drivers for EV adoption by corporates are also similar to that of the general public, led by a desire to reduce emissions and air pollution.

EXHIBIT 433: **Fleet owners' view of barriers to EV adoption roughly mirror public views**



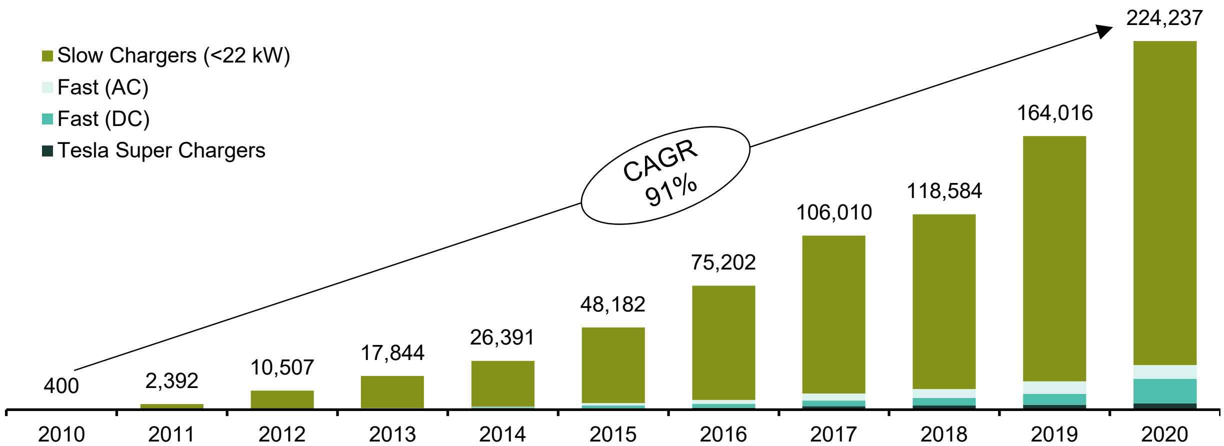
Source: The Climate Group and Bernstein analysis

PROGRESS OF CHARGING INFRASTRUCTURE ROLLOUT

We would highlight that there has been progress in increasing charging networks across regions. In Europe, five large OEMs have built a fast-charger network of 300 stations under a collaboration called Ionity. In the US, Electrify America (funded by Volkswagen as a fall-out of Dieselgate) is investing US$2bn over a 10-year period ending 2027, in both fast-charging stations along high-traffic corridors in 39 US states and in public chargers in 17 metropolitan areas.

The public charger network has expanded in the past few years. See Exhibit 434 for the evolution of public charging in Europe. Although slow chargers still represent 88% of all public charging points, fast charging has grown much faster at a 137% CAGR since the first fast chargers were installed in 2011 compared to the slow public charging network, which has grown at a 88% CAGR since 2010 (or 57% over the same period, since 2011). Within Europe, the Netherlands has the largest stock of slow chargers (63,000), whereas Germany leads in fast charging (7,500 chargers).

EXHIBIT 434: **Public charge points in Europe by type**

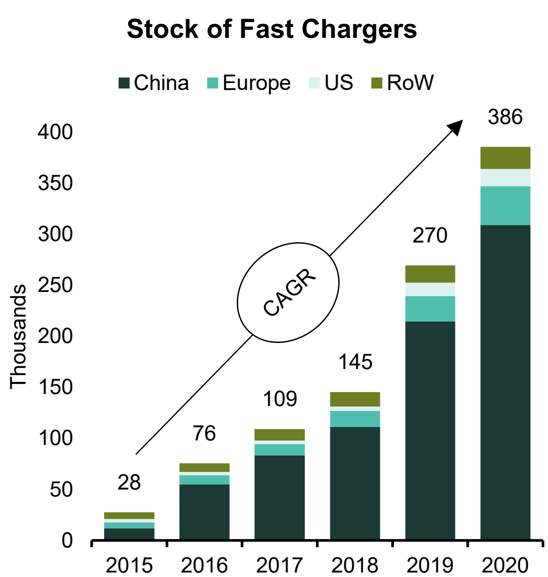


Note: EU + UK

Source: EAFO and Bernstein analysis

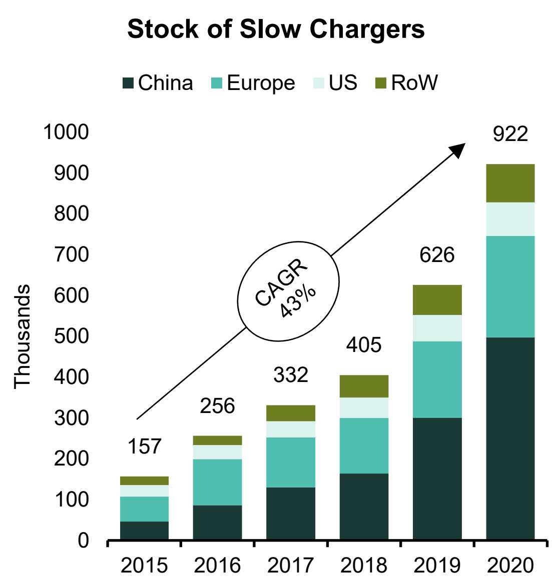
Globally we see a similar picture, with slow charger network growth slower than fast chargers, but from a much higher base; 1.3 million public chargers were deployed by 2020, of which 30% were fast chargers (see Exhibit 435 and Exhibit 436). However, Europe has the lowest fraction of fast chargers (12%), compared to the US (17%), RoW (19%), and China (38%). The growth rate in public chargers was stunted slightly by the pandemic (up 45% in 2020 versus 85% in 2019).

EXHIBIT 435: **Fast chargers have been growing at a 69% CAGR...**



Source: IEA and Bernstein analysis

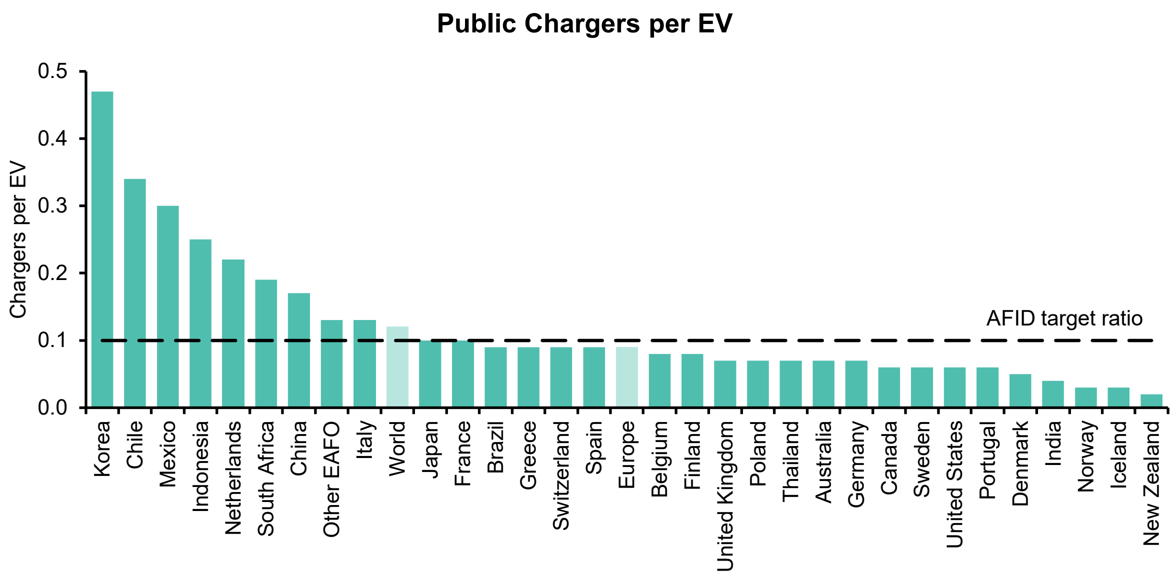
EXHIBIT 436: **...while slow chargers have been slower at a 43% CAGR, but from a much higher base**



Source: IEA and Bernstein analysis

The Alternative Fuel Infrastructure Directive (AFID) set a target with the EU of deploying one public charger per ten EVs by 2020 (an AFID ratio of 0.1). As a whole, the EU didn't quite achieve this target, with a ratio of 0.09, although globally the ratio is 0.12, and within the EU the Netherlands (0.22) and Italy (0.13) did exceed the target, while France achieved a ratio of 0.1 exactly (see Exhibit 437). The lowest AFID ratios tend to belong to countries with higher EV penetration, such as Norway (0.03), Iceland (0.03), and Denmark (0.05) — this likely reflects EV adoption outpacing the growth of the charger network, while being affected by the fact that these countries are all sparsely populated. Thus, most EV owners live in houses with private parking and are able to use private home charging.

EXHIBIT 437: **Ratio of public chargers per EV by country, 2020**



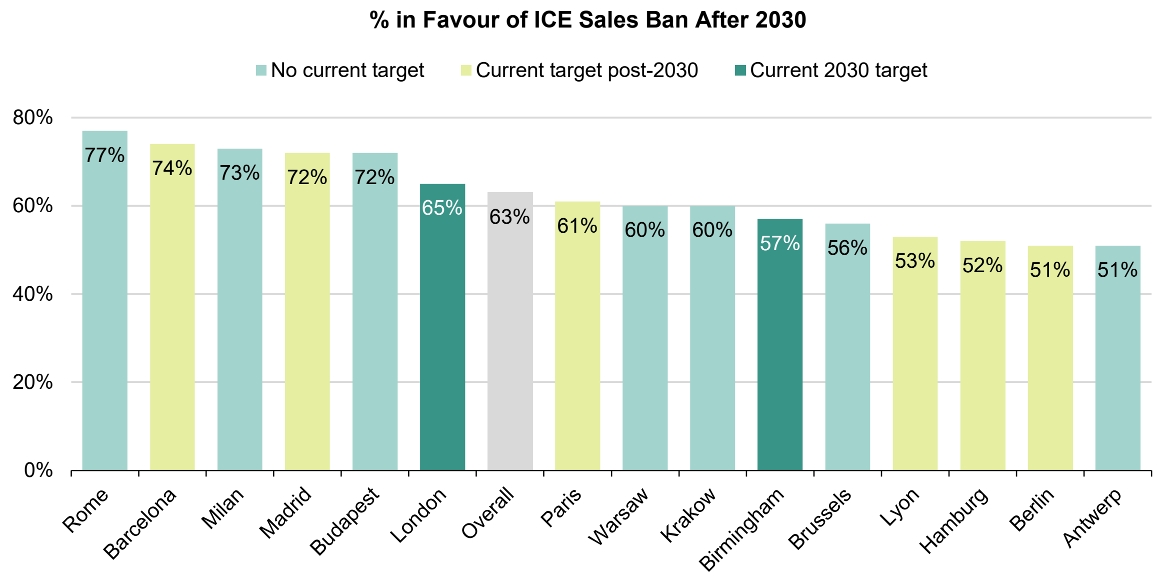
Source: IEA and Bernstein analysis

DEEP-DIVE INTO PUBLIC CHARGING INFRASTRUCTURE NEEDS IN EUROPE

We have built a detailed model that can predict the amount of public charging infrastructure needed to support mass EV rollout in Europe. We update our previous forecast of ~€88bn by 2050 made a year ago, as we now assume a faster ramp of electrification (with the ban of ICE sales by 2035 versus by 2040 earlier).

We have modeled an EV deployment scenario under which EV sales reach 100% by 2035 and the fleet is completely electric by 2050, which corresponds to a net zero by 2050 emissions target (see Exhibit 439). We highlight the growing consumer support for such a move (see Exhibit 438) and also highlight Ford and Volkswagen's recent announcement that they would stop selling ICE cars in Europe after 2035.

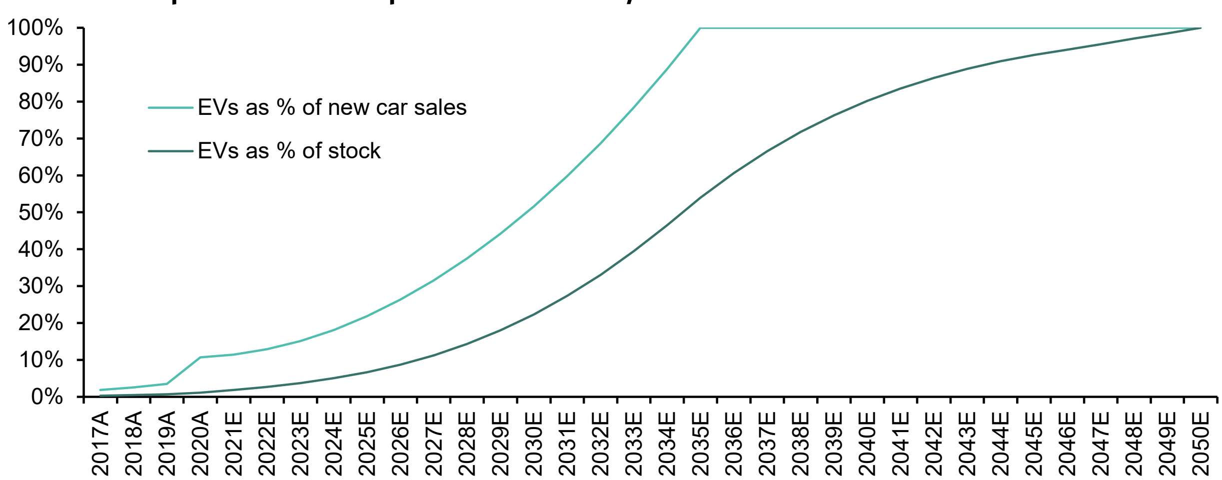
EXHIBIT 438: **63% of consumers in major European cities favor an ICE ban after 2030**



Source: Transport & Environment, and Bernstein analysis

Under such a deployment scenario, there would be ~290 million EVs in Europe by 2050 (~100% of the total passenger car stock). Assuming a mix of super-fast, fast, and slow chargers, we conclude that investments of ~€91bn would be needed from now to 2050 (see Exhibit 440), at an annual average investment of just €3bn p.a. (see Exhibit 441), to support the deployment of ~2.6 million charging points (spilt as 13% super-fast, 54% fast, and 33% slow chargers). This amounts to just ~3% of the annual spend of transport infrastructure in the EU of €100bn.

EXHIBIT 439: **EV penetration in Europe under a net zero by 2050 scenario**



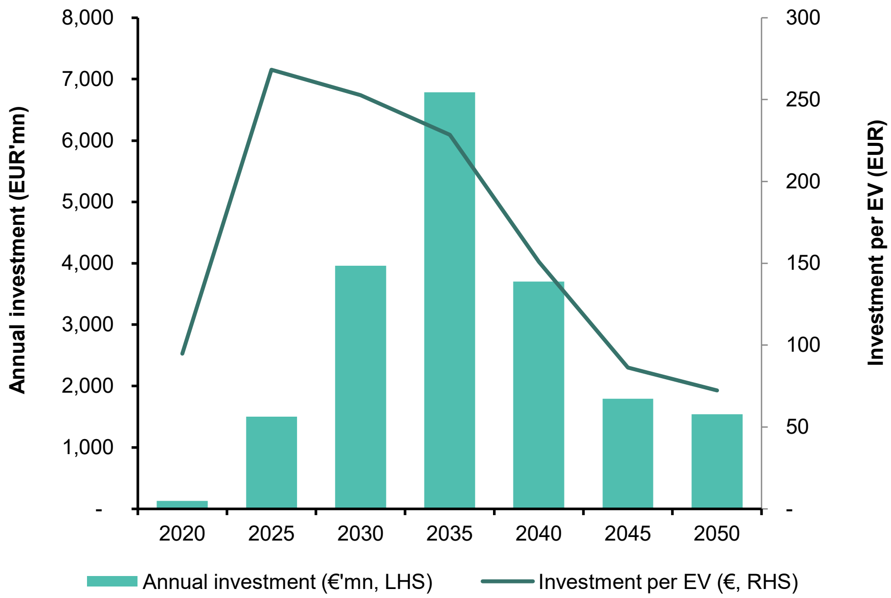
Source: ACEA, and Bernstein estimates and analysis

EXHIBIT 440: **Public charging infrastructure required to support 100% EV penetration in Europe**

	2017A	2020A	2025E	2030E	2035E	2040E	2045E	2050E
EVs as % of new car sales	1.9%	10.7%	21.8%	51.6%	100.0%	100.0%	100.0%	100.0%
EVs as % of stock	0.3%	1.1%	6.7%	22.3%	54.0%	80.2%	92.7%	100.0%
Total # of EVs	121,661	213,367	347,631	847,047	1,608,916	2,057,111	2,276,620	2,412,734
# of super-fast charging points	2,454	3,569	16,410	61,162	156,396	240,560	284,658	312,550
# of fast charging points	8,858	17,815	75,434	268,510	670,910	1,017,696	1,193,107	1,301,330
# of slow charging points	110,349	191,983	255,787	517,375	781,610	798,855	798,855	798,855
investment required (EURm)		**129**	**1,498**	**3,961**	**6,789**	**3,702**	**1,791**	**1,542**
Cumulative investment (EURm)		**687**	**4,179**	**18,483**	**47,207**	**71,246**	**83,607**	**91,343**
% of fast/super-fast charging points		10%	26%	39%	51%	61%	65%	67%

Source: ACEA, IEA, and Bernstein estimates and analysis

EXHIBIT 441: **As EVs pick up, annual investments are expected to increase before starting to decline in the 2030s**



Source: ACEA, IEA, and Bernstein estimates and analysis

Our calculations on the number of chargers required and, therefore, investments are very sensitive to assumptions on the extent to which public chargers will be used by EV users versus at-home/at-work charging — in our base case, we assume 60% of the charging is done at home/work and the balance at a public charging station. Exhibit 442 shows the sensitivity of investments required to levels of reliance on the public charging network.

EXHIBIT 442: **Investments required at different levels of public infrastructure usage, €mn**

% of charging done at home/work	45%	50%	55%	60%	65%	70%	75%
Investments needed by 2025	6,557	5,764	4,971	**4,179**	3,389	2,601	1,972
Investments needed by 2030	26,226	23,645	21,064	**18,483**	15,905	13,328	10,752
Investments needed by 2035	65,721	59,550	53,378	**47,207**	41,038	34,871	28,704
Investments needed by 2040	98,774	89,598	80,422	**71,246**	62,072	52,900	43,728
Investments needed by 2045	115,771	105,049	94,328	**83,607**	72,888	62,171	51,454
Investments needed by 2050	126,409	114,720	103,032	**91,343**	79,658	67,974	56,290

Source: Bernstein estimates (all data) and analysis

HOW DO OUR ESTIMATES COMPARE TO OTHER ESTIMATES?

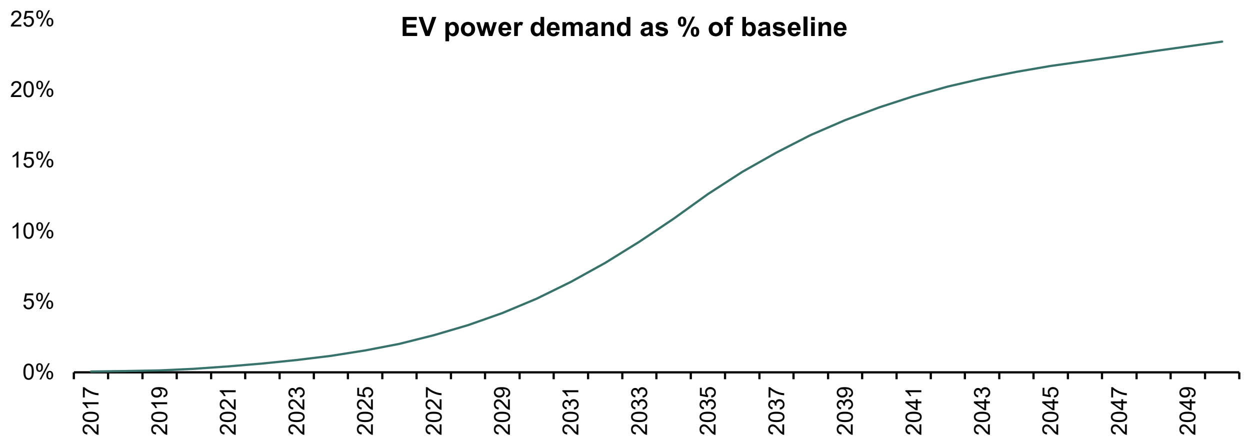
The UK's Committee for Climate Change estimates that the UK will need to spend £9.6bn by 2050 on public charging infrastructure to electrify its car and van fleet; scaling this to the rest of Europe gives a total spend of €87bn. In a recent analysis, Transport & Environment expects Europe to spend €20bn by 2030 to support the deployment of 44 million cars, on a path complaint with net zero emissions by 2050. Scaling this to 100% of the passenger fleet would result in a total spend of €114bn.

INVESTMENTS IN DISTRIBUTION NETWORKS

IMPACT ON ELECTRICITY DEMAND FROM EVS

We expect electricity demand to increase due to the adoption of EVs to increase by 15-25% when there is full-electrification. For example, in Europe, we expect power demand to increase by 23% when the entire fleet is electric (see Exhibit 443) and by 5% by 2030.

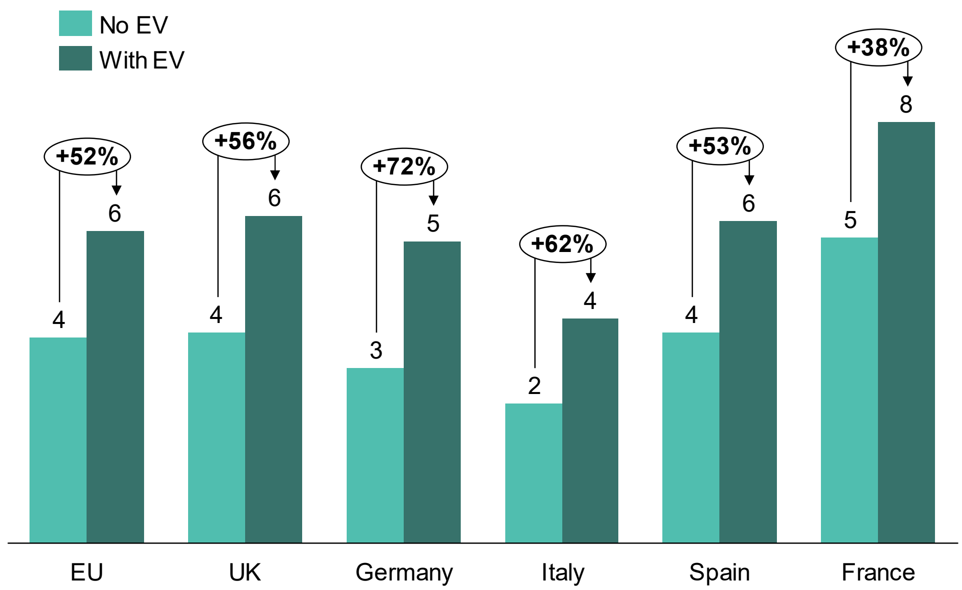
EXHIBIT 443: **Impact of EVs on power demand in Europe**



Source: Bernstein estimates (all data) and analysis

However, at the individual household level the impact can be significant as electricity demand can double (see Exhibit 444) and the impact on the load curve can be disproportional, depending on the extent of EV penetration, speed of charging, and time of charging. Further, as the speed of at-home charging increases, there is additional stress at the local distribution grid level.

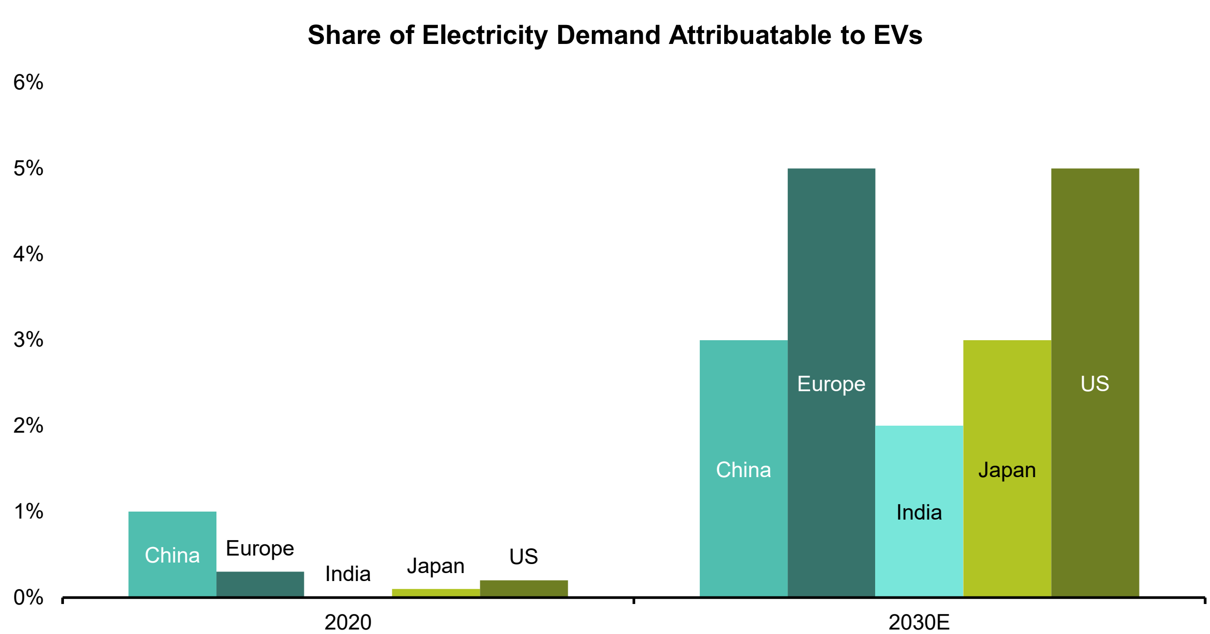
EXHIBIT 444: **Average electricity consumption per household, MWh per annum**



Source: Eurostat, www.odyssee-mure.eu, and Bernstein analysis

According to the IEA's Sustainable Development Scenario, by 2030 EV charging will consume 861TWh/year of electricity, more than ten times the 80TWh consumed in 2020. Although China remains the largest consumer of electricity for EVs in 2030, the proportion of electricity demand attributable to EVs falls relative to other countries (see Exhibit 445).

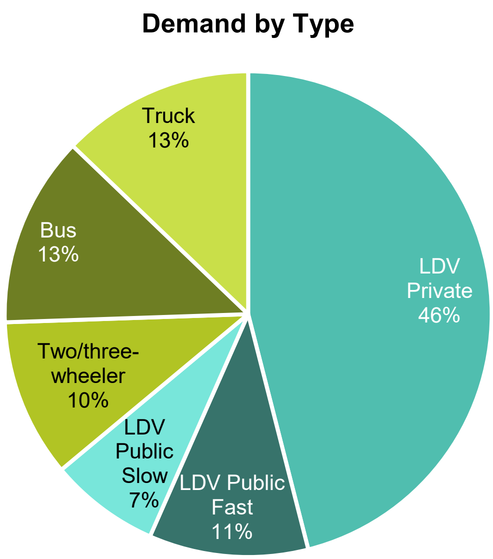
EXHIBIT 445: **EV's share of electricity demand set to rise from 0-3% today to 2-5% in major regions by 2030 under the IEA's Sustainable Development Scenario**



Source: IEA (SDS Scenario) and Bernstein analysis

Of the total electricity demand for EV charging that the IEA expects in 2030, private charging for light duty vehicles will require 396TWh/year of electricity, or 46% of the total. Public charging for light duty vehicles represents a further 18%, of which 11% (91TWh) is fast charging and 7% (63TWh) is slow charging; the final category of private vehicles identified is two- and three-wheelers, which the IEA estimates will also represent 11% (91TWh) of the total demand. Aside from this, both buses and trucks are expected to require 110TWh or 13% of total demand — this is likely lower than private vehicle categories due to the likely adoption of hydrogen for heavy CVs.

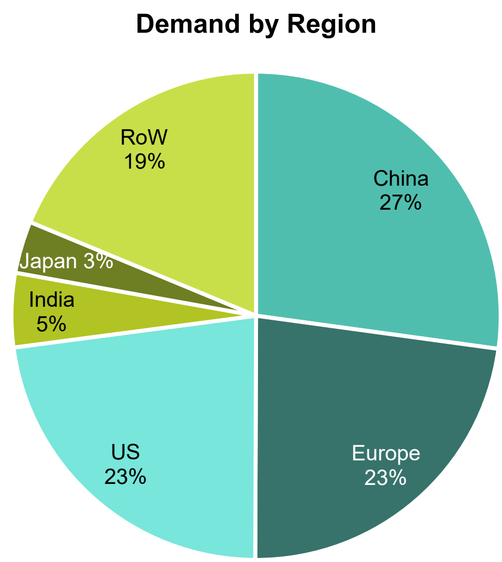
EXHIBIT 446: **Global EV electricity demand of 861TWh/year in 2030 by charger type...**



Note: LDV= Light Duty Vehicles

Source: IEA and Bernstein analysis

EXHIBIT 447: **...and by region**



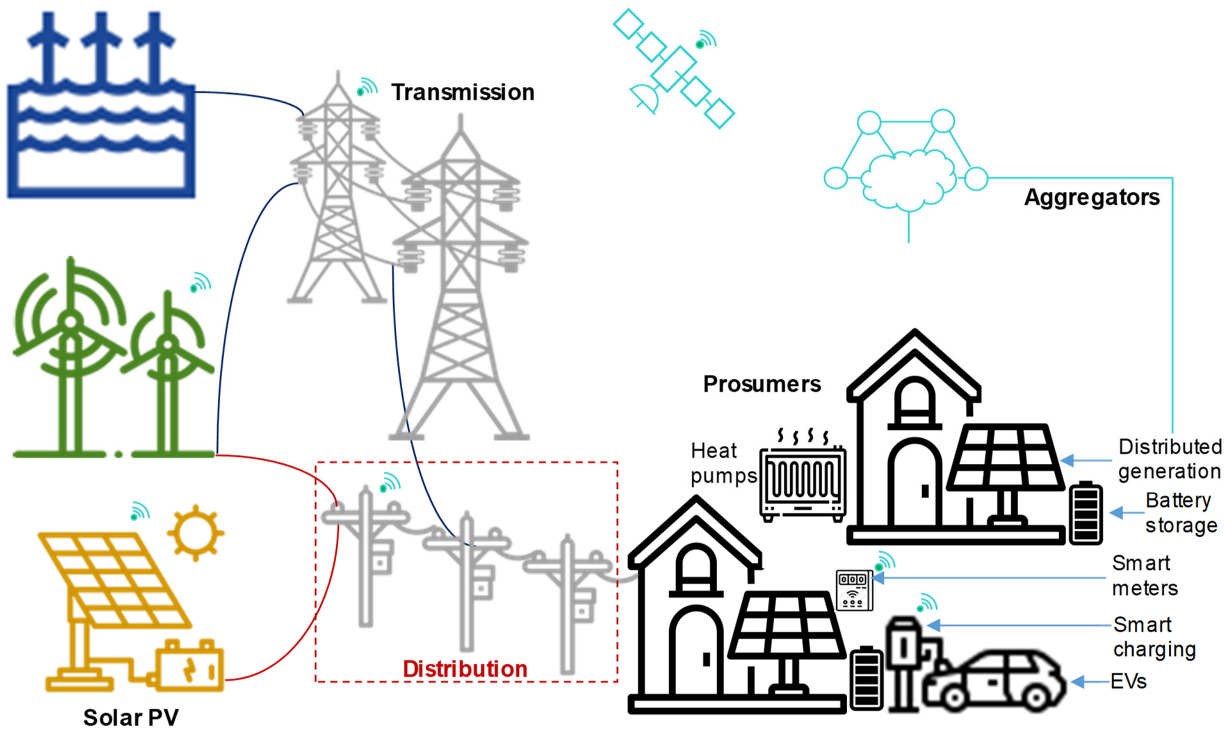
Source: IEA and Bernstein analysis

Geographically, China is expected to continue to consume the most electricity (27%) for EV charging, while Europe and the US will each consume 23%. India and Japan are expected to consume 5% and 3% of total EV electricity demand, respectively, leaving 19% for the rest of the world.

INVESTMENTS IN THE GRID BACKBONE

Electricity networks form the backbone of electricity systems, moving electrons from the point of production to the point of consumption; electricity distribution covers low-, medium-, and high-voltage lines, while transmission covers high- and extra-high-voltage lines. Electricity distribution networks play a critical role (see Exhibit 448) in delivering decarbonization ambitions by connecting and integrating decentralized renewables generation, supporting integration of EVs and heat-pumps while maintaining high reliability and quality of supply, and digitalizing particularly through smart meters and other smart grid technologies.

EXHIBIT 448: **Electricity distribution networks integrate renewables and two-way flows and enable decarbonization of transport and heat**



Note: Image credits: FlatIcon[71]

Source: Bernstein analysis

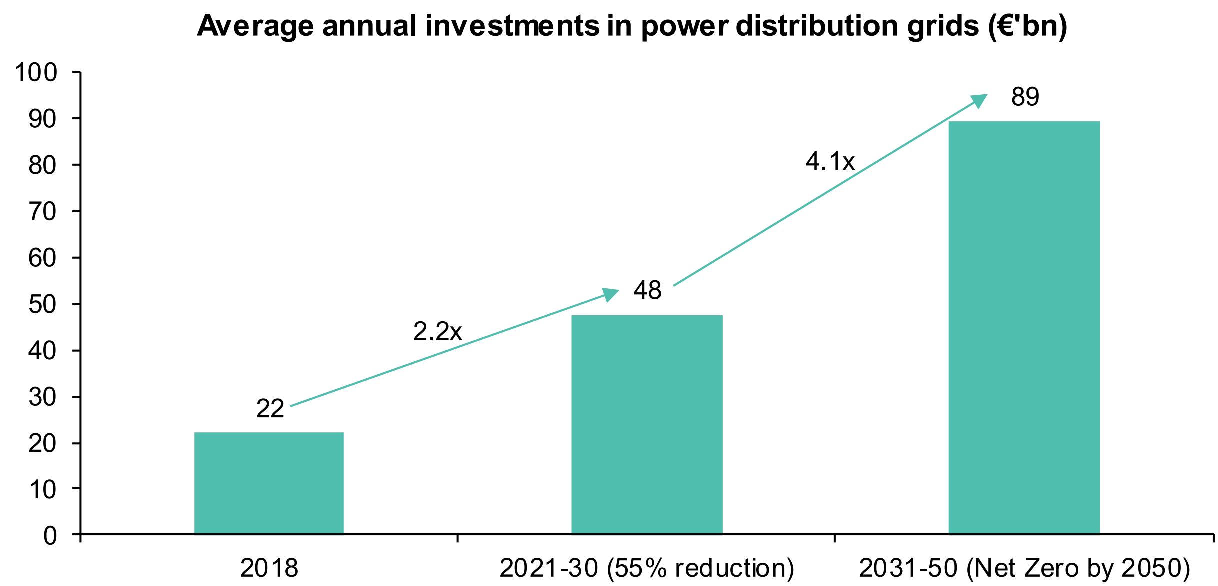
At the EU-27 level, according to analysis done by the European Commission on the European Green Deal, investments in distribution grids increase to ~2.2x in 2021-30 compared to 2018 and to 4x in 2031-50 (see Exhibit 449).

Industry bodies, Eurelectric and E.DSO, recently conducted a comprehensive study to assess distribution investments required for the energy transition in Europe. A first of its kind, the study was carried out by Monitor Deloitte on the basis of detailed empirical data from 10 European countries.

As per the study, distribution grids in the EU-27 plus the UK, will require €375-€425bn of investments during 2020-30 (see Exhibit 450) and another €25-€30bn could be required to reach the new target outlined in the Green Deal. Of the €375-€425bn, around half is expected to go toward the energy transition — renewables integration, electrification of transport, building heating, and industry — with the rest going toward modernization of the aging grid and digitization (including smart meter installation). **Roughly 7-8% of the overall spend will go toward integrating EVs.**

[71] Icons created by Good Ware, Freepik, and Linector, and hosted on FlatIcon.

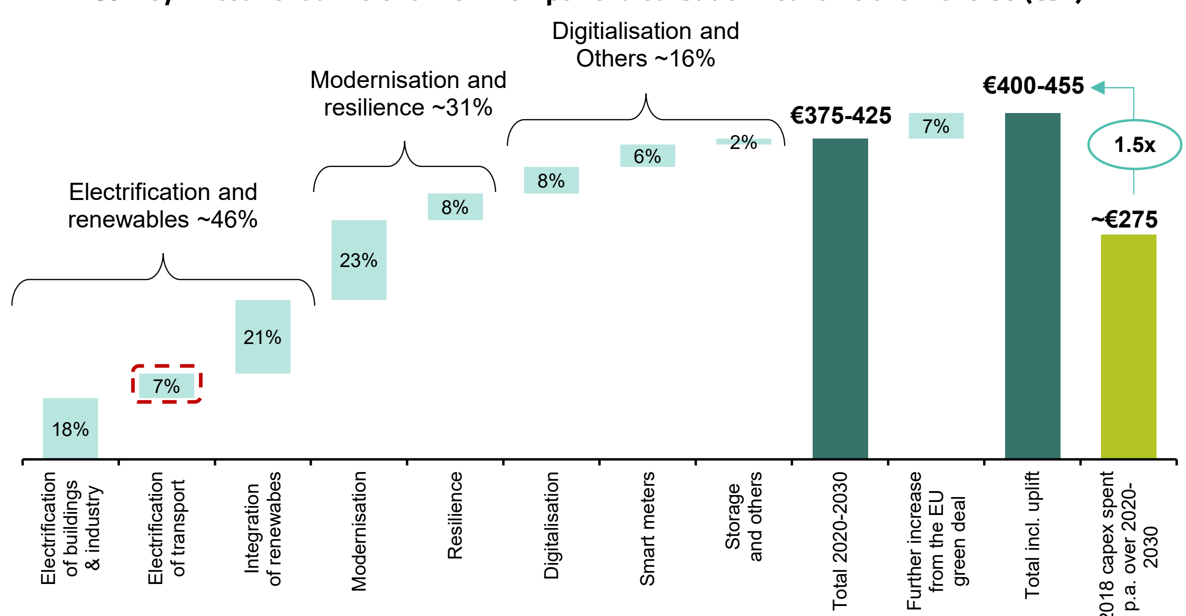
EXHIBIT 449: **Investments in EU-27 power distribution networks will need to increase to 2.2x in the 2020s and to 4x beyond 2030**



Note: Assuming investments in distribution grids is two-thirds of total network investments. Assuming inflation of 2% p.a. to convert 2015 money to mid-point of the periods.

Source: European Commission, and Bernstein estimates and analysis

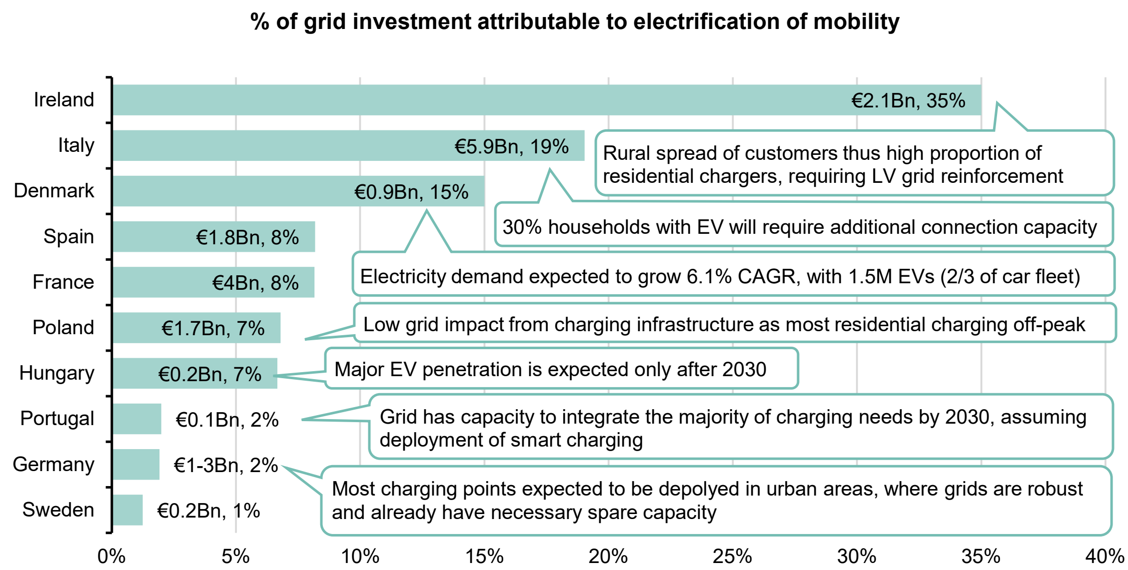
EXHIBIT 450: **Key investment drivers for EU27+UK power distribution networks over 2020-30 (€bn)**



Source: Eurelectric/E.DSO, Monitor Deloitte data and estimates, and Bernstein analysis

While at the overall EU level, electrification of transport is 7-8% of investments to 2030, the picture varies significantly by country (see Exhibit 451), reflecting the state of the existing grid and spare capacity and density of population, share of EV owners with access to private residential charging points, non-residential charging infrastructure costs (power grid capacity, charging capacity per point, location in urban areas versus motorways), and smart charging ambition (e.g., diversifying EV charging).

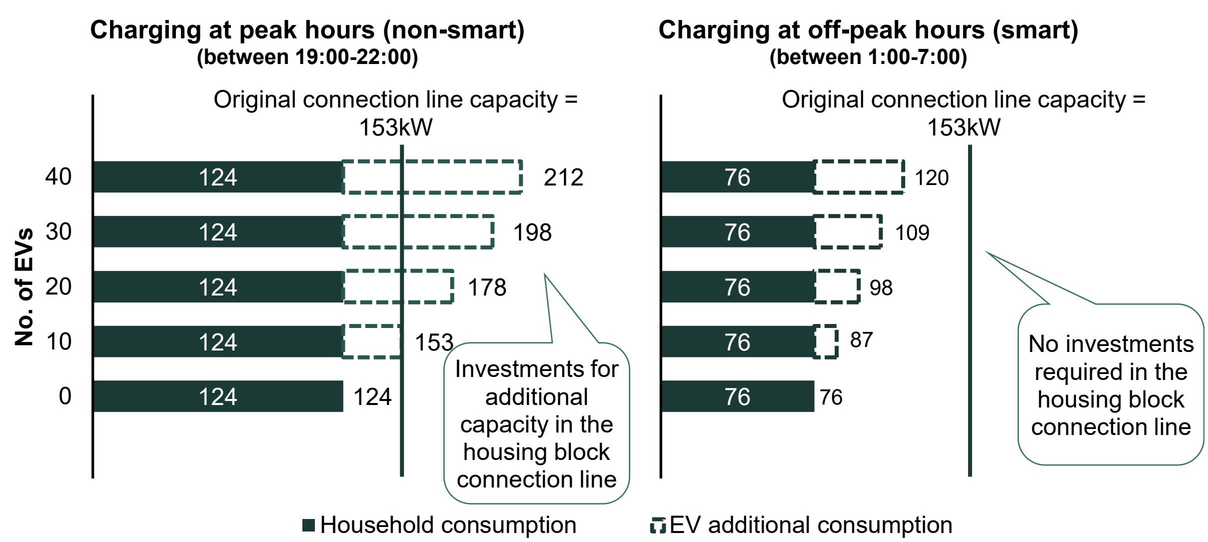
EXHIBIT 451: **Requirements for grid investment to support EV infrastructure varies significantly by country**



Source: Eurelectric/E.DSO, Monitor Deloitte, and Bernstein analysis

Specifically, existing grid capacity and extent of off-peak charging will determine investments needed. See Exhibit 452 for an illustrative example for low voltage connection capacity to a housing block.

EXHIBIT 452: **Impact of EV smart charging in saturating the connection line in a housing block, kW**



Source: Eurelectric/E.DSO, Monitor Deloitte, and Bernstein analysis

How much investment do we need in the distribution grid to support EVs in Europe?

For Europe, we calculate a distribution grid capex of €100-€185bn, using the amount of spend required in the distribution network based on analysis by a few operators/research studies.

- **Eurelectric/E.DSO study:** This study concludes that distribution grid investments of €25-€35bn would be needed by 2030 for a penetration of 50-70 million vehicles; the study also provides a sensitivity of €2-€4.5bn for a 5 million change in EV penetration. Scaling up this number to 100% of EV penetration of 308 million vehicles, the total investment would be €120-185bn.

- **E.ON:** E.ON calculates that in its service territory in Germany, to support the transition of 6.5 million cars to EVs, it would need to spend €2.5bn over 25 years. Scaling this to all of Germany and all of the EU gives an estimate of €17bn (Germany) to €100bn (EU), in the absence of smart charging. Smart charging could reduce this by as much as 50%, according to E.ON.

- **Oliver Wyman** calculated investments of €11bn in Germany at 50% EV penetration. Scaling this to all of Europe, we get to a spend of €120bn (Europe), in the case of uncontrolled charging behavior. With smart charging, the capex can be lower.

- Estimates of the impact of **smart charging** on reducing distribution capex ranges from 60% to 30%.

In the context of the annual EU electricity grid capex of €30bn, a spend of €100-1€85bn over 25 years is just 13-25% and will be supported by regulatory frameworks already in place.

WHAT IS THE IMPACT OF EV CHARGING ON GRIDS?

A study conducted in the UK for the Committee on Climate Change modeled the impact of an accelerated deployment of EVs and heat pumps in the UK and concluded that significant investments will need to be made in network reinforcements and, as a result, capex on distribution networks would need to double relative to today's levels. The study found that these additional reinforcements are driven by voltage constraints or thermal constraints, with the former driving investments in early years and the latter driving investments in later years.

- **Thermally driven constraints.** An increase in electricity demand may raise the power flow above a network cable or transformer's capacity.

- **Voltage-driven constraints.** Longer network lines suffer from a voltage drop, where the voltage decreases the further the electricity travels. An increase in demand (and therefore power flow) on a network line could cause the voltage to drop below 6% of its nominal level. In that case, a lower resistance (higher capacity) cable would be needed to limit the voltage drop, even if the rated capacity of the line is adequate for the increase in demand.

The impact of EVs on grids would depend on the nature of the charging, which in turn depends on the use-case. While ultrafast 150-350kW DC chargers installed at highway hubs require dedicated high-voltage lines and transformers to be installed at costs of >£70,000 and lead times of 16+ weeks, and requiring close coordination with grid operators to satisfy demands >10MW, slow AC chargers installed at homes or in public charging locations require little to no grid upgrades and are unlikely to cause any material power demand issues. We summarize in Exhibit 453 and Exhibit 454, the nature of network upgrades and grid impacts from EV charging, based on analysis from ENTSO-E and WPD.

EXHIBIT 453: **Grid impact varies substantially by charging type and use-case — slow/fast**

	Slow		High power charging
Use case	Home, company fleet	Public charging	Bus depots and night charging
Power	<7 kW AC	<50 kW AC	50-100 kW AC/DC
35 kWh charge time	5-12 hours	1.5-5 hours	20-45 mins
Network upgrades	Sometimes limited local reinforcement	Low voltage lines	Medium voltage lines. Possible shared conection with other LPT loads
Grid impact	Power issues in secondary substations and LV lines in the event of multiple installations		Single depot could require 5-10MW, often in rural areas. Need for coordination between grid operators and local public transport operators
Connection lead times	Immediate	4-12 weeks	8-16 weeks
Connection costs	£0 - 3,000	£3,500 - £12,000	£3,500 - £12,000
Flexibility potential	High due to long connection times	Moderate due to moderate connection times	Low due to time/power constraints. However good control of consumption due to predictable usage

Note : LPT = Large Power Transformers

Source: WPD, ENTSOE, and Bernstein analysis

EXHIBIT 454: **Grid impact varies substantially by charging type and use case — fast/ultrafast**

	Fast/ultrafast charging	Multiple ultrafast charging
Use case	Fuel station model & urban hyper hubs	Highway hyper hubs
Power	50-350 kW DC	150-350 kW DC
35 kWh charge time	5-20 mins	5-15 mins
Network upgrades	Medium voltage lines. Shared (fuel station) or dedicated (hyper hub) POD	High voltage lines. Dedicated POD
Grid impact	Power issues in LV and MV lines	Single hub could require >10MW, often in rural areas. Need for coordination with grid oeprators to locate hubs close to existing HV lines
Connection lead times	16+ weeks	16+ weeks
Connection costs	£70,000 - £120,000	£70,000 - £120,000
Flexibility potential	Low. Energy storage systems could be installed to limit peak power requirements	Low. Energy storage systems could be installed to limit peak power requirements

Note: POD = Power Oscillation Damping

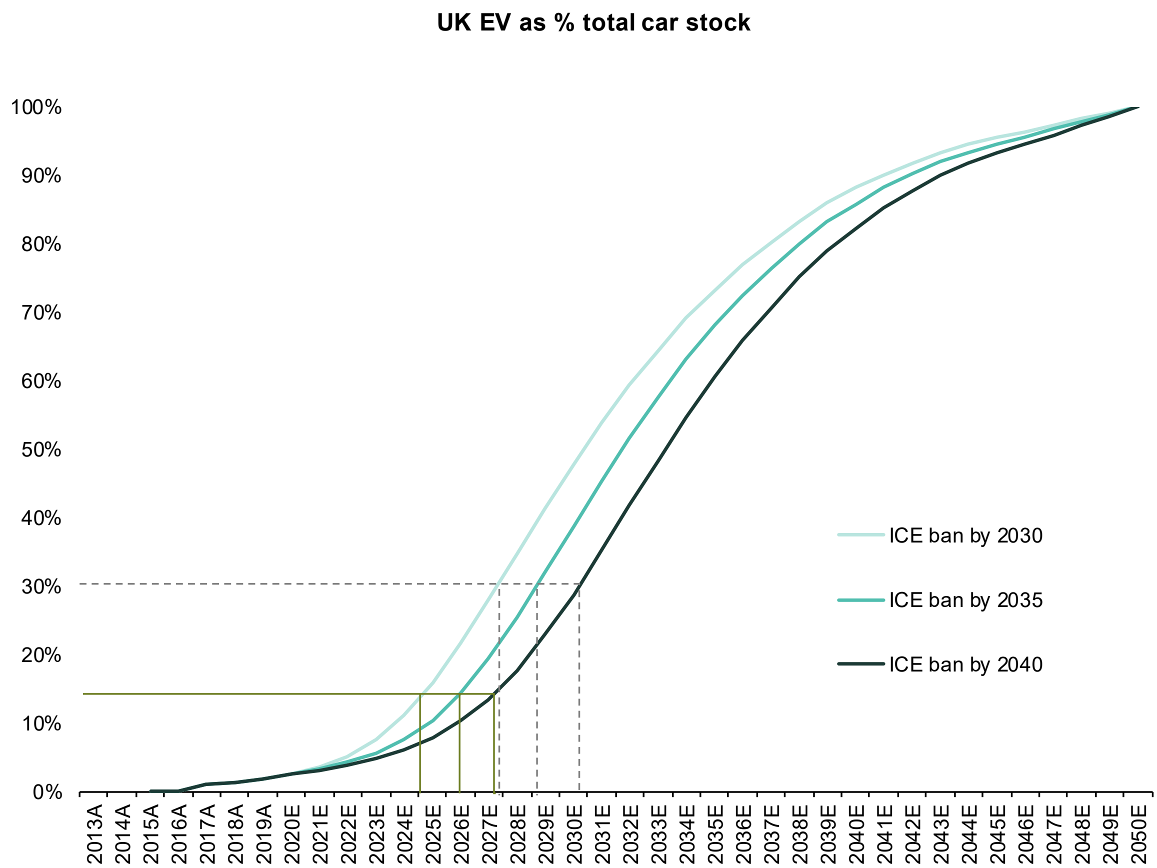
Source: WPD, ENTSOE, and Bernstein analysis

In its study on the impact of electromobility on the German electric grid, McKinsey concluded that the main infrastructure components requiring investment are residential transformers in areas with high penetration of EVs and, to a lesser extent, circuits and switchgear. As EVs gain traction and charging rates evolve from the current AC slow rate (less than 4kW) to improved rates (4kW to 15kW) and finally AC fast rates (15kW to 22kW), the number of overloaded residential transformers increases exponentially. McKinsey's estimates show a spike in transformer upgrades once approximately 3 million EVs are in operation, which could happen as soon as 2025. At the same time, DCFC charging stations (with rates of 350kW DC for cars and up to 600kW DC for heavy CVs) may challenge the stability of the network, requiring dedicated substations (in most cases) or major overhauls of transformers and cables.

Grid critical EV penetration investment levels

From a number of research studies and based on comments from our utility companies, we conclude that at low levels of EV penetration, there is no or little impact on the distribution grid infrastructure. However, as EV penetration increases, we start seeing impact at the distribution grid which requires reinforcement — especially if the charging behavior is uncontrolled. According to a study by Oliver Wyman & TUM, grid expansion becomes necessary when EV penetration reaches 30% of the fleet. Likewise, for the UK it computes that brownouts from EVs could begin by the time they represent 25-30% of the fleet. Most distribution network operators believe the grid would need to be strengthened when EV penetration reaches 15-30% — but the impact after this point could be non-linear. We believe grid-critical levels of EV penetration could be reached in the mid- to late-2020s, depending on the date the ICE ban is in force (see Exhibit 455).

EXHIBIT 455: **EV penetration is sensitive to the shape of the adoption curve and date of ICE ban and reaches grid-critical levels in the mid- to late-2020s in Europe**

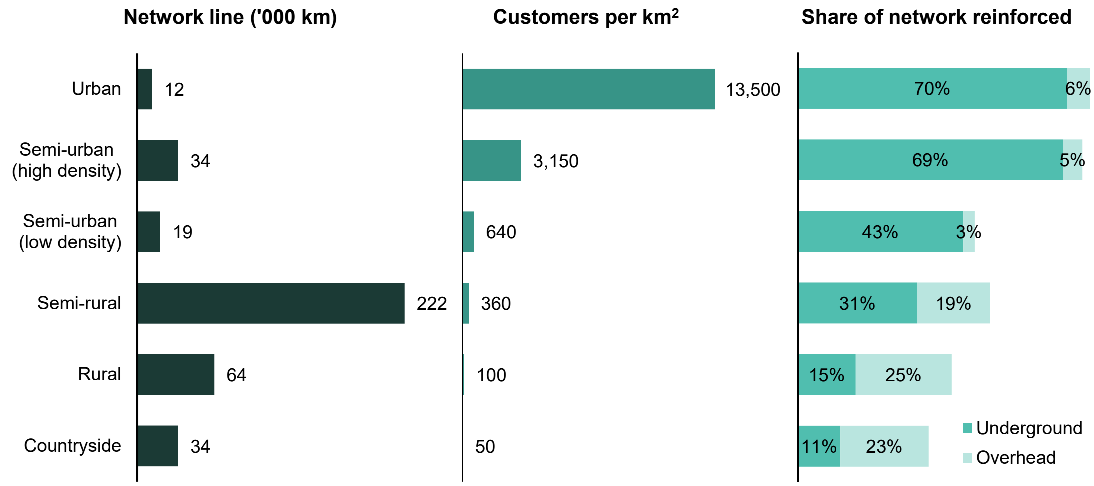


Source: ACEA, Eurostat, and Bernstein estimates and analysis

Network reinforcements are costly and disruptive — oversizing is cheaper than undersizing

The costs of oversizing network infrastructure are very low, as cable capacity accounts for just 8-10% of upgrade costs. As a result, future-proofing investments by oversizing network infrastructure is a very low-regrets option. Disruptiveness is likely to be particularly acute in urban and semi-urban areas with high customer density (see Exhibit 456), due to the large number of customers affected by outages, the high share of the network likely to need reinforcing, and predominance of underground lines.

EXHIBIT 456: **UK distribution network reinforcement by 2035 under rapid electrification scenario**



Source: Vivid Economics, Imperial College, and Bernstein analysis

EVS ALSO PRESENT AN OPPORTUNITY TO THE GRID AND UPGRADES CAN BE MINIMIZED THROUGH SMART CHARGING

In general, there are three charging behaviors, which will in turn have an impact on the spend required in the grid infrastructure, as well as whether EVs can present an opportunity to the grid or represent a burden:

- **Uncontrolled charging:** EVs are charged as soon as they arrive at a charging point. This could be, for instance, when EV owners return from work, which also coincides with peak electricity consumption.

- **Smart charging:** Here, charging is based on consumer preferences and actual charging can shift within the timeframe that the car is parked. Charging can be shifted to match off-peak demand or when the carbon intensity of the grid is highest. Common incentives to shift demand to off-peak periods are:

    - **Time of use pricing:** Charging is cheapest during periods of low grid utilization and vice versa.

    - **Critical peak pricing:** Capacity limits are set for specific time periods and if an EV draws power in excess of the capacity limit, the customer must pay a penalty.

- **Smart charging plus:** Here, the charging behavior is refined beyond a single parking instance. The scenario assumes that a software application has sufficient information to determine whether it would be more cost-effective to charge to the desired level at a later time and charging is optimized over several uses and parking periods.

While stationary and unoccupied, EVs form a distributed network of batteries. In a traditional charging process, the rate of charging is determined simply by the higher of maximum power (kW) that the charger can provide or that the battery can accept. However, this can, should, and increasingly is being replaced by smart charging systems (V1G) that connect to the grid and control charging rates (and hence power demands) and schedules to benefit the grid (as well as the user). Furthermore, bi-directional charging (V2G) can enhance many of these advantages by using the vehicle battery to supply power back to the grid.

By controlling the profile of power demand as well as properly scheduling charging cycles, grid operators and EV owners can take advantage of this opportunity in a number of specific ways:

- **Reshaping the power load curve:** By adjusting charging schedules, power demand can be shifted away from peak times (evening) to off-peak hours. By reducing the higher-cost marginal power requirement at these peak hours, charging costs can be significantly reduced (and passed through to the consumer, encouraging this scheduling), and the need for marginal fossil-fuel-based generation is limited. This also reduces peak loads on grids, which reduces the need for costly and disruptive grid upgrades.

- **Providing services to the grid:** Through V2G systems, EV batteries can be used to support balancing of the transmission grid, keeping the frequency close to 50Hz, provide fast-frequency reserve, and help with voltage control. As a distributed resource, EV batteries connected to V2G chargers can help with grid congestion by providing a "boost" in local areas at peak times. Renewable energy intermittency can also be alleviated, as smart chargers can match charging demands to available resources in real time.

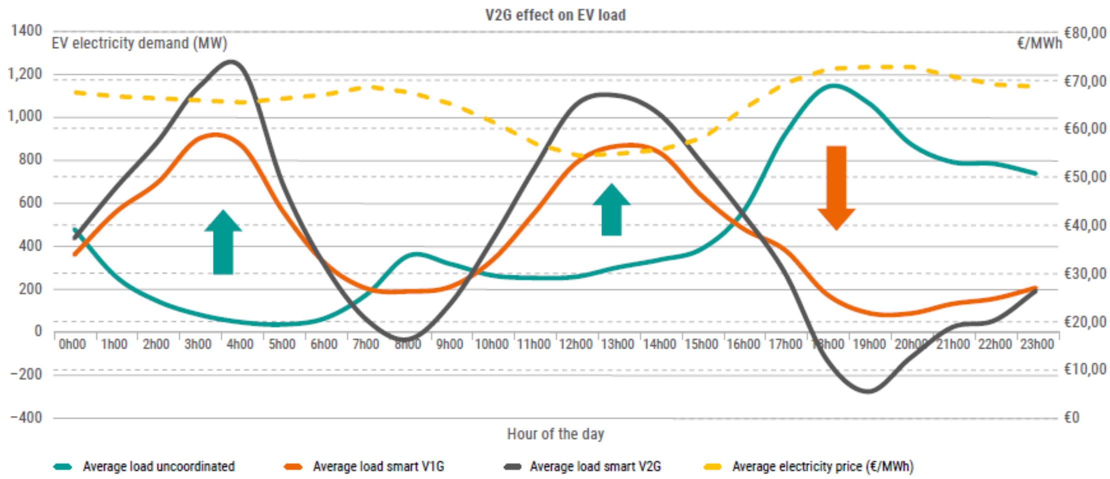
- **Local advantages:** Smart charging can provide advantages local to the charger in two ways:

    - **"Behind the meter" batteries:** EV batteries can be used as any other domestic storage system, reducing energy costs.

    - **Freeing up fast chargers for HGVs:** Battery powered HGVs require fast charging with intensive usage and little flexibility for smart charging. By managing charging of personal vehicles, grid resources can be directed to their most important uses.

Looking at the example of Belgium in 2030 (see Exhibit 457), modeled by Elia which owns transmission grids in Belgium and one of the transmission grids in Germany, we can see that EV electricity demand without smart charging or V2G systems peaks at the worst possible time, the evening hours when load is already at its highest, requiring costly additional generation and likely using fossil fuels. Using smart charging, load can be shifted away from these problematic times to late at night when existing electricity demand is at its lowest and wind generation is highest and the daytime when PV generation is available.

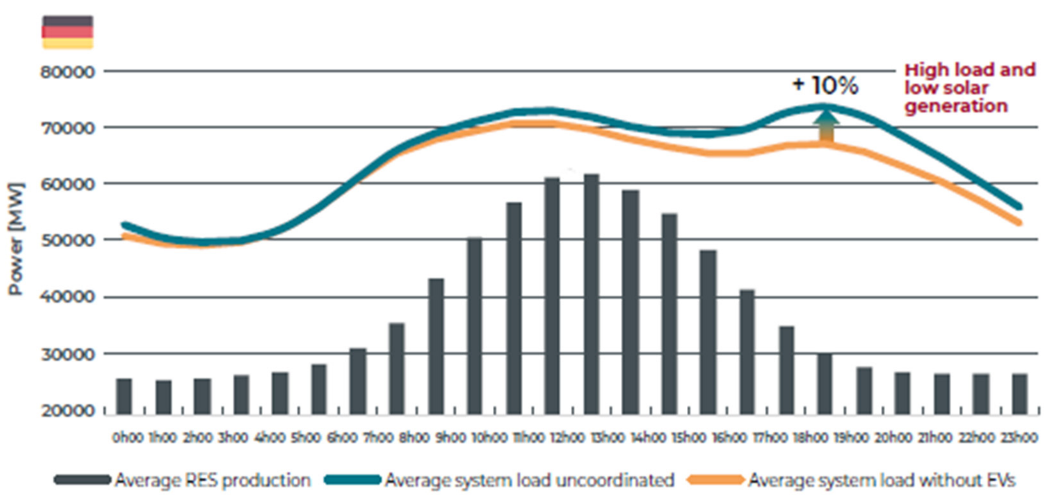
EXHIBIT 457: **Smart charging (V1G) and vehicle to grid (V2G) systems can dramatically alter grid load from charging — Belgium 2030 example**



Source: Elia

In this 2030 Belgian scenario, using smart charging to shift charging to times when electricity is cheaper can save an EV driver €35/year in electricity costs, while the use of V2G to inject power back into the grid could earn the driver back a further €15/year. Moreover, as renewables represent a greater part of the energy mix and intermittency becomes more prevalent, the arbitrage between peak and trough electricity prices will widen, furthering driver savings. Similarly, by reducing the need for additional fossil fuel generation at peak times and using up excess renewable generation at off-peak times, the CO2 emissions associated with a single EV could be reduced by 5-10% (see Exhibit 458 and Exhibit 459).

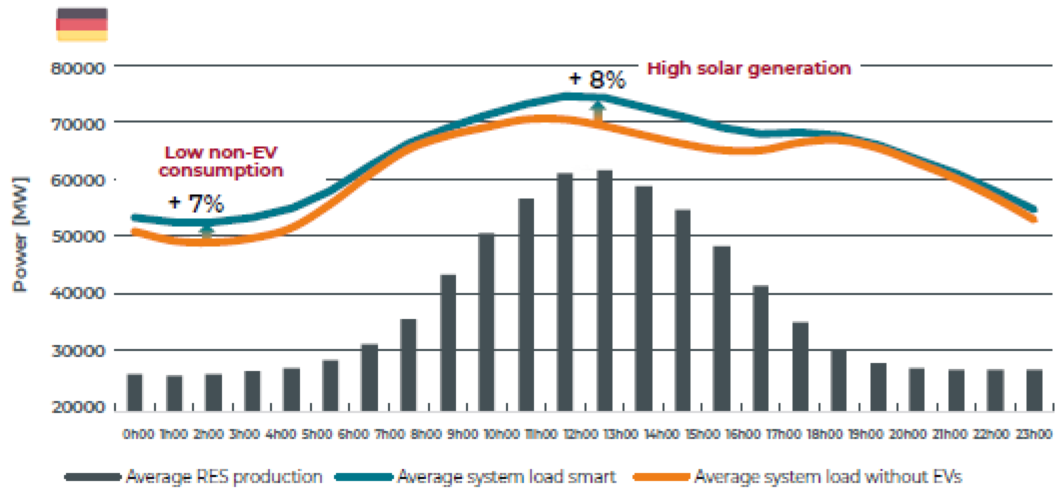
EXHIBIT 458: **Uncontrolled charging may not be aligned with renewables generation...(Germany 2030 example)**



Source: Elia

Smart charging can dramatically reduce peak residual load (-10% around 7pm), while increasing load at noon to make full use of solar PV resources.

EXHIBIT 459: **...while smart charging makes better use of renewables generation (Germany 2030 example)**

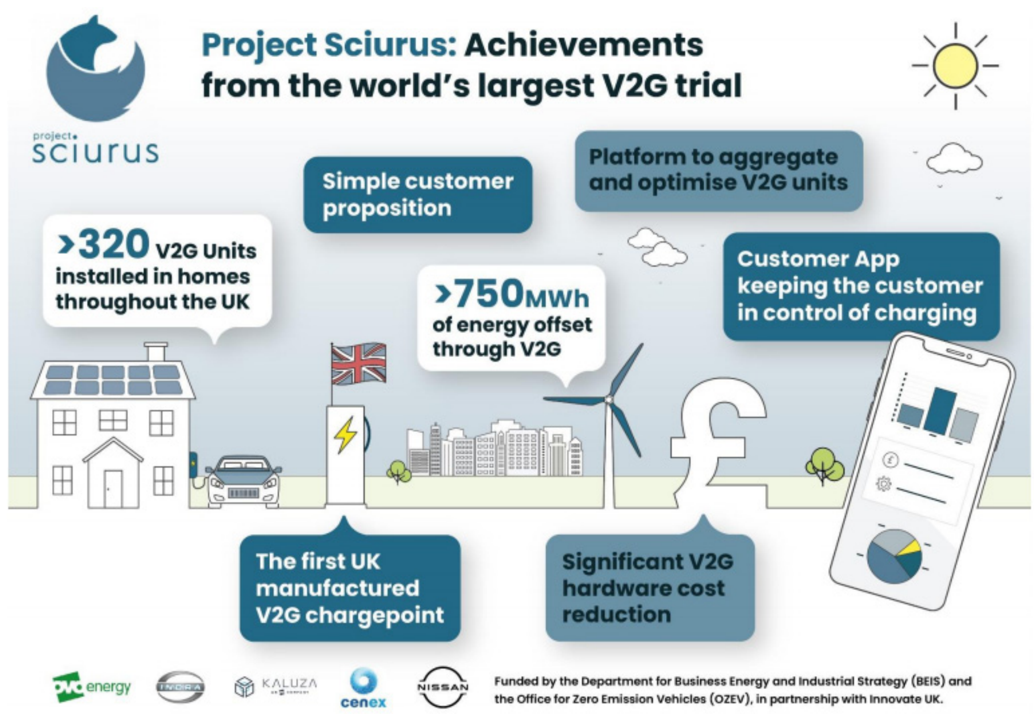


Source: Elia

V2G WORKS IN PRACTICE: INSIGHTS FROM OVO'S REAL-WORLD V2G TRIALS IN THE UK

In a real-world example from **OVO Energy** (unlisted), a UK energy retailer, ran the world's first and largest residential V2G program in 300+ homes across the UK over 18 months from April 2018.

EXHIBIT 460: **World's largest V2G trial lead by OVO energy**



Source: Cenex

OVO's V2G trial has drawn the following conclusions:

- On average, 36% of EVs are plugged in and available at all times to either import or export power to the grid. However, due to driver habits impacting the battery state of charge across the day, the capacity is more available for balancing at peak times and overnight, and less available during the day.

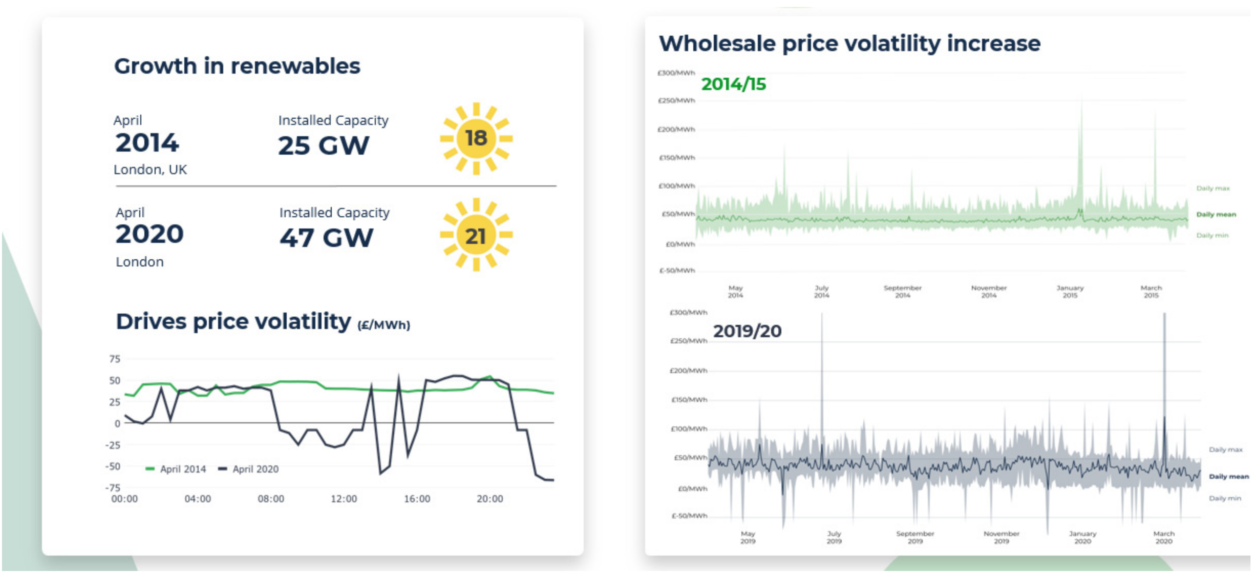
- The average customer imported 11.36kWh and exported 6.77kWh per day and customers plug-in to charge on average 18 times per month. In the trial, 319 V2G connected EVs offered 0.38MW of capacity to support the grid at peak times. Scaling this up to the UK vehicle fleet of 35 million vehicles implies a capacity of 42GW to support the grid at peak times, which is a significant amount and around two-thirds of current UK peak demand of 60GW.

- The key revenue streams for V2G in a domestic context are optimization against a time-of-use tariff, offering flexibility to central markets via an aggregator, and maximizing self-consumption of onsite PV. On average, customers on the trial earned £420 per annum, primarily based on arbitraging opportunities.

- Over time, revenues for customers should increase with growing price volatility and market access to grid balancing revenue streams. As an example, Exhibit 461 shows how wholesale price volatility in the UK has increased just in a matter of six years.

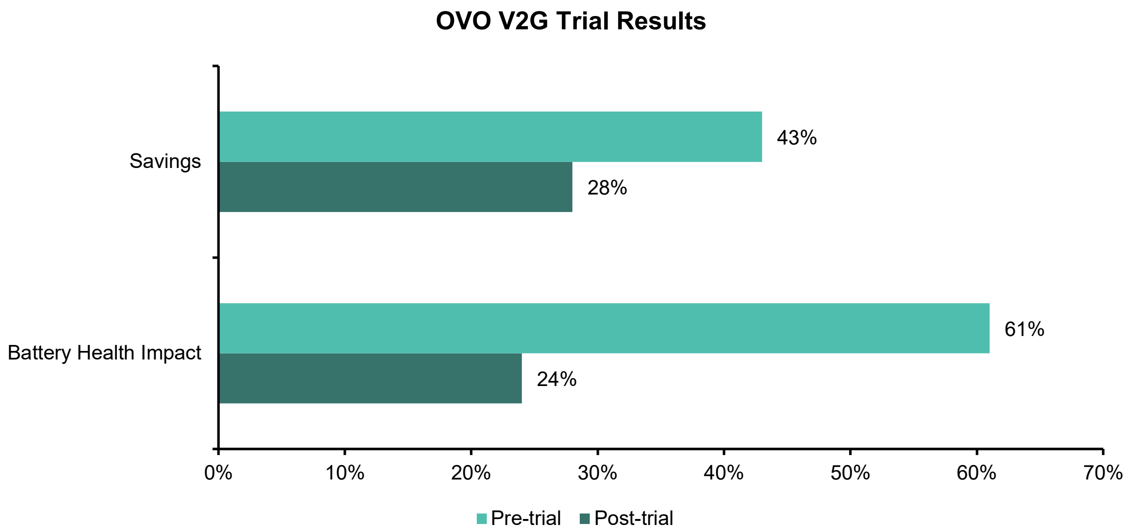
- Customer worries reduced as the trial proceeded, particularly on battery degradation and cost savings from V2G.

EXHIBIT 461: **Increasing renewables penetration increases wholesale price volatility, which improves V2G incentives**



Source: Kaluza

EXHIBIT 462: **Customer concerns on battery degradation and savings have abated post-trial**



Source: OVO and Bernstein analysis

- Hardware costs of bi-directional chargers came down dramatically from £15,000+ in 2017 to £2,500-£3,500. If OEMs incorporate bi-directional charging technology built into the EV, costs to consumers will be significantly lower at £350, as a standard home charger can be used for V2G in the future.

INVESTMENT IMPLICATIONS

- The two main infrastructure investments to enable EV rollout are a public charging network and upgrades to the electricity distribution grid to cope with the rise in peak charging demand. We forecast investments of €90bn in the public charging networks in Europe and distribution grid investments of €100-€185bn for EV integration. Grid investments can be reduced by 30-60% through smart charging and V2G technologies; furthermore, intermittent renewable resources can be better utilized.

- Companies with meaningful exposure to electricity distribution networks in our coverage include E.ON, National Grid, SSE, NextEra, Enel, EDP, Iberdrola, and EDF (all rated Outperform), and Endesa (rated Market-Perform). The following companies are involved in EV charging infrastructure with some scale: E.ON, NextEra, Enel, EDP, Iberdrola, and EDF (all rated Outperform), and Fortum (rated Underperform).

Equity – Banks

Sector: Banks

Hit the (Electric) Throttle

Rise of EVs and Role of Auto Lenders

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WHY READ?

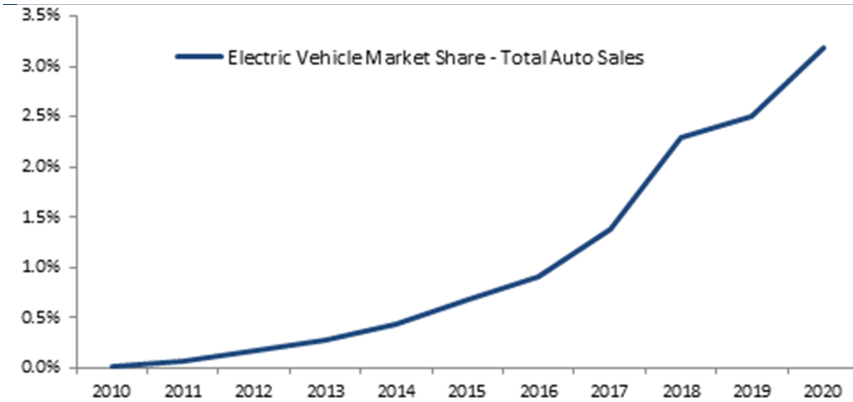
As part of Bernstein's Electric Revolution research series, we explore the impact of electric vehicles (EVs) on the auto lending industry. EVs make up a tiny share of the global auto market today, representing ~3% of total volumes in 2020, though growth has accelerated considerably in recent years. EVs have much higher financing and leasing penetration than ICE-powered vehicles. Thus, captives are well positioned to increase the market share of auto financing in an EV world. However, so far, EVs also have much weaker residual values, creating a dilemma for captives.

- **Overview**: The EV market share is tiny at just ~3% of total global auto sales in 2020, but considering EV sales were a rounding error just a decade ago, sales growth for EVs has gained considerable momentum. We anticipate the market share shift toward EVs to slowly transition over the next couple of decades rather than an imminent wholesale paradigm shift.
- **Auto finance market structure:** In the US auto finance market, captives (e.g., Ford Motor Credit) now represent the largest market share at 34% of total financing in 2020, representing the first year captives have captured the top spot — a position historically held by banks. We believe the value of captives further increases in an EV world as OEMs will have greater incentive to "own the consumer" to sell software updates, battery performance upgrades, autonomous driving features, connectivity, etc.
- **Lease rates:** In the US, new vehicles tend to be purchased most commonly with loans (56%); the next most common auto financing method is leasing (26%) and the rest are purchased outright in cash (18%). EVs tend to have considerably higher lease rates and we believe as the whole concept of "mobility as a service" becomes more attractive, people we turn more toward leasing vehicles.
- **Residual values:** EVs do not have the greatest reputation of holding their value off-lease, as rapidly improving battery technology makes models just a few years old seem quite outdated. There is also a that risk the residuals of EV drop as pricing is inflationary on the back of massive government incentives. For now, of course, the used EV market is tiny. Longer term, carmakers should be in a much better position to manage residual values with all the vehicle data and more sophisticated software. We believe better, less volatile residuals will help the leasing model become more attractive.

Overview

We contemplate the role of auto lenders in a world of electric and connected vehicles, with a focus on the US auto lending market. Consumers have shown an increased willingness to ditch traditional gas-guzzling ICE-powered vehicles in exchange for high-tech and environmentally friendly EVs. Today, the EV market share is tiny at just ~3% of total global auto sales in 2020, but considering EV sales were a rounding error just a decade ago, sales growth for EVs has gained considerable momentum (see Chart 1).

Chart 1: EVs steadily growing market share of global auto sales



Source: IEA and Autonomous

China is widely considered the leader in EVs, followed by Europe and the US, growing at a 72%/41%/22% five-year CAGR over 2015-19, respectively (see Chart 2). The rise of EVs in the US has lagged as: (a) the US government hasn't made as strong a push to incentivize EV ownership versus Chinese and EU counterparts and (b) American consumers have a strong cultural attachment with traditional ICE vehicles (i.e., Ford's F-series was the top-selling car in the US in 2020 for the 39th straight year).

Chart 2: EV sales volume growth led by China and Europe, followed by US

Source: IEA and Autonomous

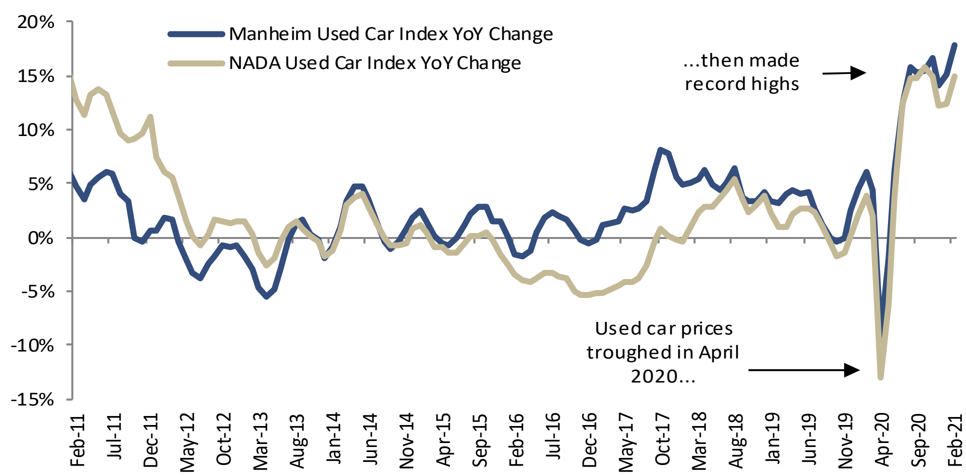
As EVs become more widely adopted, benefiting from rapidly improving technology and expanding charging infrastructure, there is a focus on the pace of transition from ICE-powered vehicles. One concern is that if ICE-powered cars experience a "Netflix moment," i.e., the transition to EVs is a step-change, residual values of ICE would be negatively impacted. In a tweet in early 2020, Elon Musk warned of this exact scenario (see Chart 3).

Chart 3: Elon Musk's ominous warning for ICE vehicles' residual value

Source: Twitter and Autonomous

Shortly after Elon Musk's February 2020 tweet, Covid-19 hit and used car prices declined by ~(10)% in April 2020 due to the uncertainty the auto industry and consumers were facing. However, we saw an extraordinary rebound in the summer of 2020, bringing used car prices to all-time highs on account of low new car inventories and a resilient consumer aided by government stimulus (see Chart 4). So, while Musk expects residual values for gas-powered vehicles to decline in the coming years, in the near term, used car prices in the US have been rising to all-time highs.

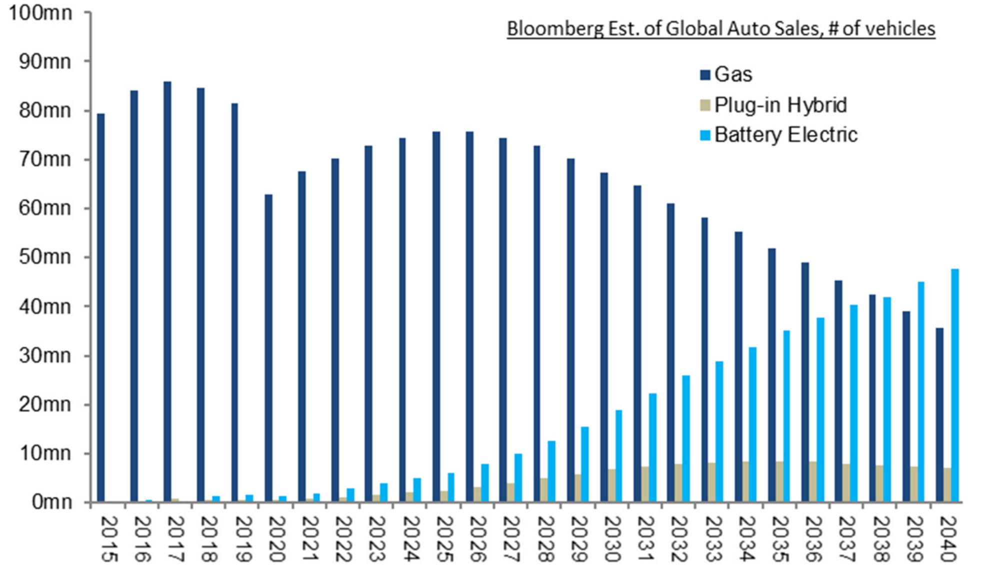
Chart 4: Residual car values rose at a record pace in late 2020 and beyond



Source: National Automobile Dealers Association (NADA), Manheim, and Autonomous

We anticipate the market share shift toward EVs to slowly transition over the next couple of decades rather than an imminent wholesale paradigm shift. For example, Bloomberg expects EV global auto sales volume to overtake gas-powered vehicles by 2039. That said, some auto manufacturers have set much more aggressive timelines, such as GM's goal to go all electric and phase out gas and diesel engines by 2035. Still, we do not expect the EV transition to happen fast enough to cause a shock on residuals for ICE vehicles (see Chart 5).

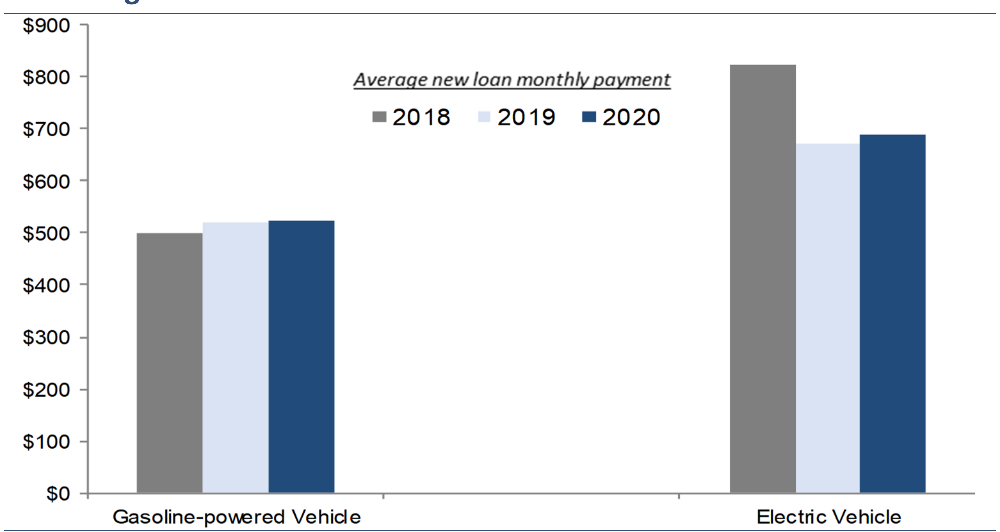
Chart 5: Transition to EVs from ICE vehicles expected to take some time



Source: Bloomberg data and estimates (2021+) and Autonomous

One of the limiting factors in faster adoption of EVs is cost. EVs tend to be meaningfully more expensive up-front compared to the average ICE vehicle. That said, battery technology improvements and greater manufacturing scale point to EVs becoming more competitive on price over time (see Chart 6). Beyond cost, other common consumer concerns with EVs include: (1) range limitations, (2) driving performance, and (3) limited charging infrastructure.

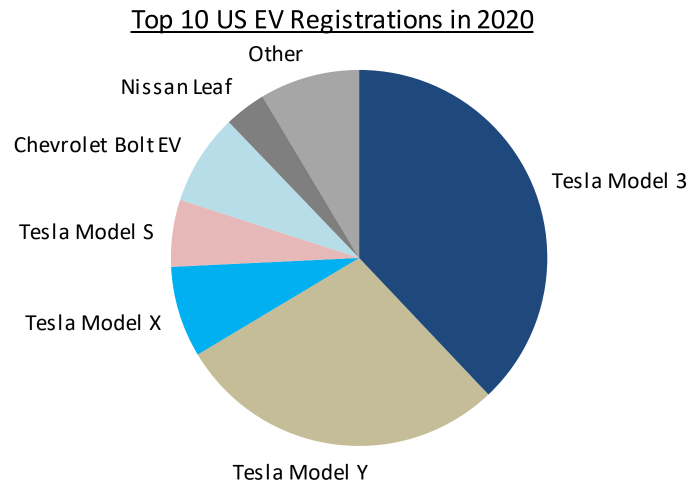
Chart 6: EV costs have limited widespread adoption, but they are becoming more affordable



Source: Experian and Autonomous

One consideration for the US EV market is that Tesla reigns supreme, accounting for ~80% of total new EV registrations in 2020 with four models in the top 5 (Chevy's Bolt EV is #3, just ahead of Tesla's Model S and X) (see Chart 7). Tesla has unique dynamics compared to the broader EV market due to its dedicated following and supply constraints. Thus, as explored later in this chapter, when looking at industry-level statistics, it is important to keep in mind how Tesla may skew the data.

Chart 7: Tesla dominates the US EV market, representing ~80% of new registrations in 2020

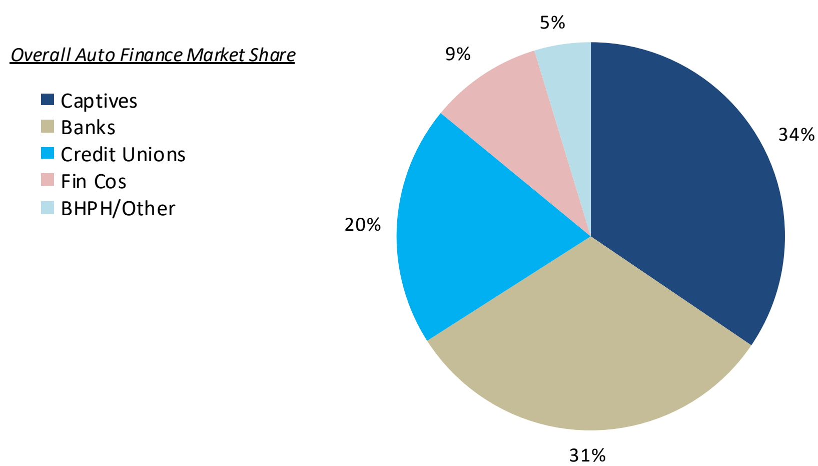


Source: U.S. Department of Energy and Autonomous

Role of Captives in an EV World

OEMs' fully owned captive finance subsidiaries have been quite profitable for carmakers, and have become a leading force in the auto finance industry. Today, captives (e.g., Ford Motor Credit) represent the largest market share at 34% in 2020, followed by banks at 31%, credit unions at 20%, and finance companies at 9% (see Chart 8). Interestingly, 2020 represents the first year that captives have captured the top spot, a position historically held by banks.

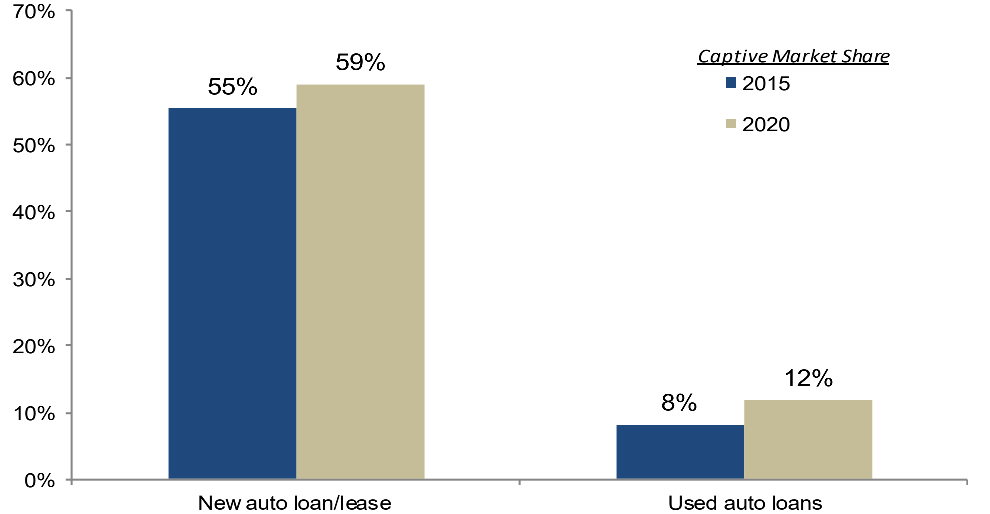
Chart 8: Captives now represent the largest market share in auto finance



Source: Experian and Autonomous

Since 2015, captives have gained share in both new and used auto lending markets, representing 59% of new auto loans and leases, and 12% of used auto loans in 2020 (see Chart 9). Captives have been able to gain market share by offering more favorable terms to borrowers compared to other lenders — thanks to captives' support of automakers' core business of moving metal.

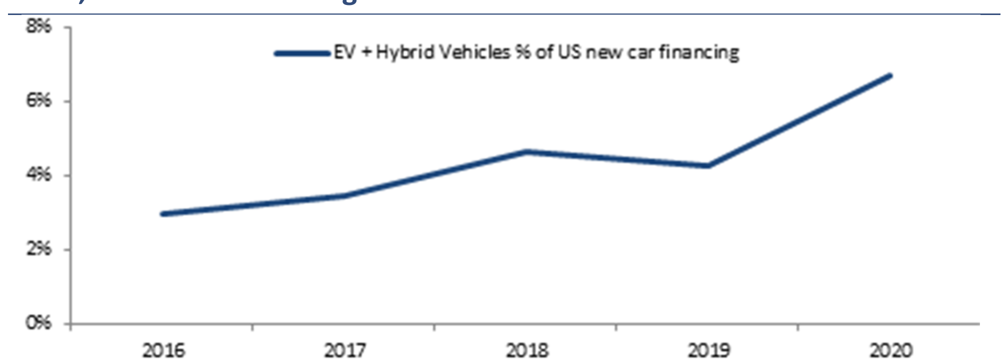
Chart 9: Captives have gained share in both new and used auto lending



Source: Experian and Autonomous

We don't have a crystal ball to see what the market structure of the auto finance industry will look like. That said, our colleagues at Bernstein focusing on Automotive Research led by Arndt Ellinghorst believe the advantages of captives increase in an EV world. This is underpinned by the notion that OEMs will want to "own" the consumer as the economics may change with increased EV penetration. In an EV world, carmakers will look to generate incremental revenue streams beyond the core business of moving metal, such as selling software updates, enhanced battery performance, autonomous driving capability, connectivity and a host of other add-on features. With that, fully owning the customer via leasing of the financing agreement massively helps. This indicates captives are well positioned to take market share as EV adoption increases.

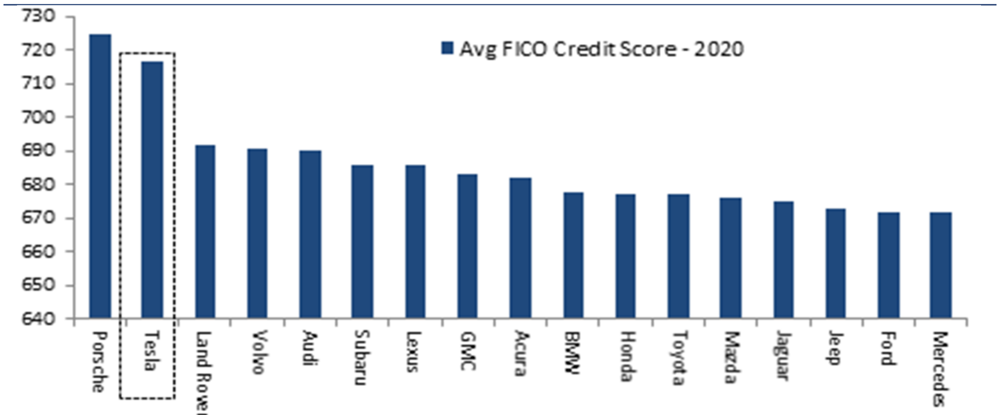
Chart 10: EV + Hybrid vehicles represented ~7% of new car financing in 2020, more than doubling market share from 2016 levels



Source: Experian and Autonomous

As for the more immediate impact to auto lenders, while we don't expect any shocks as noted, traditional auto lenders focused on financing ICE vehicles may face headwinds from lower sales volumes and used car pricing. Today, the impact can be felt in the super prime auto leasing market as Tesla has successfully attracted a younger, more affluent, and higher-income demographic — the average Tesla buyer has the second-highest FICO score across all carmakers (see Chart 11). That can partly be attributed to the high cost of a Tesla specifically and EVs more broadly. Going forward, as battery technology improves and EVs become more affordable, we could very well start to see more prime, near-prime, and subprime borrowers opting to go electric and present a headwind to auto lenders traditionally focused on ICE vehicles across credit tiers.

Chart 11: Tesla buyers tend to have high credit scores, taking a bite out of the super-prime auto borrower market

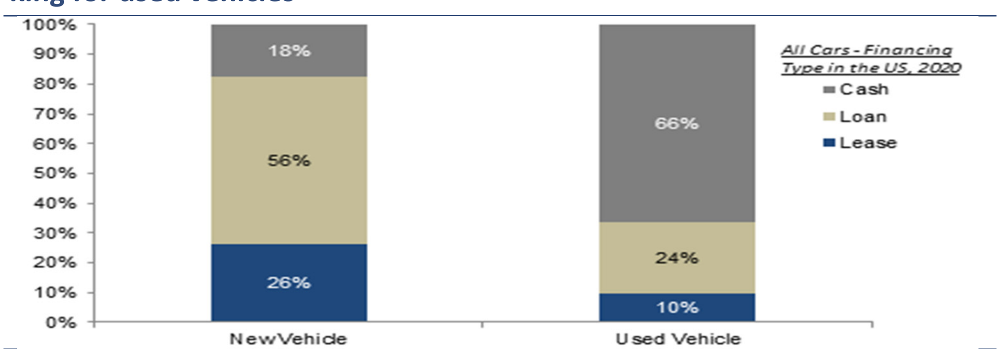


Source: LendingTree and Autonomous

Future of EVs: Does the Leasing Model Have Room to Run?

Overall for the auto finance industry, new vehicles tend to be purchased most commonly with loans (56%); the next most common auto financing method is leasing (26%) and the rest are purchased outright in cash (18%) (see Chart 12). Used cars are more commonly purchased in cash (66%), followed by loans (24%) and finally leases make up just 10% of used auto financing.

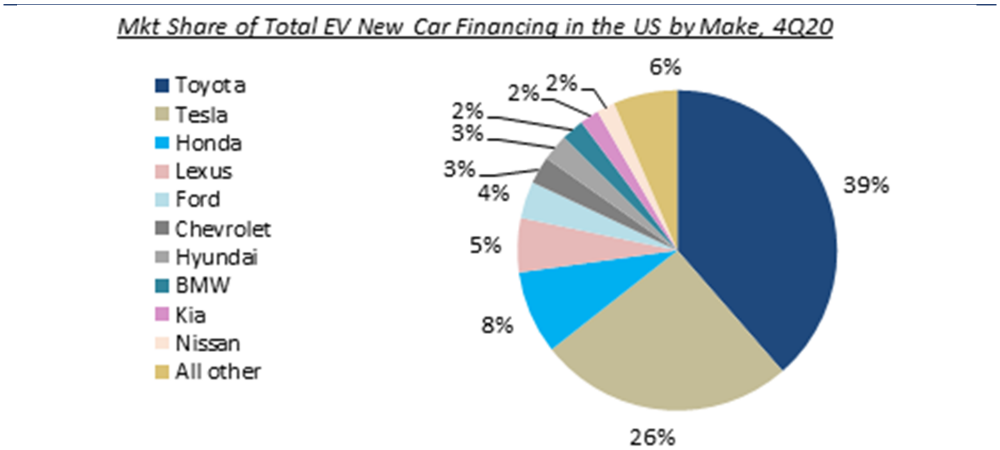
Chart 12: Loans make up the majority of new car financing, while cash is king for used vehicles



Source: Experian and Autonomous

Lease rates for EVs tend to be considerably higher for fully battery EVs and PHEVs versus the traditional ICE vehicle. According to a news publication (click here), lease penetration for EVs (excluding Tesla) was an astonishingly high 80% versus just 30% for all vehicles just a couple years ago (see Chart 13). Early adopters of EVs may opt to lease their cars at a higher rate for a few key reasons: (1) battery, technology, and other capabilities (i.e., autonomous driving features) have been improving at a rapid pace in the past decade; the lease option ensures the consumer is on a relatively short three-year replacement cycle; (2) depreciation of EVs tends to be much steeper than ICE counterparts due to the thin used EV market, rapid improvement in technology, and government incentives inflating MSRPs; and (3) the uncertainty of owning an EV long term with respect to potential range degradation and battery replacement.

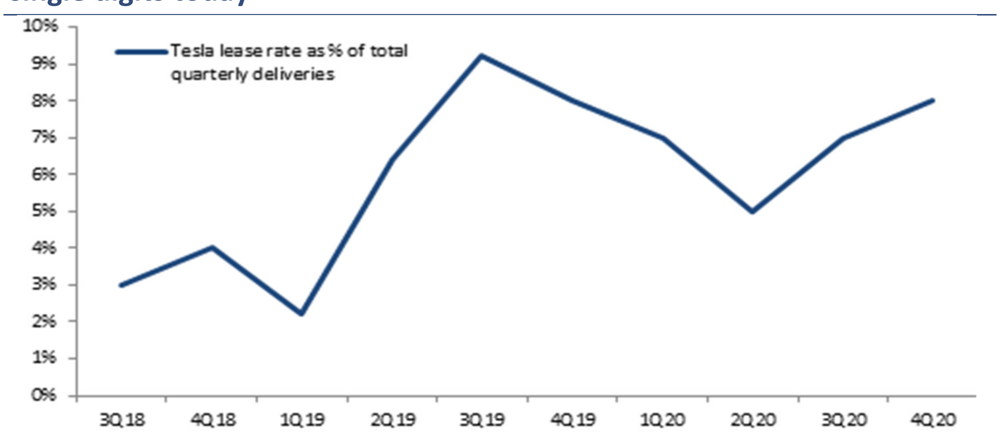
Chart 13: Toyota and Tesla lead in the EV new car financing market



Source: Experian and Autonomous

Tesla tends to have a lower lease rate — in the single-digit range — of all vehicles delivered in any given quarter versus other EVs. This could partly be explained by the unique demand/supply dynamics Tesla benefits from as well as the perception that Tesla vehicles have superior technology that makes them "future proof" to an extent (see Chart 14). While lease rates are relatively low compared both to ICE counterparts and especially low versus EV competitors, lease rates of deliveries over the past several quarters have trended higher, going from low single digits in 2H18 to high single digits today.

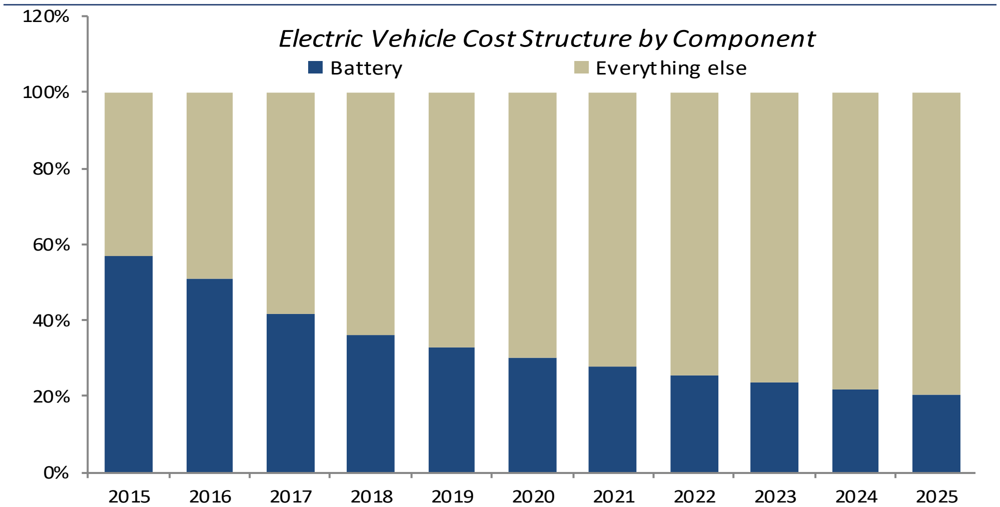
Chart 14: Tesla lease rates have been trending higher, though in high single digits today



Source: Company filings and Autonomous

EVs are prime for leasing models for two primary reasons: (a) as noted previously, EVs are more digital products and OEMs will need to "own the customer" in order to sell software-related services; and (b) batteries have significant value in their second and stationary life; thus there is a need for batteries to be managed by OEMs (see Chart 15).

Chart 15: Batteries make up a significant portion of EV cost structure

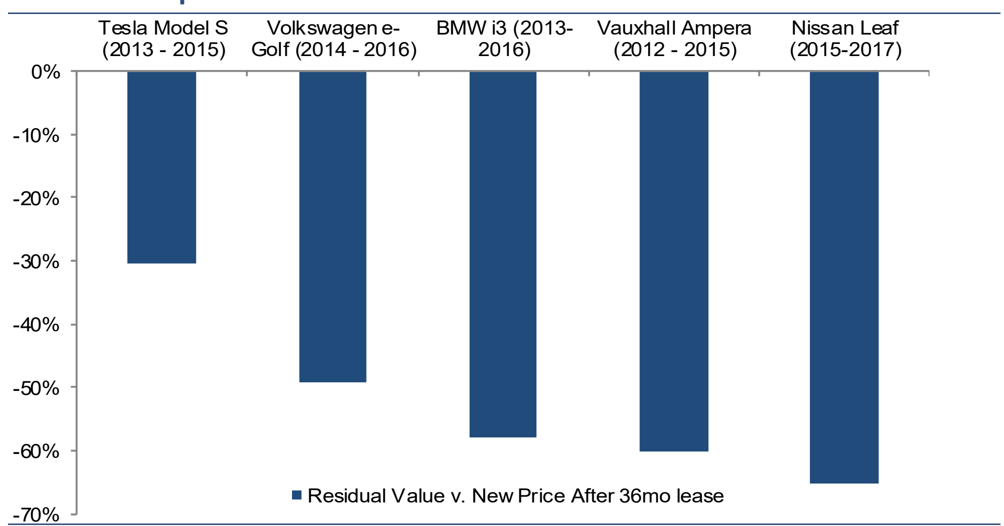


Source: Bloomberg and Autonomous

EV Residual Values

Residual values, the estimated worth of a vehicle once it is off lease, is a key factor in consumers' buy versus lease decisions, pricing of leases and used cars, and determining collateral for lenders. Given how important residual values are, one key aspect of EVs is that they tend to have steeper depreciation schedules compared to their ICE counterparts (see Chart 16). For example, according to an online publication, "A new sedan depreciates 39% after three years while trucks do a little better at 34%. EVs drop an astonishing 52% however, making their owners lose quite a bit of their investment." That said, not all EVs are made the same. For instance, a Tesla depreciates in line with or better than ICE vehicles, likely due to higher demand for used Tesla models and more resilient technology.

Chart 16: Depreciation is a concern for EVs outside of Tesla



Source: DrivingElectric and Autonomous

There is hope that as EVs become more sophisticated and "future-proof," depreciation schedules will improve and residual values will be better managed by OEMs, given the data carmakers will be able to utilize. Today, steep EV depreciation can be attributed to:

- Technology becoming outdated quickly. EVs were always expected to depreciate a little faster than regular ICE vehicles because they feature "unproven" technology that'll be a little more worrisome to a second or third owner, out of warranty, than to an eager new car buyer and early adopter. There is hope that as EVs become more "future-proof," the vehicles will be able to better retain their value. Tesla is clearly a leader in terms of technology (i.e., all cars manufactured today have autonomous driving capability), thus it depreciates less than other EV counterparts.

- Significant government subsidies inflating new EV prices. As an example, a new Nissan Leaf MSRP was about US$31,000 for the base trim of the vehicle in 2017. After adding in federal tax rebates, consumers paid ~US$22,000 for the vehicle off lot. Thus, vehicle depreciation versus sticker price for the Nissan Leaf and other EVs isn't necessarily entirely absorbed by the initial car buyer.

CHINA'S EV CHARGING CONSTRAINTS: IS (SUPER) FAST-CHARGING OR BATTERY SWAPPING THE SOLUTION?

OVERVIEW

- As carmakers roll out more and more EV products, the discussion on the pace of EV adoption increasingly shifts to charging infrastructure. **In this context, charging concerns remain a key hurdle to EV adoption in China.** EV sales penetration is highest in the top 6 cities because of license plate restrictions (14% in 2020), but mass-market adoption in the rest of the country remains very low (3% in 2020). Many Chinese consumers are concerned that it's difficult to find chargers and that charging speed is slow.

- **Only one-third of public EV chargers are functioning.** As of April 2021, China had 868,000 public chargers, yielding a ratio of 6.5 EVs per public pole (down from ~7.5:1 at the end of 2019 and ~8:1 at the end of 2018). Assuming that Chinese drive an average of ~40km a day and most of the top-selling EVs in China now offer a driving range of at least 200-400km, EV owners only need to plug-in their cars once or twice a week. However, the majority (58%) of public charging poles are slow AC chargers. In addition, a significant portion of public charging poles do not work. Furthermore, a proportion of public charging poles are in low-traffic locations and/or not maintained. Many charging poles have been abandoned and it is also not uncommon for ICE cars to be parked in a spot equipped with EV chargers. VW estimates that only 30-40% of currently installed public poles qualify as real supply.

- **Parking infrastructure constraints limit residential/overnight charging.** Due to concerns regarding current public charging infrastructure, the availability of residential charging remains a key factor regarding the speed of EV adoption in China. In 2020, only 18.5% of BEV sales came with a wall-box charger, down from 31.5% in 2019 and 34.0% in 2018. The main issues facing the installation of residential EV chargers are infrastructure limitations (related to local power infrastructure or the availability of parking spaces) and restrictions imposed by property landlords.

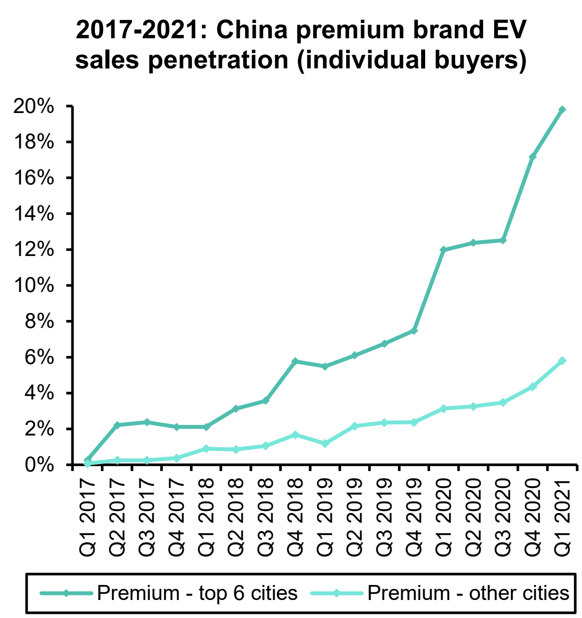
- **Is battery swapping the solution to China's EV charging problem?** To materially accelerate EV adoption in China, it is critical to offer users stress-free charging. Given China's fundamental constraint of lack of residential parking, widespread availability to (super) fast charging is a must-have. Alternatives to current mainstream charging include battery swapping and wireless charging. Looking at Nio's battery swapping that takes as little as three minutes, the technology is mature and Chinese consumers are very receptive to it, but we are concerned about the financial sustainability of this high capex and high-working-capital operation. For wireless charging, we think the technology is too immature at this juncture.

CHARGING CONCERNS TURN CAR BUYERS AWAY FROM EVS

EV charging concern is one of the top reasons that hinder EV adoption in China. EV sales penetration is high in the top 6 cities as a result of license plate restrictions (14% in 2020), but mass adoption (3% in 2020) in the rest of the country is lagging in both the premium brand and mass-market segment (see Exhibit 463 and Exhibit 464).

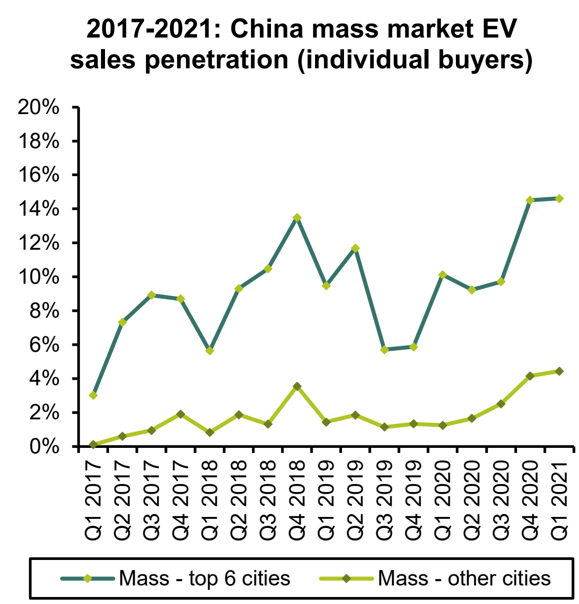
While many Chinese consider purchasing an EV, the conversion rate to purchase is deemed low. In a survey conducted by McKinsey, 45% of car buyers in China who considered an EV in their last purchase, complained about battery and charging. In comparison, only 35% of car buyers in Germany, Norway, and the US expressed the same concern (see Exhibit 465). Also, the primary concern of EV owners in China is the difficulty in finding chargers, followed by slow charging speeds and location of chargers.

EXHIBIT 463: **EV sales penetration is high in the top 6 cities as a result of license plate restrictions...**



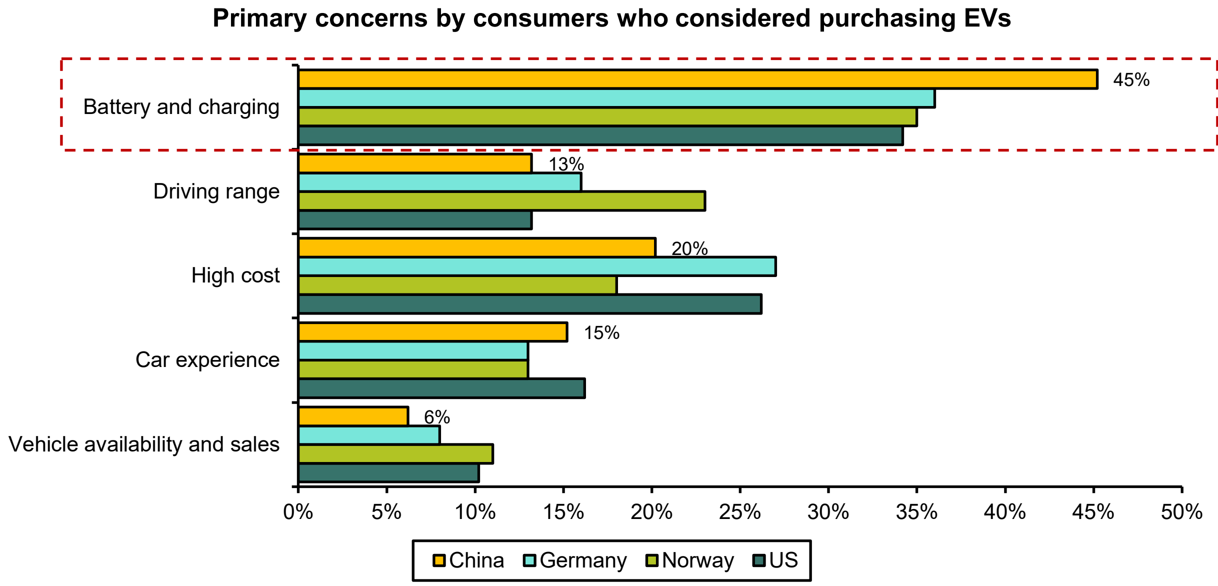
Source: C.A.D. and Bernstein analysis

EXHIBIT 464: **...but mass adoption in the rest of the country is lagging in both premium brand and mass market segments**



Source: C.A.D. and Bernstein analysis

EXHIBIT 465: **45% of Chinese consumers surveyed are most concerned about battery and charging**



Source: McKinsey EV Consumer Survey 2019 and Bernstein analysis

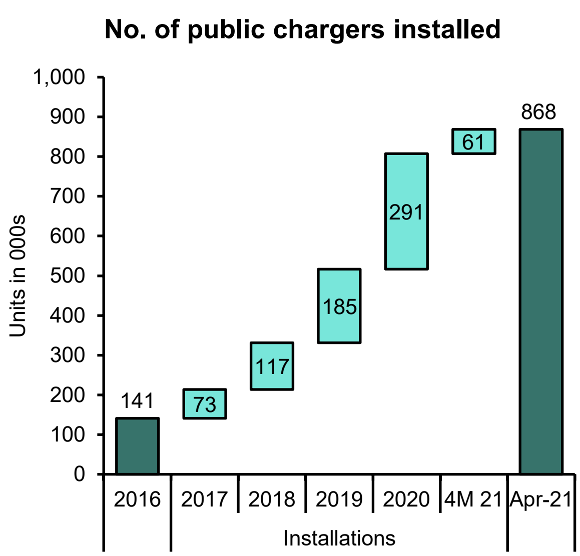
PROBLEM WITH PUBLIC CHARGING INFRASTRUCTURE IN CHINA: ONLY A THIRD IS OPERABLE

China EV parc reached 5.51 million by the end of 1Q2021 according the Ministry of Public Security, and China's EV Charging Infrastructure Promotion Alliance (EVPICA) had 868,000 public chargers on record as of April 2021 (see Exhibit 466) These data points imply an EV parc to public pole ratio of ~6.5:1, improving from ~7.5:1 at the end of 2019 and ~8:1 at the end of 2018 (see Exhibit 468). Going off the assumption that Chinese on average drive ~40km a day and most top-selling EVs in China now offer a driving range of at least 200-400km, EV owners would technically only need to plug in their cars once or twice a week. Hence, coupled with the private/residential chargers build-out (959,000 units as of April 2021), one might think an EV parc to public pole ratio of 6.5:1 might be considered enough.

However, this does not give a complete picture of the charging infrastructure shortage in China. Based on EVICPA data, ~60% of public charging poles are fitted with slow AC charging (i.e., output power setting at 3.5kW, 7kW, or 15kW) and ~40% with DC charging poles (output power setting ranges from 30kW to 180kW) (see Exhibit 467). For example, China's Tesla Model 3 with a 55kWh battery can take up to 10 hours to fully charge with slow charging, versus around one hour with fast charging. While slow charging may be acceptable for charging overnight, it may be difficult to access if it is offered far from residential neighborhoods, or if the chargers are occupied by others.

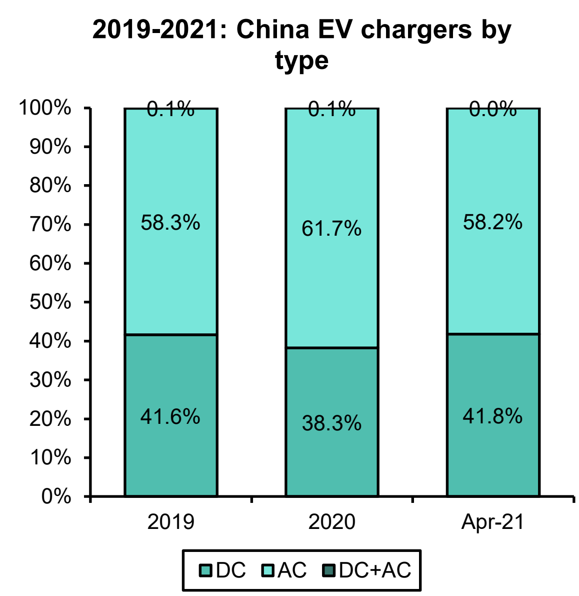
In addition, we understand a good portion of public charging poles on record today are inoperable. Government subsidies in the earlier years attracted a lot of investment in EV charging infrastructure; however, that does not necessarily make the best business case. A number of public charging poles were built in low-traffic locations and/or not maintained or upgraded. Because of low utilization and insufficient return, many charging poles have since been abandoned (also known as "phantom poles"). It is also not uncommon for ICE cars to be parked in a spot equipped with EV chargers. According to VW, ~30% of charging spots in China are routinely occupied by non-EVs and another ~30% of the charging poles are defective, leaving only 30-40% of public poles on record as real supply. We also calculated average daily utilization per public charging pole. Taking electricity consumed, and dividing it by the number of charging poles and an estimate of output power settings, we arrived at a utilization rate of merely ~1.2 hours per day per pole. And this calculation does not account for peak demand (see Exhibit 469). Public EV chargers are poorly equipped to deal with surge demand (e.g., during popular shopping hours, or on the highway during the few weeks every year when all of China takes to the roads), and maintenance can be an issue too. Other problems include the very fragmented nature of the EV charger industry, with operators often insisting on the use of proprietary smartphone apps that do not necessarily offer a seamless charging experience for users (although this appears to be improving).

EXHIBIT 466: **The number of useable public EV chargers could be only 30-40% of what is on record**



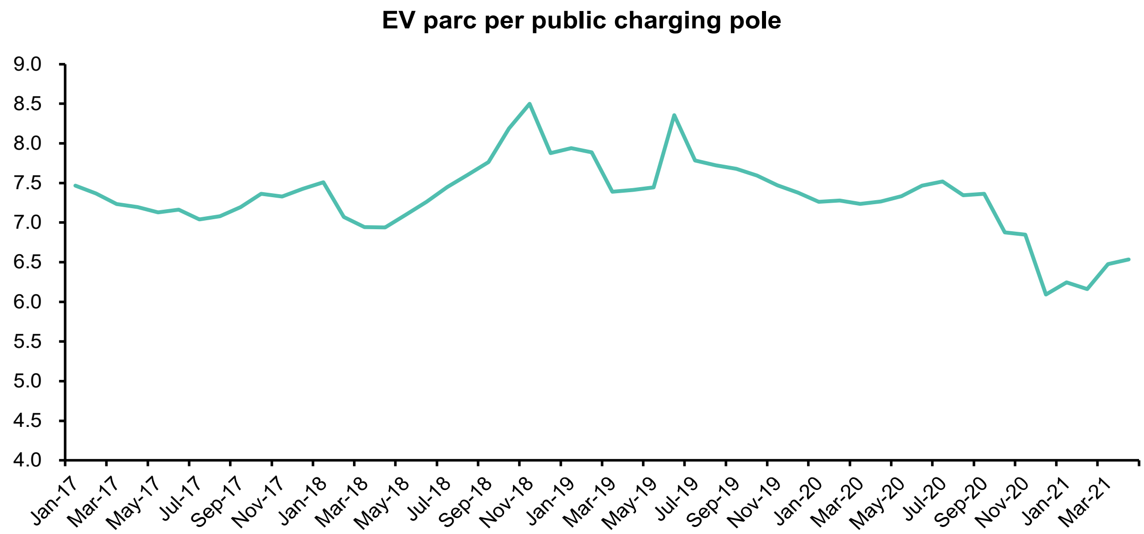
Source: EVCIPA and Bernstein analysis

EXHIBIT 467: **As of year-end 2020, ~60% of public poles are still fitted with slow AC charging, compared to ~40% with DC charging**



Source: EVCIPA and Bernstein analysis

EXHIBIT 468: **EV parc per public charging pole has decreased to ~6.5:1; still insufficient to ease worries**



Source: EVCIPA, CAAM, and Bernstein analysis

EXHIBIT 469: **Many public charging poles are inoperable: they were either built in low-traffic locations, not maintained, and/or occupied by ICE vehicles; public charging poles are being utilized for EV charging only around one hour a day on average**

	2020
Electricity consumption by public charging (excl. State Grid, Putian) (in mm kwh)	**7,055**
Number of public charging poles - excl. State Grid, Putian (year end)	**611,170**
DC (~60 kw)	38%
AC (~7 kw)	62%
Output power setting (blended AC & DC) (kw)	27.3
Average hours in use per day (hours)	**1.16**

Source: EVCIPA and Bernstein analysis

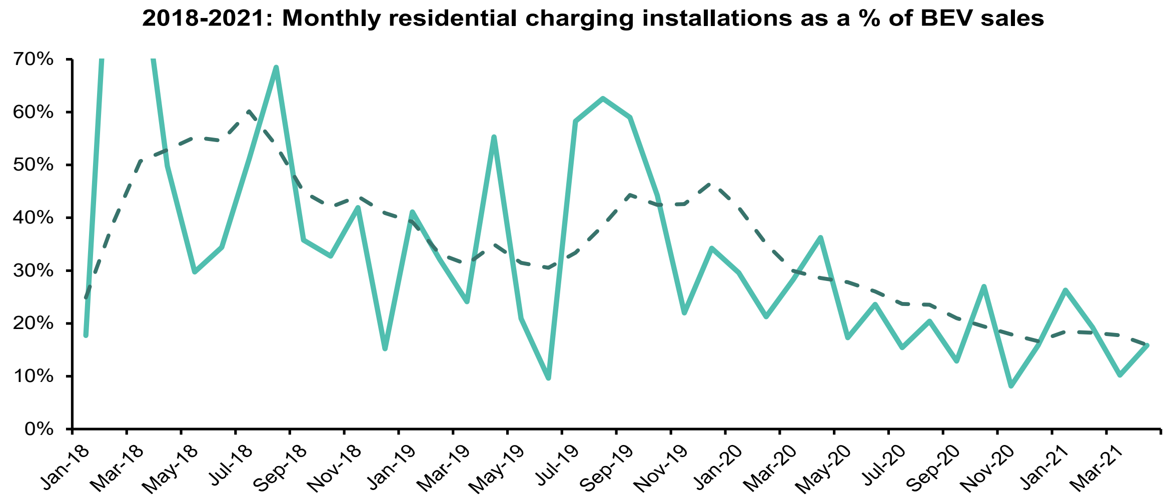
AVAILABILITY OF PARKING SPACES AND LOCAL POWER INFRASTRUCTURE LIMIT RESIDENTIAL CHARGING

We consider the availability of residential charging an important determinant for a car buyer in China to consider buying an EV. In 2020, only 18.5% of BEV sales came with a wallbox charger, down from 31.5% in 2019. Excluding Wuling Honguang Mini, a best-selling micro BEV which can be charged by directly plugging into a 220V power point, the ratio is still only at 21.1% still. The ratio worsened coming into 2021. LTM (up to April 2021), only 16.8% of BEV buyers were able to install a wallbox charger (20.1% excluding Wuling Honguang Mini). We expect the residential charging-to-EV sales ratio will continue to remain at low levels and will likely decline further (see Exhibit 470).

The main issues facing the installation of residential EV chargers meanwhile include infrastructure limitations (related to local power infrastructure or the availability of parking spaces), or restrictions otherwise imposed by property management offices. Following one of the Tesla fires in 2019, a number of residential complexes reportedly banned the installation of EV chargers at underground parking spaces.

We expect China's lack of residential parking to remain an issue for EV adoption. At the end of 2017, the Beijing and Shenzhen governments noted that the cities had residential parking deficits of 1.3 million and 1.8 million spaces, respectively. Our more recent discussions with industry contacts close to Shenzhen city planners reflected an increase in the deficit to some 2.0 million residential parking spaces (see Exhibit 471 and Exhibit 472).

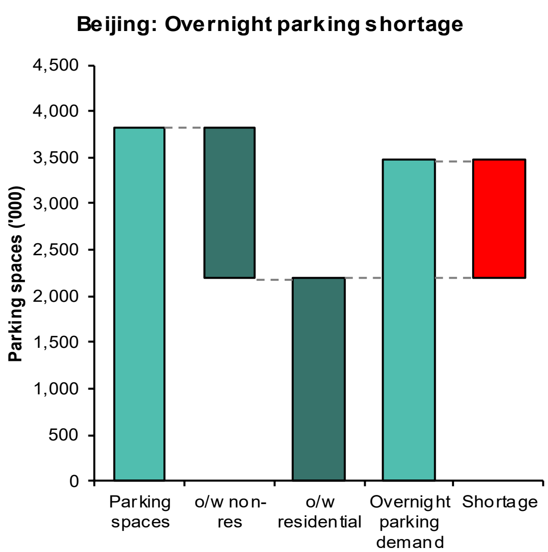
EXHIBIT 470: **We expect the residential charging-to-EV sales ratio will continue to remain at low levels and will likely decline further; the constraint in parking spaces and, hence, wallbox installations, could limit EV sales growth**



Note: Dotted line denotes six-month rolling average.

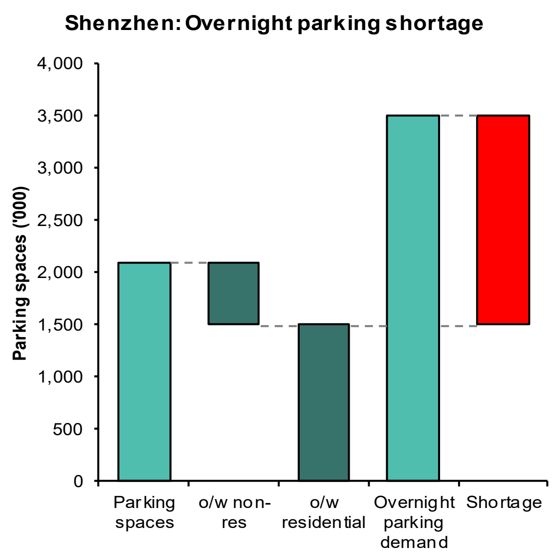
Source: C.A.D., EVCIPA, and Bernstein analysis

EXHIBIT 471: **According to government reports, Beijing had a shortage of 1.3 million overnight parking spaces...**



Source: Government reports and Bernstein analysis

EXHIBIT 472: **...and for Shenzhen, it stood at almost 2 million**



Source: Government reports and Bernstein analysis

The problem with China's residential charging regulations

Since 2015, the Chinese government has started to require developers of new residential, commercial, and public sector buildings to incorporate EV charging capabilities as part of the construction of residential complexes. Out of the 35 cities in China we deem to be tier 1-2, 27 had explicit government regulations mandating developers to provide "infrastructure enabling EV charger construction" as part of new residential developments. In 24 cities, local government regulations mandated all residential parking spaces to be equipped with such infrastructure. But only in six cities — Shenzhen, Chongqing, Dongguan, Chengdu, Changsha, and Zhengzhou (in all 2% of residential parking spaces) — regulations mandated developers to construct EV chargers (see Exhibit 473).

There are several important issues with the Chinese government's regulation around charging infrastructure, in our view.

- First, the building of "infrastructure enabling EV charger construction" typically only meant laying down power lines and ensuring the local power grid could handle EV charging. Often consumers would still need to seek permission from property management as well as various government offices to install an EV charger.

- Second, in most of China's higher-tier cities the typical ratio between apartments in residential complexes and parking spaces has been something in the range of 2:1 to 4:1, depending on location and price point. In these cities where most households have cars, this means a significant proportion of households do not own their own parking space. So, the penetration of EV chargers per household is even lower than the target levels for EV charger installation penetration.

- Third, the long life of residential property means it takes many years for newer residential complexes to become an appreciable proportion of the residential property stock in each city. Most city-level regulations around residential EV charging infrastructure were introduced in 2015-17, suggesting that less than 10% of residential complexes in higher-tier cities were built while the new rules were in place.

There is no publicly available data on the distribution of residential EV chargers in China, but anecdotally we've encountered numerous examples of residential complexes in a variety of cities where it was simply not possible to install EV charging, either due to limitations to the power infrastructure in the residential complex or surrounding area, or simply because property management stood in the way for other reasons.

EXHIBIT 473: **All of China's tier 1-2 cities have rules in place that require property developers to facilitate EV charging infrastructure (e.g., lay down power lines), but only six cities require any EV chargers to be built**

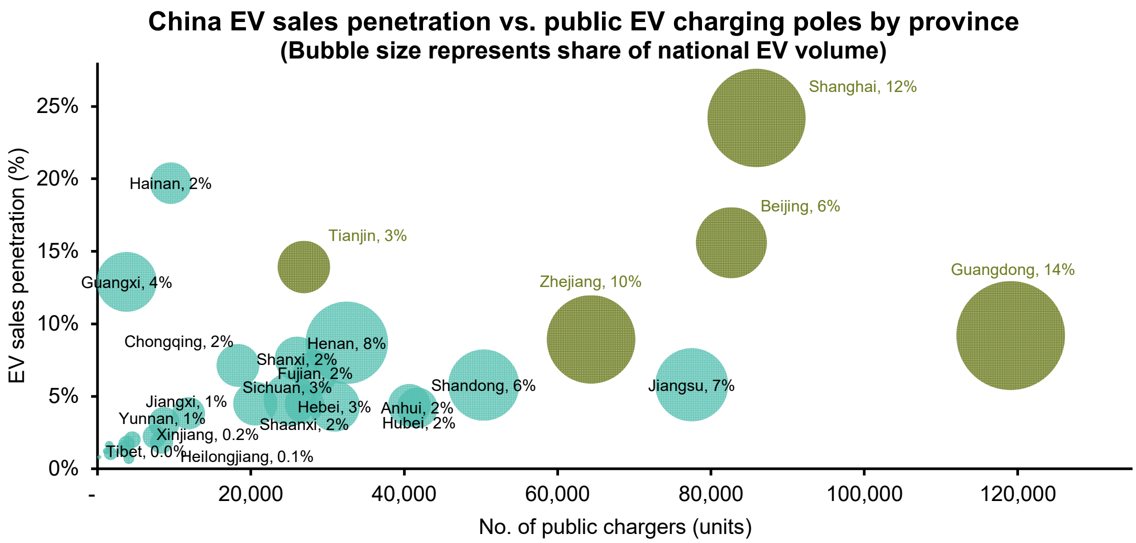
City	Regulations announced	% of residential parking spaces: EV charger infrastructure	% of residential parking spaces: EV charger
Cities with license plate restrictions			
Beijing	2017	100%	n.a.
Shanghai	2015	>10%	n.a.
Shenzhen	2018	>30%	>30%
Guangzhou	2018	100%	n.a.
Hangzhou	2016	100%	n.a.
Tianjin	2016	100%	n.a.
Other tier 2 cities			
Chongqing	2018	100%	>30%
Dongguan	2017	100%	>25%
Chengdu	2017	>20%	>20%
Changsha	2017	100%	>10%
Zhengzhou	2017	100%	>2%
Dalian	2016	100%	n.a.
Foshan	2019	100%	n.a.
Harbin	2016	100%	n.a.
Jiaxing	2016	100%	n.a.
Jinan	2020	100%	n.a.
Nanjing	2017	100%	n.a.
Qingdao	2016	100%	n.a.
Shenyang	2016	100%	n.a.
Taizhou	2020	100%	n.a.
Wenzhou	2017	100%	n.a.
Xiamen	2016	100%	n.a.
Xi'an	2017	100%	n.a.
Zhenjiang	2016	100%	n.a.
Zhongshan	2015	100%	n.a.
Zhoushan	2016	100%	n.a.
Zhuhai	2017	100%	n.a.

Source: Government websites and Bernstein analysis

WIDESPREAD AVAILABILITY TO (SUPER) FAST CHARGING IS A MUST TO MATERIALLY ACCELERATE EV ADOPTION IN CHINA

Limitations around residential charging reemphasizes the importance of building out public charging infrastructure to drive EV sales in China. Currently, public charging infrastructure build-out is highly concentrated in a handful of provinces. Guangdong, Shanghai, Beijing, and Zhejiang come top nationally in terms of both EV sales and EV charger installation. Those provinces also house five of the top 6 cities with license plate restrictions. There is a long tail of provinces with EV sales penetration significantly below the national average and have minimal public charger build-out. The industry should continue to invest in fast-charging infrastructure across provinces to boost EV sales. We argue that the lack of chargers around the country will deter car buyers who need to make longer trips outside the top cities. EV startups are rapidly expanding their battery and charging network in China, with Tesla being the forerunner. Nio and Xpeng are playing catch up as well (see Exhibit 474 to Exhibit 477).

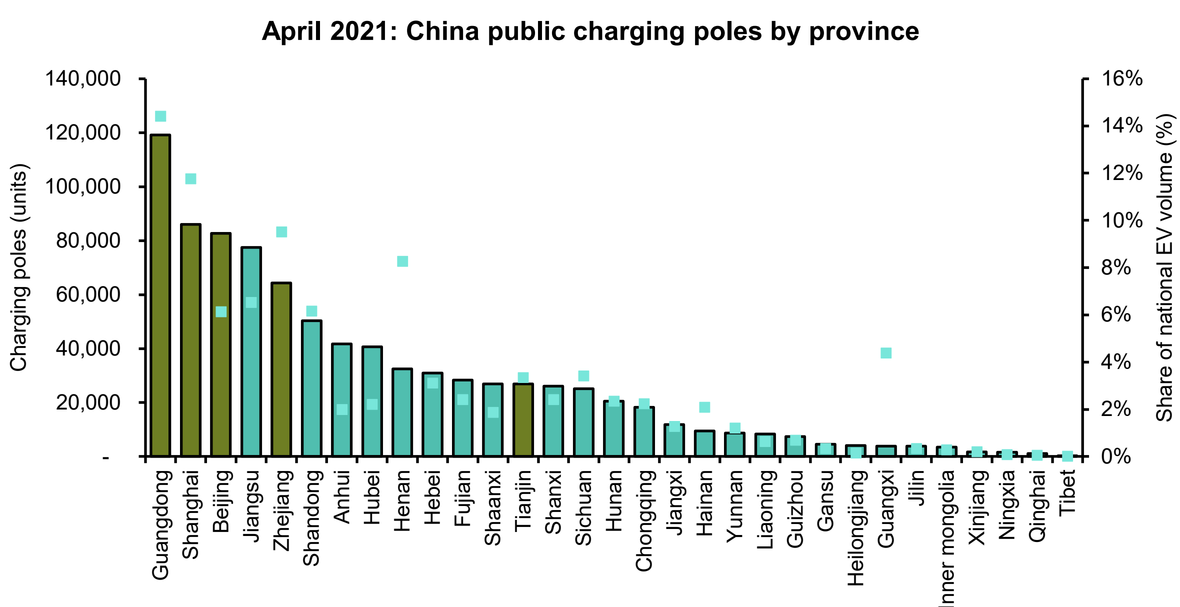
EXHIBIT 474: **Guangdong, Shanghai, Beijing, and Zhejiang stand out nationally in terms of both EV sales and EV charger installation**



Note: Provinces highlighted in dark green (dark gray in print) house cities with license plate restrictions: Guangzhou and Shenzhen are located in Guangdong province and Hangzhou is the biggest city in Zhejiang province.

Source: C.A.D., EVCIPA, and Bernstein analysis

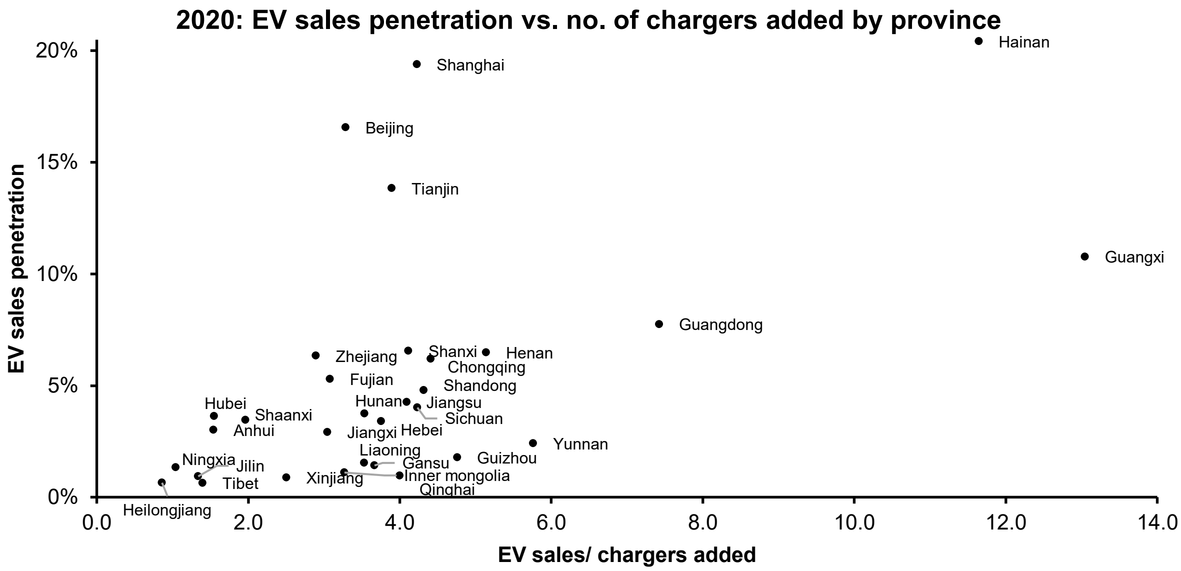
EXHIBIT 475: **There is a long tail of provinces with EV sales penetration significantly below the national average and minimal public charger build-out**



Note: Dotted line denotes national average EV sales penetration; provinces highlighted in dark green (dark gray) have license plate restrictions

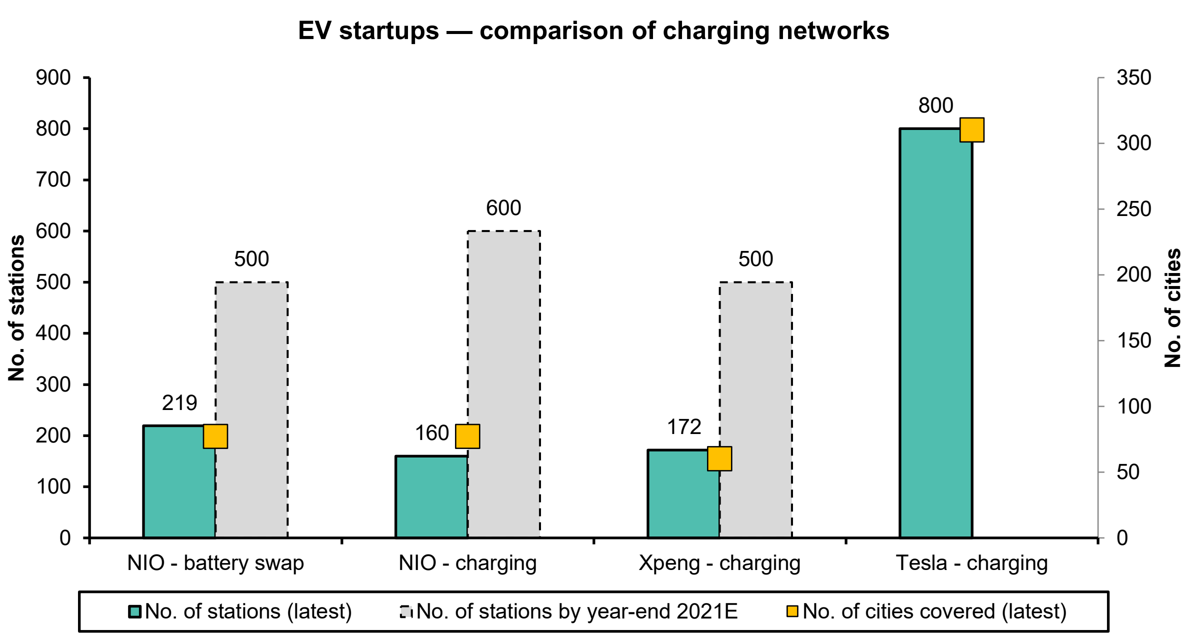
Source: C.A.D., EVCIPA, and Bernstein analysis

EXHIBIT 476: **The industry should continue to invest in public charging infrastructure across provinces to boost EV sales; the lack of chargers around the country will deter car buyers who need to make longer trips outside the top cities**



Source: C.A.D., EVCIPA, and Bernstein analysis

EXHIBIT 477: **EV startups are rapidly expanding their battery and charging networks in China**



Note: Latest information up to March 2021 for Xpeng, and May 2021 for Nio and Tesla. Nio has signed a deal with Sinopec to cooperate on developing battery swapping stations. Sinopec has plans for 5,000 battery swapping stations by 2025.

Source: Company reports and Bernstein analysis

ALTERNATIVE SOLUTIONS TO RANGE, BATTERY, AND CHARGING CONCERNS

In this section, we look at alternative solutions including battery swapping and wireless charging.

BATTERY SWAPPING: WILL NIO MAKE IT WORK THIS TIME AROUND?

Battery swapping takes the car's depleted battery and replaces it with a fully charged one. The empty battery is then fully recharged in the station and ready to be swapped into another vehicle. Early pioneers that adopted this battery swap technology included Project Better Place in Israel (2012-13) and Tesla in California, US (2015). Better Place filed for bankruptcy in 2013 and Tesla (covered by Bernstein's Toni Sacconaghi) shelved the project in 2015. Nio (not covered) is the latest consumer-facing EV startup adopting this technology and so far it has made more progress than the earlier ones, but is the strategy sustainable?

Case study on Nio

Nio launched its first battery swapping station in May 2018 and the second generation of battery swapping stations ("Power Swap station 2.0") in April 2021. Nio claims the entire swap process can be completed within three minutes, which is comparable to traditional gasoline refueling and significantly faster than fast charging (around one hour) (see Exhibit 478).

Nio's business model:[72] Nio offers six battery swaps a month for free and charges for the seventh battery swap onward if the customer forgoes installing a wallbox charger at home. Nio charges RMB180 per swap at launch, before deciding to give owners free monthly swap quotas. Swap charges vary across locations depending on the electricity charge and operating costs. The price point is higher than the charging cost but less than what it would cost to fill up a gas tank. Nio owners could also subscribe to a "Worry-Free Power Plan" for RMB980 per month, which comes with 15 battery swaps (or door-to-door valet charging service) every month.

Nio's battery swap offering is gaining traction. The company completed 2 million battery swaps up to late March, of which 1 million were completed between October 2020 and March 2021. Although the number of swaps per station per day has gone up to ~30 times, that is still a long way below the capacity that the stations were built for (see Exhibit 479 and Exhibit 480).

Our take — consumers love it, but it's tough to get the economics to make sense when scale is hard to come by

Battery swapping offers significant convenience for EV owners who do not have residential/overnight charging, which is a significant issue especially in China. Best of all, it

[72] Other potential models for battery swapping include swapping out the battery for one of a larger size, enabling higher range for a shorter period of time, and to have a vacant space in the vehicle which can take an additional battery to boost range. In both instances, the user would probably pay a daily rental.

takes less than five minutes, which is the fastest solution today to replace a dead battery with a 100% charged battery. With automated parking, the driver doesn't even need to get out of the EV to complete the process. Battery swapping seems like a neat solution, but it has several drawbacks.

For battery swapping to be as easy as charging, standardization is required. Otherwise, it will be difficult to achieve economies of scale. At present, batteries are not swappable across brands and this situation is unlikely to improve, especially since batteries have increasingly become a structural element of the vehicle. Battery swapping also requires huge working capital in order to finance the inventory of sufficient battery-pack capacity across the entire system of swapping stations.

In addition, the infrastructure is expensive:

- The swapping station requires a large machine that looks like something out of Iron Man, if several customers are anticipated to arrive at a rate of more than one every five minutes.

- The batteries need to be plugged in even while out of the vehicle to maintain an optimum state of charge, and they need to be kept in temperature-controlled conditions (akin to a giant server room).

- The facilities, therefore, need access to high power lines, which require special safety systems (see Exhibit 481).

Experience from Project Better Place in Israel, an early adopter of the technology, suggests that people want to keep "their" battery. If this is true, battery swap stations would have to keep the original battery to one side while awaiting the original owner, requiring a larger physical footprint. This feeling of proprietorship seems to exist even when the battery is rented, but since EV is still in its infancy, it is difficult to be definitive. Looking at the take rate of Nio's BaaS battery subscription service, battery proprietorship does not seem to bother Chinese users, however. If anything, they seem happy about getting a battery-free EV for a lower price and pay for battery rental every month (more on Nio's BaaS later) .

In the case of Nio, battery swap is practically offered for free. Based on average commute distance (~40km daily average), most EV owners' electricity needs can be taken care of with the six swaps per month that come for free (should the Nio owner forgo installing their own wallbox charger). In other words, Nio basically assumes most of the capex, working capital, and operating costs involved. Also, the inherent cost associated with battery degradation is also shifted to Nio. However, the agreement with Sinopec to build battery swapping stations may help share some of the financial burden (or at the minimum, help with locating swapping stations at prime spots). Also, the Chinese government is supportive of promoting the battery swapping technology. Even though the government is scaling back subsidies for EVs with selling prices above RMB300,000, an exemption to the price cap was made for vehicles like Nio equipped with battery swap technology. Furthermore, this service offering no doubt helps promote Nio's brand as one that is focused on enhancing the user experience and should drive sales volume. We have often heard that Nio's battery charging and swapping options were important factors that drove purchase decisions.

EXHIBIT 478: **Nio's battery swap takes only ~3-5 minutes, significantly faster than super-/fast- charging (around one hour)**

Operator	Power (kW)	Time to full charge	Cost (RMB/100km)	Assumption
Tesla/Nio/Xpeng super-charging	~120 - 250	< 1 hr	~ 25	Super-charging costs ~RMB1.5-2/kWh
Third-party fast-charging (e.g., State Grid and Star)	~60 - 120	~ 1hr	~ 20	Fast-charging costs ~RMB1-1.5/kWh
Home charging	~ 7 - 20	~ 8 - 10 hr	~ 8	Household electricty costs ~RMB0.55/kWh
Nio battery swapping		3 - 5 min	~ 40	Battery swap costs RMB180 per swap for a 70 kWh battery
Gasoline refueling		~5 min	~ 65	Gas mileage of ~9L/100km and gasoline costs ~RMB7/L

Note: Approximate time to fully charge a 70kWh battery.

Source: Company reports, media reports, and Bernstein estimate and analysis

EXHIBIT 479: **Nio launched a second-generation battery swapping station in April 2021, with 3x the capacity of its predecessor; Nio has plans for 500 battery swap stations by year-end 2021, which will come with significant capex spend**

1st Generation

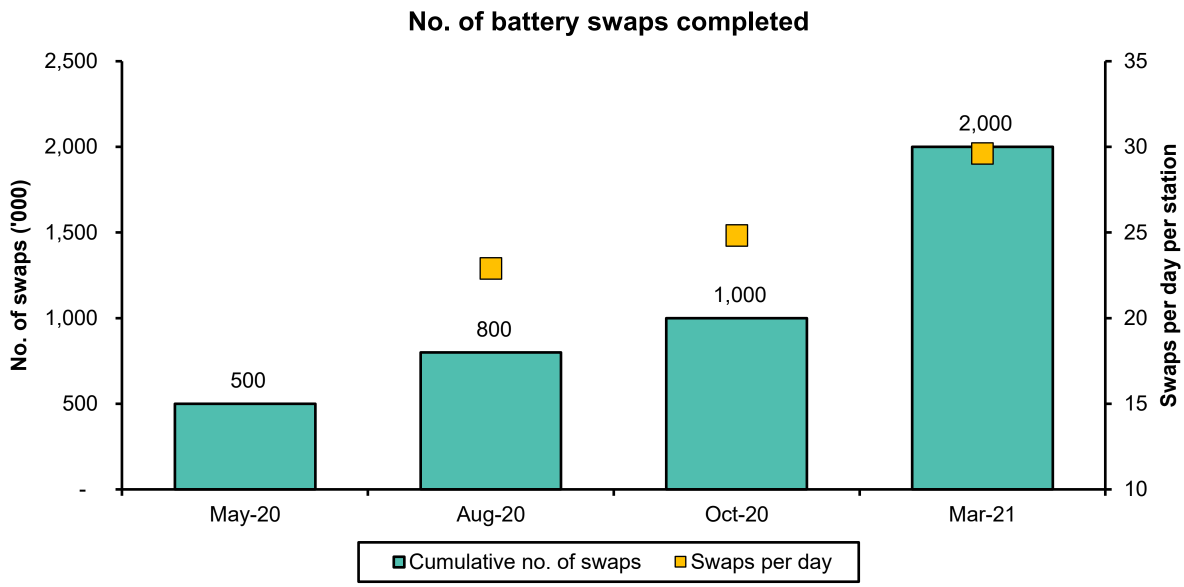
- 5 batteries per station
- ~100 swaps / day
- ~ 5 min needed

2nd Generation

- 13 batteries per station
- Up to 312 swaps / day
- ~ 3 min needed

Source: NIO, company reports, and Bernstein analysis

EXHIBIT 480: **Nio completed 2 million battery swaps by late March 2021 and provided 30 swaps/station/day on average; consumer reception to the service is growing, but is that just because it is offered for free?**



Note: Nio owners are offered six free swaps per month if they forgo having their own wallbox charger.

Source: Company reports and Bernstein analysis

EXHIBIT 481: **Battery swaps bring significant convenience to EV owners, but require significant capex and working capital**

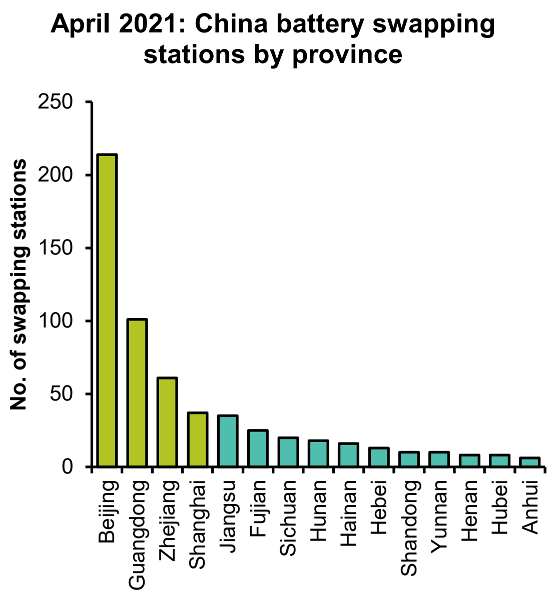
Benefits	Drawbacks
• Positive consumer reception — solves the concern over long charging times (takes less than five minutes) • Brings significant convenience for EV owners who do not have access to residential/ overnight charging • With automated parking, the driver doesn't even need to get out of the EV to complete the process • The technology can potentially offer users the flexibility to trade up their batteries (e.g., upgrading from a 70kWh battery to a 100kWh or a 150kWh battery), depending on one-off needs/ technological advancements	• High capex — the infrastructure of the swapping station is expensive (e.g., high power lines are needed and require special safety systems, batteries need to be kept in temperature-controlled conditions, etc.) • Huge working capital requirement in order to finance the inventory of sufficient battery-pack capacity across the entire system of swapping stations • Difficult to achieve economies of scale as batteries are not standardized and, therefore, not swappable across brands (and will likely remain that way)

Source: Bernstein analysis

Other battery swapping operators in China focus more on taxis and ride-hailing companies

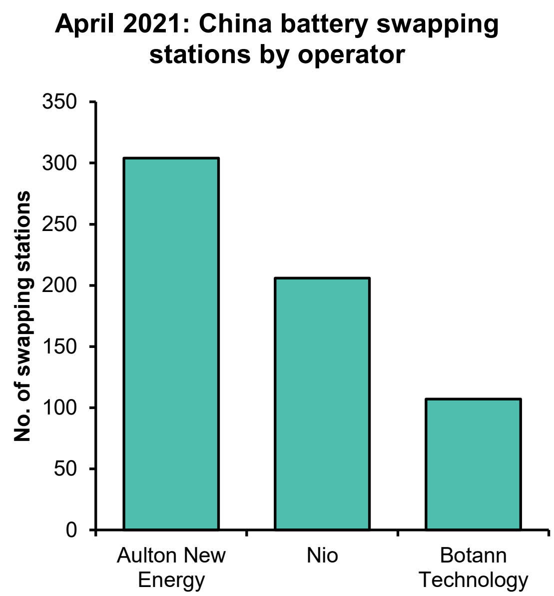
Aside from Nio, other battery swapping operators in China focus more on EVs for commercial use. The largest battery swapping operator in China is Aulton New Energy, which had ~300 swap stations in China as of April 2021. Aulton mainly partners with BAIC's NEV subsidiary (BJEV) to service battery swapping for electric taxis. On the other hand, Botann Technology, which has ~100 swap stations, works mainly with Dongfeng and Lifan, among others. Most battery swapping operators in China focus more on serving taxis and ride-hailing vehicles, where standardization and scale are easier to achieve (see Exhibit 482 and Exhibit 483).

EXHIBIT 482: **Beijing houses more than a third of the battery swapping stations in China...**



Source: EVICPA and Bernstein analysis

EXHIBIT 483: **...as Aulton, the largest battery swapping operator in China, partners with BAIC to service swapping for electric taxis in Beijing**



Source: EVICPA and Bernstein analysis

Nio's BaaS — battery rental subscription service

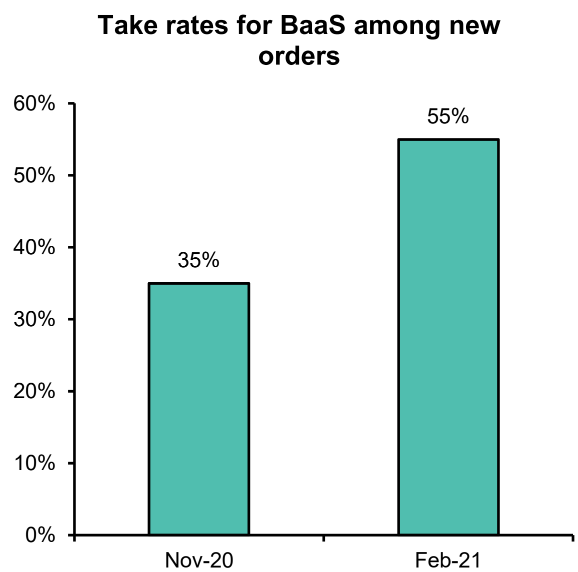
Nio launched the Battery as a Service (BaaS) in August 2020. Under BaaS, car buyers enjoy RMB70,000+ off the listed car price (MSRP) and buy the EV "battery-free." Instead, users lease battery packs of various sizes according to their needs, and pay on a monthly basis, starting from RMB980/month. BaaS users may upgrade their battery at any time (e.g., from a 70kWh battery to a 100kWh or a 150kWh battery). Since rollout, BaaS has been very popular and reached over 50% take rate within six months (see Exhibit 484 and Exhibit 485). The buyer enjoys a lower upfront cost and has reduced worries of battery degradation. Theoretically, BaaS could encourage buyers to trade up after buying the car, swapping out their smaller capacity batteries for larger ones on-demand, based on their needs. Management spoke briefly on this, suggesting that the larger 100-150kWh batteries could provide an opportunity to improve gross margins among its existing user base. The high take rate of BaaS possibly suggests that Chinese consumers are receptive to the idea of not having to "own" their EV battery.

EXHIBIT 484: **Nio drivers taking up BaaS save RMB70,000 upfront, and pay RMB980/month for renting a 70kWh battery**

	ES8		EC6		ES6	
	70kWh	100kWh	70kWh	100kWh	70kWh	100kWh
MSRP (RMB)	468,000	526,000	368,000	426,000	358,000	416,000
Post-subsidy (RMB)	450,000	503,500	350,000	403,500	343,600	393,500
Price with BaaS (RMB)	380,000	375,500	280,000	275,500	273,600	265,500
Upfront savings (RMB)	70,000	128,000	70,000	128,000	70,000	128,000
Monthly fee (RMB/mth)	980	1,480	980	1,480	980	1,480
Payback period (yrs)	6.0	7.2	6.0	7.2	6.0	7.2

Source: Company reports and Bernstein analysis

EXHIBIT 485: **Nio's BaaS is a popular offering with over 50% take rate**



Source: Company reports and Bernstein analysis

Wireless charging: immature technology that is coming to market too slow

Next, we take a look at wireless EV charging (WEVC) or wireless power transmission (WPT).

- WPT technology can be split into four main types: (1) **magnetic coupling resonance (MCR)**, (2) magnetic induction, (3) radio reception, and (4) capacity coupling. MCR is by far the most applicable for EV charging due to its good efficiency, moderate operable distance, and relatively high-power rating. See Exhibit 486 for a brief comparison between the other types of WPT. We note that this can be further split into static charging (i.e., charging when the car is stationary), and dynamic charging (i.e., charging when the car is in motion).

- For now, WPT is primarily restricted to static commercial applications, but wireless charging functions are making their way into mainstream PVs. Notably, Zhiji (SAIC-Alibaba JV) launched its L7 in April 2021 (delivery in 2022), which includes wireless charging capabilities. See Exhibit 487 for a summary of notable applications of wireless charging in China to date.

- Driver convenience aside, proponents believe WPT suits autonomous vehicles (specifically autonomous parking), due to the ability to park and charge the car without human intervention. There are touted economic benefits in terms of battery longevity as well.

- Disadvantages of WPT include outsized initial and maintenance costs, lower economies of scale at the moment, and lower efficiency versus fast charging options today. Also, the charging environment too is sensitive, and operators have to ensure that the charging pad is clear of debris or any electromagnetically sensitive items such as pacemakers. See Exhibit 488 for a summary of the pros and cons of WPT.

Our take: We lean on the skeptical side of this technology. It seems far too immature at this point, and supercharging technology can recharge an EV battery to 80% full in ~30 minutes already. While dynamic charging seems game-changing, we'd highlight that stretch of road needs to be long enough to make the effects appreciable — and current estimates stand at RMB7,000 per sqm (vs. the threshold for mass adoption at RMB3,000/sqm). Investors should also be cognizant of potential resistance to change by OEMs that could be adverse toward increasing the weight of their vehicles while changing the design, location, and specifications of their charging ports and receivers.

EXHIBIT 486: **There are four main types of wireless charging technology; magnetic coupling resonance is a frontrunner in terms of viability**

Type of wireless charging	Resonance	Magnetic Induction	Radio Reception	Capacity Coupling
Transmission power	W-kW	W	mW	1-10W
Distance	cm-m	mm-cm	Around 10m	mm-cm
Avg efficiency	>80%	75-85%	38%	70-80%
Convenience	High	Acceptable — depends on application	High	Acceptable — depends on application
Advantages	Suitable for moderate distance, high power charging with good efficiency	High efficiency, suitable for very short distance charging	Suitable for long distance, low power charging	Suitable for short distance charging with high conversion efficiency and low heat generation
Disadvantages	Relatively lower efficiency versus inductive charging	Needs to be aligned closely and accurately to the charging pad — vehicle suspension systems vary in the tens of cms and easy to overheat	Low charging efficiency and extremely long charging times	Low power restricts technological headroom and charging times for EVs

Source: Media reports and Bernstein analysis

EXHIBIT 487: **China's WEVC development began with commercial bus fleets, but is gradually making its way into mainstream view...the latest launch being Zhiji L7 from SAIC and Alibaba in April 2021**

Date	Segment	Companies involved	Elaboration
Apr-21	PVs	Zhiji (SAIC-BABA JV)	• The 2022 Zhiji L7 comes with an 11kW wireless charging function, with an efficiency of ~91%
Dec-20	PVs	FAW Hongqi	• Launched the Hongqi E-HS9 that supports wireless charging technology
Jan-20	PVs	ZTE, Geely	• ZTE and Geely made a joint demonstration on wireless charging with an EV equipped with ZTE wireless charging systems
Apr-19	PVs	GAC	• Aion S with high-power wireless charging enabled was unveiled at the Shanghai Auto show • The equipment was provided by Beijing Yougan and has an energy conversion efficiency of over 90% and a power rating of 11kW
May-18	PVs	SAIC	• Launched the Roewe Marvel X model that supports wireless charging
Nov-16	PVs	Preh Qualcomm	• Preh (subsidiary of Joyson), signed a license agreement with Qualcomm to embed the company's wireless EV charging tech into its product portfolio
Aug-16	Commercial bus fleets	ZTE West Bus	• West Bus announced that ZTE won a tender for a charging operation service project
Jul-16	General charging pile	Zhonghui Chuangzhi	• Zhonghui Chuangzhi unveiled its new-generation 6.6-7.7kW wireless charging pile with a transmission efficiency of ~92%
Jun-16	Commercial bus fleets	PRIMOVE	• Qingdao West Coast New Area Sino-German Ecological Park signed an agreement with PRIMOVE to jointly build a 200kW wireless fast-charging bus
Oct-14	Shuttle bus fleets	ZTE Shudu Bus	• ZTE and Shudu Bus released the world's first wireless charging shuttle bus solution at the Western China International Expo; two wireless charging buses took part in trials in Chengdu in February 2015
Sep-14	Commercial bus fleets	ZTE Dongfeng Motor	• ZTE and Dongfeng Motor jointly released China's first wireless charging commercial bus • The Xiangyang wireless charging bus was put into commercial use, and five wireless charging stations were built at the starting and terminal station

Source: Media reports and Bernstein analysis

EXHIBIT 488: **Taking a step back, these are the commonly agreed on pros and cons regarding WEVC**

Pros	Cons
• **Improves battery longevity** by encouraging small top-up charging — drivers may not bother to plug in/charge for 5-10 minutes at a time, but wireless charging suits that behavior and keeps the battery charged between 40% and 80%, optimal for battery life • Autonomous parking will likely be achieved faster than driving — enables **vehicles to park and charge without human intervention** • **Less prone to vandalism and loosening/oxidation of electric connections**, typically ground-based with no street clutter • **Less fuss in handling dirty/unwieldy cables especially in inclement weather —** Qualcomm believes some drivers could find wired charging unsafe in wet weather	• **High initial cost** in terms of equipment/ infrastructure, and **lower economies of scale** • **Higher maintenance costs and outsized energy consumption** due to less efficient transmission • **Typically slower-than-normal wired charging** (~95% efficiency) and yet to reach the level of fast charging • **Stringent requirements for charging environment** (e.g., clear of debris, pacemakers, and sensitive equipment)

Source: Bernstein analysis

INVESTMENT IMPLICATIONS

Sales in the Chinese auto industry have continued to improve in recent months, helped by a combination of consumers returning to car ownership, access to credit, and easy comps versus Covid-19 lows in 2020. However, there are notable near-term risks, including an industry-wide chip shortage and slowing credit growth. That said, bright spots still exist — premium continues to significantly outperform the mass market, although mass market sales too have improved. Going forward, we remain more bullish on the premium segment — demand here should be more resilient, as shown by recent above-trend growth rates. We rate Great Wall and Geely Outperform and GAC, SAIC, Brilliance, and BAIC Market-Perform.

HOW RARE EARTH ELEMENTS IMPACT ELECTRIC VEHICLES

OVERVIEW

With the electric vehicle (BEV and PHEV) market increasing from 3.4 million to around 25 million units by the end of the 2020s, electric motors will substantially gain importance. Not only does the E-motor determine the efficiency of E-powertrains and hence the size of the battery, it is also a meaningful part of the cost of the vehicle and it exposes carmakers to rare earth elements (REEs) costs.

REEs came prominently into the global spotlight during the US-China trade war in 2019. In response to sanctions by the US on tech giant Huawei, China retaliated by restricting its REE exports. And now again, REEs have come into the limelight due to their importance in clean energy technologies such as wind power and EVs. For starters, REEs are not rare per se, at least from a geological perspective. What makes them rare is their economic viability — meaning that locating a mineral ore is a tough task. Also, they tend to mineralize along with radioactive contaminants, making their mining difficult.

There are 17 REEs available in the earth's crust. Around 73% of these are used in mature industries, including glass, ceramics, and metallurgy. The remaining 27% are used in the production of neo magnets, which are essential components in EVs. The REEs primarily used in EVs are neodymium, dysprosium, praseodymium, and scandium — mainly for use in permanent magnets in electric motors.

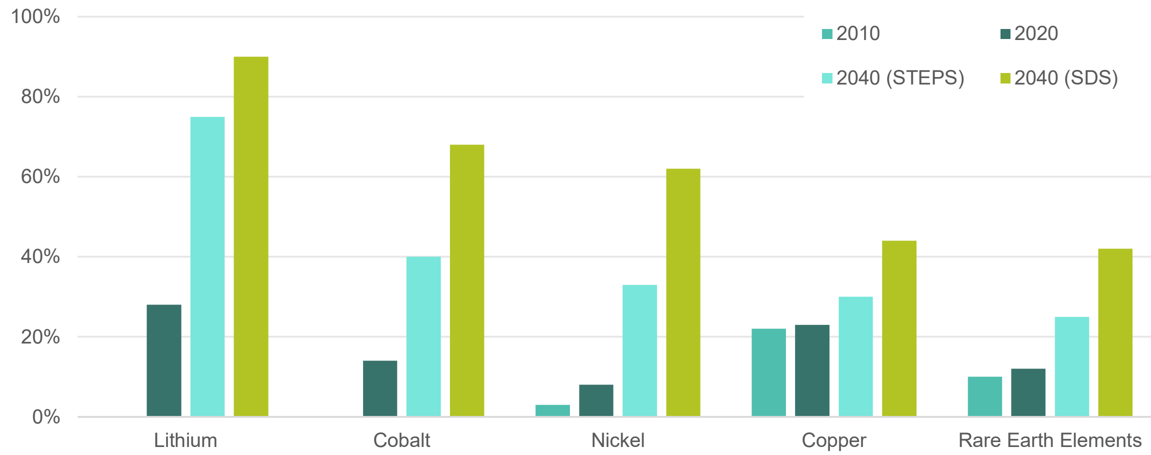
The REE market is projected to grow from US$5.3bn in 2021 to US$15.6bn by 2030. According to Adamas Intelligence, demand is expected to increase at a CAGR of 9.7% and prices are projected to grow at a CAGR of 5.6-9.9% over the same period. These growth and pricing forecasts are highly volatile and will depend on EV sales momentum. Growth is expected to be led by neodymium oxide. A hybrid car contains 650-1,000 grams of neodymium. The usage of REEs in permanent magnets is expected to grow 12-14% in the next five to 10 years as shown in Exhibit 489.

ISSUES WITH RARE EARTH ELEMENTS

Growing scrutiny of environmental and social performance

According to the Chinese Association of Rare Earths, between 9,600 and 12,000 cubic meters of waste is disposed in the form of gas containing concentrated dust, hydrofluoric acid, sulfur dioxide, and sulfuric acid, for each ton of extracted REEs. This also includes around 75 cubic meters of acid wastewater and a ton of radioactive waste.

EXHIBIT 489: **Share of clean energy technologies in total demand for selected minerals**



STEPS: Stated Policies Scenario, based on sector-by-sector analysis of today's policies
SDS: Sustainable Development Scenario, indicating what would be required in a trajectory consistent with meeting the Paris Agreement goals.

Source: IEA and Bernstein analysis

Moreover, most REEs contain either uranium or thorium oxide, or both, which needs to be removed during the refining process. This makes waste disposal more dangerous; mines regulate and increase the cost of capital for these projects. While dealing with waste/byproducts isn't just specific to REEs, following existing environmental regulation and certifying the entire value chain is an important task that OEMs should take seriously.

Geographical concentration of REEs

Naturally, extraction and processing of many energy-transition minerals is more concentrated than that of oil, steel, or aluminum (i.e., traditional raw materials that carmakers are used to). Exhibit 490 shows that for lithium, cobalt, and REEs, global output is controlled by three nations. The Democratic Republic of the Congo and China were responsible for around 70% and 60% of global production of cobalt and REEs, respectively, in 2019.

China's share of refining is around 35% for nickel, 50-70% for lithium and cobalt, and nearly 90% for REEs. This virtual monopoly has led to trade restrictions, price volatility, and supply disruptions. Western governments in conjunction with industry bodies are thus working hard to reduce some of these problematic elements in their EV powertrains. For instance, Canada is committed to further build out its leading role in mining minerals needed for the transition to a lower carbon economy. Building and controlling high-quality EV value chains is of the utmost importance, also in the context of all ESG discussions.

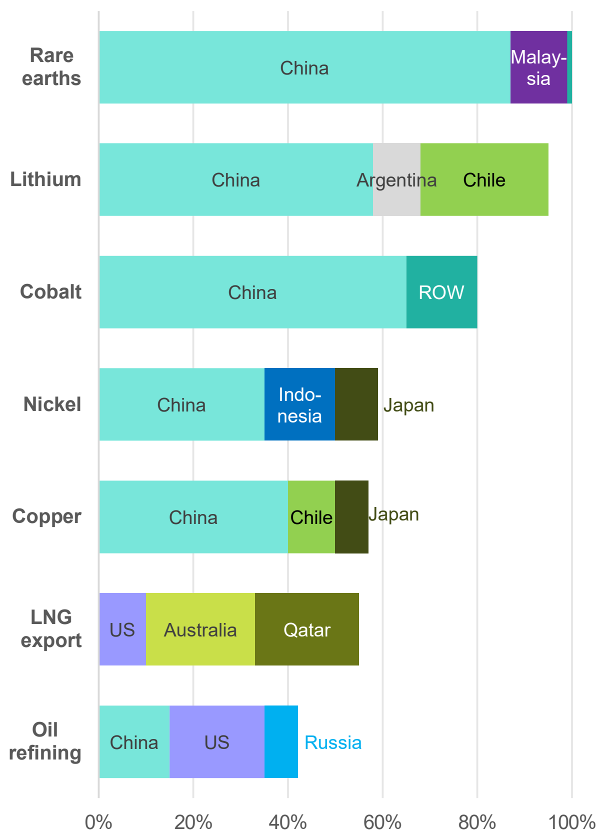
At a recent FT conference, Glencore CEO Ivan Glasenberg stated: *"Western companies haven't done it (insourcing the EV value chain). They either believe this isn't an issue or they believe they are going to get the batteries from China. But what happens if that doesn't occur and the Chinese say we are not going to export batteries, we are going to export EVs? Where are the batteries going to come from?"*

Fluctuating cost of REEs

Due to their extreme geographical concentration and current/forecasted increases in new energy technologies, prices of REEs can materially fluctuate. In 2011, global prices of REEs rose suddenly when China introduced a 40% cut on its export quotas. Carmakers are experts in supply chain management; however, in the case of REEs, they reach their limitations as many are sold in private markets, thereby making their prices tricky to track, monitor, and secure.

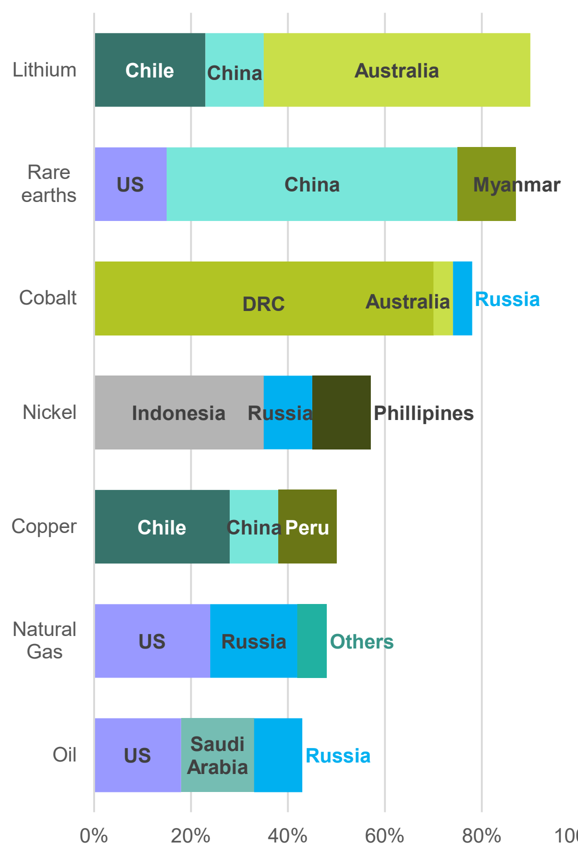
For example, the price of neodymium has surged over the past six months from around US$60/kg in June 2020 to over US$120/kg in February 2021, while the cost of dysprosium oxide rose to about US$1,470/kg from US$700-US$740/kg due to a surge in demand. A couple of tens or hundreds of additional costs per vehicle might not sound much in the context of vehicles that retail for US$30,000-US$50,000. However, assuming a US$30,000 car generates a 5% return on sales (ROS), i.e., US$1,500 in profit, an additional few hundreds of costs related to some minerals can be a big deal for contribution margins.

EXHIBIT 490: **Processing: Share of top three nations**



Source: EA and Bernstein analysis

EXHIBIT 491: **Extraction: Share of top three nations**



Source: EA and Bernstein analysis

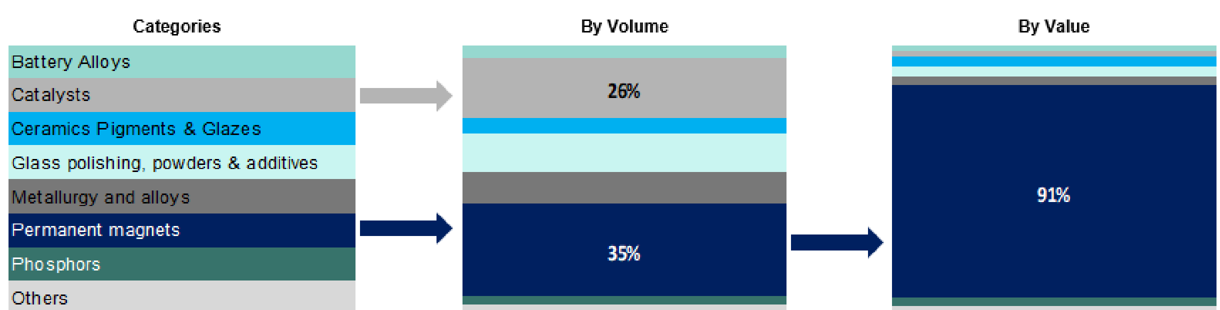
WHY ARE RARE EARTH ELEMENTS USED IN EVS?

EVs get propulsion from an E-motor and the power to drive this electric motor comes from the battery pack. Thus, an EV's motor efficiency directly influences the size of the battery. Every 1% lower efficiency requires 1% more power from the battery (in other words more battery cells).

Permanent magnets are a primary component in an electric motor. They are the largest demand drivers by value as well as by volume, as shown in Exhibit 492. A motor operates when these strong magnets encircle a coil of wire thereby making it spin. The electric current induced in the coil emits a magnetic field, which creates a repulsive effect with the opposing magnetic field emitted by the strong magnets. This repulsion then makes the coil (attached to an axle) rotate at a high speed/force (torque).

Permanent magnets can be classified into three groups: alnico, ferrite, and rare earth neodymium iron boron (NdFeB). Alnico magnets mainly contain aluminum, nickel, cobalt, and iron. Ferric magnets are mainly composed of ferric oxide and are best-placed candidates to replace rare earth magnets. Presently, the most prominently used magnet in motors of hybrids and BEVs is a rare earth magnet NdFeB. These have been used as a lightweight alternative to ceramic and ferrite magnets in motors, allowing for greater efficiency in battery energy use. They are highest in coercivity and density to their counterparts. When combined with the REE dysprosium, they help motors function at high temperatures. This combination makes them perfect for high-powered EVs. Scandium, meanwhile, is used for its relatively low weight, and is alloyed with aluminum to make bodies for EVs. The two most used motors for vehicular propulsion systems are induction motors and rare-earth permanent magnet synchronous motors (PMSMs). Exhibit 495 summarizes the comparison between different E-motors.

EXHIBIT 492: **Permanent magnets are the largest demand drivers by value as well as by volume**



Source: Adamas Intelligence (AI) and Bernstein analysis

Induction motors

These are brushless alternative current (AC) machines which offer high simplicity, low cost, reliability, robustness, and low maintenance. In addition, they don't use REEs. The rotor contains a cast aluminum cage in which rotor currents are induced by the rotating magnetic field generated by stator windings, thus producing electromagnetic torque. However, some drawbacks include slightly inferior efficiency, higher power losses, and low inverter usage. Therefore, SCIMs are applied more in full electric vehicles (FEVs) than in HEVs or PHEVs due to space restrictions. These motors are used in the Tesla Model S, the Mahindra e2o, and the Toyota RAV4. Although induction motors do not use REEs, they require substantial amounts of copper (11-24 kg/motor). Having said that, the Audi E-tron uses an aluminum rotor instead of copper in its induction motor.

Permanent magnet synchronous (brushless) motors or PMSMs

These motors, such as brushless DC motors (BLDC), have a permanent magnet as a rotor and a stator with a coil wound over it. Like BLDC motors, the only difference is that PMSMs are sinusoidally wound, generate a sinusoidal back-EMF (electromotive force), and are fed by sinusoidal currents which makes them a better feature for EVs motors. However, in most applications rare-earth permanent magnets are used because of their superior magnetic properties, even though they are costlier than both induction motors and BLDC motors. Thus, high cost coupled with many geopolitical and economic concerns, has led to many efforts to develop rare earth-free motors to substitute PMSMs.

There are several ways to reduce REE use in E-motors:

- Improving material efficiency in magnet production, i.e., obtain NdFeB magnets with less REE content;
- Reducing NdFeB amount in PMSMs; and
- Substituting permanent-magnet motors with REE-free motors. Ferrite magnets are being researched to replace rare-earth magnets. However, unlike NdFeB, ferrite magnets have much lower magnetic flux density and, hence, cannot directly replace NdFeB magnets in permanent magnet motors.

Automakers that use PMSMs are: the BMW i3, Nissan Leaf, Volkswagen e-Golf, Mitsubishi i-MiEV, Volkswagen e-UP, Citroën C-Zero, Peugeot iOn, Citroën Berlingo Electric, Ford Focus Electric, Fiat 500e, Bolloré Bluecar, Chevrolet Spark EV, Kia Soul, Mercedes-Benz Vito E-Cell, and Smart fortwo ED.

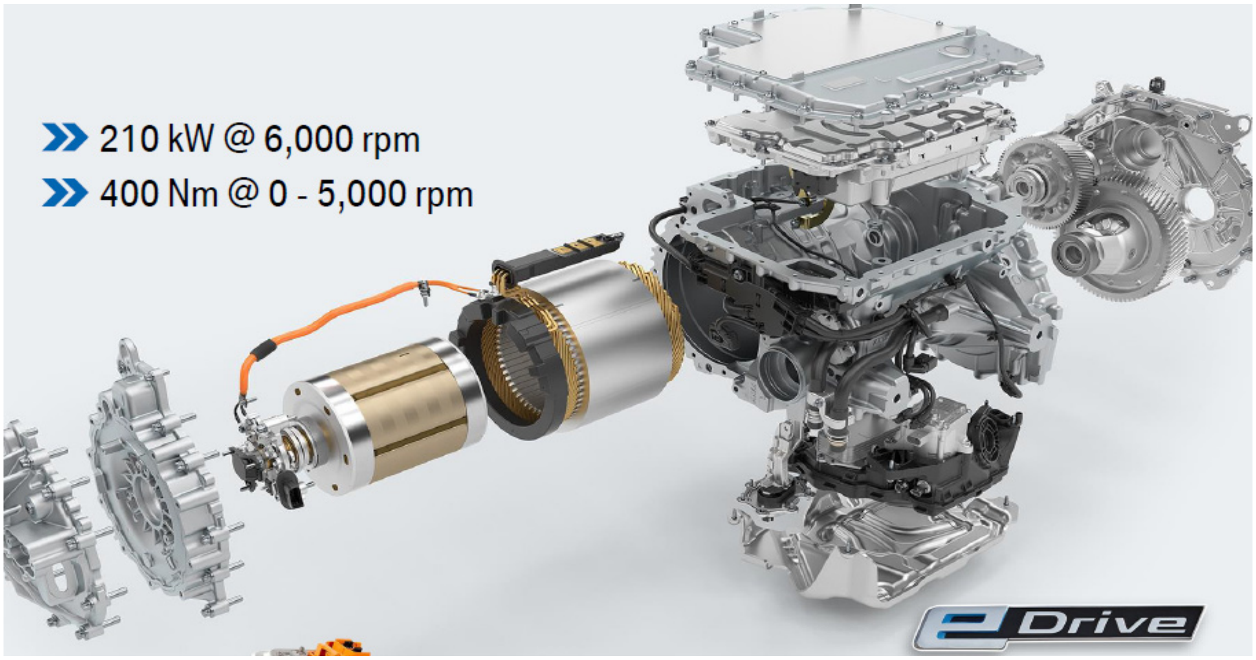
Switched reluctance motor (SRM)

This motor has not yet entered the market and is still under research. The main benefit of SRMs is their high torque and robustness. This is because the rotor of an SRM is made of laminated steel with no winding or permanent magnets, enabling it to operate at high speed. Drawbacks are complexity to control and high torque ripple. However, with optimum motor design, these issues can be resolved.

STEPS TAKEN BY MAJOR OEMS

Given the average hybrid or EV uses 2-5 kg of REEs depending on the design, the market is expected to expand massively in the next decade. Vehicle manufacturers are obviously aware of the issues pertaining to REEs and many have made claims about either the

EXHIBIT 493: **BMW Gen5 eDrive uses electrically excited synchronous (ESM) machine technology, avoiding magnets and REEs**

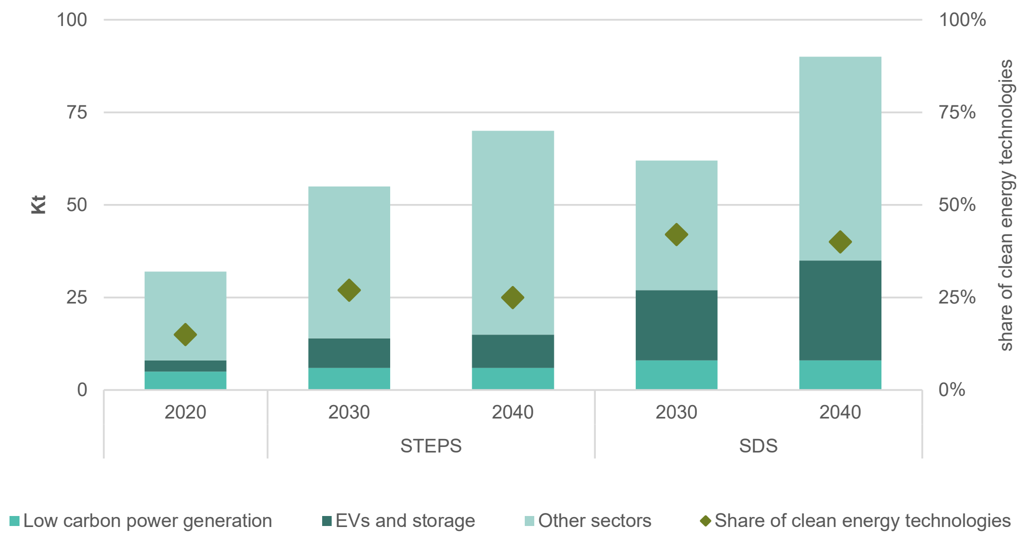


Source: Company filings and Bernstein analysis

elimination or reduction of REE content in their electric motors. Renault makes cars with synchronous motors but without REEs because they use electromagnets. The Renault Zoe has utilized a wound rotor configuration to replace magnets with copper windings, BMW's new 5th generation E-drivetrain has eliminated REEs (see Exhibit 493), and Audi has opted for an aluminum rotor induction motor for the e-tron. Nio uses both AC induction motors and permanent magnet motors, while Lucid Motors uses permanent magnet motors in the Lucid Air. A variety of companies, including Bentley, are also investigating SRMs for EV applications which require no magnets or copper in their rotors. OEMs such as Nissan and Honda have reduced or eliminated the heavy rare-earth components like dysprosium. Others such as Tesla have shifted from using copper induction motors in its Model S and Model X to permanent magnets motors (IPM-SRM) in its new Model 3 and Model Y.

Despite the potential reduction of materials such as neodymium per vehicle and constant effort by OEMs to look for environmentally friendly replacements, the steepness of the demand curve will probably soften. However, the overall increase in the global EV market is still expected to lead to an overall increase in the demand for REEs. Use of permanent magnets has increased from 79% in 2015 to 82% in 2019 and is expected to continue to grow. IEA forecasts demand for dysprosium in EVs would reach 6,000-13,000 tons by 2030, while neodymium would go from 582-1,162 tons in 2017, to 20,000-40,000 tons by 2030. Exhibit 494 shows that clean energy technologies represent 15% of total neodymium demand in 2020 and their share is expected to increase to 25% by 2040 in the IEA's Stated Policies Scenario (STEPS) and over 40% in the Sustainable Development Scenario (SDS), implying that neodymium is the key element to drive REE demand in future.

EXHIBIT 494: **Total neodymium demand by sector and scenario**



Source: IEA and Bernstein analysis

EXHIBIT 495: **Electric motor drive comparison**

	IM	PMSM	SRM
Power density	Medium	Very high	Medium
Efficiency	Medium	Very high	Medium
Controllability	Very High	High	Medium
Reliability	Very High	High	Very High
Technol. Maturity	Very High	High	High
Cost	Very low	High	Low
Mineral Used	No REEs, but significant copper and aluminium	Neodymium, dysprosium, terbium	No rare earth or copper, use of laminated steel
Amount Used	copper: 11-24 kg/motor	24% neodymium, 7.5% dysprosium	
Current Status	Some BEVs	Used in all HEVs and most BEVs and PHEVs	First prototypes
Used by	Tesla Model S, Toyota RAV4, Audi e-tron	BMW i3, Nissan LEAF, VW ID.3/4, VW e-golf, Tesla Model 3	

Source: Bernstein analysis

INVESTMENT IMPLICATIONS

See the "Global Autos: When And Where Will Electric Vehicles Dominate? A Market Outlook For Electric Mobility" chapter for investment implications.

APPENDIX: FINANCIAL OVERVIEW EXHIBITS

EXHIBIT 496: **European Autos**

	BMW BMW.GR	Daimler DAI.GR	Volkswagen VOW.GR	Porsche SE PAH3.GR	Renault RNO.FP	Traton SE 8TRA.GR	Volvo AB VOLVB.SS
Rating	O	O	M	M	O	U	O
Prices as of Aug 16, 2021	81.68	74.32	300.20	89.30	32.93	26.40	200.45
Currency	EUR	EUR	EUR	EUR	EUR	EUR	SEK
Target Price	120.00	116.00	237.00	89.00	42.00	21.00	240.00
52-Week Range	56.10 - 96.39	40.55 - 80.41	131.80 - 367.80	44.44 - 102.05	20.37 - 41.42	16 - 28	148 - 221
Market Capitalization ($ bn)	59.0	88.4	144.4	29.8	11.0	12.4	395.6
TTM Performance	39.7%	72.4%	92.6%	66.2%	33.7%	50.5%	30.5%
TTM Relative Performance	13.7%	46.5%	66.6%	40.2%	7.8%	24.3%	4.3%
Bernstein EPS Forecast							
2020A	5.73	4.72	17.93	8.56	-29.51	3.04	17.64
2021E	16.50	12.70	27.91	13.21	1.79	-0.06	7.84
2022E	15.40	12.18	30.55	15.21	7.14	1.94	12.56
2023E	16.22	12.05	30.63	15.29	10.17	2.70	15.75
EPS Annual Change							
2020A-2021E	188%	169%	56%	54%	94%	-102%	-56%
2021E-2022E	-7%	-4%	9%	15%	298%	-3333%	60%
2022E-2023E	5%	-1%	0%	1%	43%	39%	25%
Consensus EPS							
2021E	14.00	11.79	29.03	13.25	2.34	2.77	15.36
2022E	12.75	11.65	32.69	15.49	6.64	3.94	17.24
2023E	13.49	11.83	35.10	17.06	9.04	4.29	18.15
P/E on Bernstein EPS Forecast							
2021E	4.9x	5.9x	10.8x	6.8x	18.4x	-420.40	25.72
2022E	5.3x	6.1x	9.8x	5.9x	4.6x	13.83	16.05
2023E	5.0x	6.2x	9.8x	5.8x	3.2x	9.94	12.80
Shares Outstanding (mil.)	660	1070	501	306	292	500	2033
Yield	2.33%	1.82%	1.60%	2.47%	n.a.	0.95%	7.48%
Dividend per Share (EUR)	1.90	1.35	4.80	2.21	0.00	0.25	15.00

Note: Stocks are benchmarked against the MSCI Europe Local Index, which had a closing price of 1,888.53 as of close August 16.

Source: Bloomberg, company reports, and Bernstein estimates and analysis

EXHIBIT 497: **Asian Autos**

	Great Wall 2333.HK	Geely 175.HK	GAC 2238.HK	SAIC 600104.CH	BAIC 1958.HK	Brilliance* 1114.HK
Rating	O	O	M	M	M	M
Prices as of Aug 16, 2021	33.10	26.55	7.08	19.17	2.80	7.30
Currency	HKD	HKD	HKD	CNY	HKD	HKD
Target Price	38.00	31.00	7.50	18.00	3.00	7.50
52-Week Range	7.57 - 39.00	14.72 - 36.45	6.08 - 10.08	18.03 - 28.80	2.38 - 4.17	5.94 - 7.99
Market Capitalization (US$bn)	67.3	32.5	20.1	33.0	2.7	4.7
TTM Performance	315.8%	69.8%	-3.9%	1.6%	-28.2%	-5.4%
TTM Relative Performance	300.9%	54.9%	-18.8%	-13.3%	-43.1%	-20.3%
Bernstein EPS Forecast						
2020A	0.59	0.56	0.58	1.75	0.24	1.34
2021E	1.05	0.75	0.82	2.05	0.46	1.85
2022E	1.39	1.25	1.08	2.36	0.55	2.07
EPS Annual Change						
2020A-2021E	78%	34%	41%	17%	92%	38%
2021E-2022E	32%	67%	32%	15%	20%	12%
Consensus EPS						
2021E	1.18	1.09	0.96	2.48	0.49	1.66
2022E	1.39	1.30	1.12	2.75	0.59	1.18
P/E on Bernstein EPS Forecast						
2020A	56.1x	47.4x	12.2x	11.0x	11.7x	5.4x
2021E	31.5x	35.4x	8.6x	9.4x	6.1x	3.9x
2022E	23.8x	21.2x	6.6x	8.1x	5.1x	3.5x
Shares Outstanding (mil.)	9,127	9,817	10,248	11,583	8,015	5,045
Yield	1.06%	0.78%	3.09%	3.37%	3.63%	1.51%
Dividend per Share	0.28	0.17	0.18	0.62	0.08	0.11

* Brilliance has been suspended from trading, and release of its 2020 annual report has been delayed.

Note the stocks are benchmarked against MXAPJ, which had a closing price of 651.37 as of August 16, 2021.

Source: Bloomberg, company reports, and Bernstein estimates and analysis

EXHIBIT 498: **Global Energy Storage**

	CATL 300750.CH	LG Chem 051910.KS	Samsung SDI 006400.KS
Rating	O	O	M
Prices as of Aug. 16, 2021	477	896,000	817,000
Trading Currency	CNY	KRW	KRW
Target Price	520	1,340,000	684,000
52-Week Range	178-582	588,000-1,050,000	406,000-828,000
Market Capitalization (US$ billion)	177	54	47
TTM Performance	142.6%	28.0%	84.0%
TTM Relative Performance	126.9%	12.3%	68.3%
Bernstein EPS Forecast			
2020A	2.40	6,666	7,439
2021E	4.46	43,276	15,236
2022E	6.20	40,562	18,497
2023E	7.87	46,007	23,054
EPS Annual Change			
2020A-21E	86%	549%	105%
2021E-22E	39%	-6%	21%
2022E-23E	27%	13%	25%
Consensus EPS			
2021E	4.36	55,280	16,250
2022E	6.72	43,895	21,173
2023E	9.01	50,426	26,163
P/E on Bernstein EPS Forecast			
2020A	199.0x	134.4x	109.8x
2021E	107.0x	18.3x	53.6x
2022E	76.9x	19.5x	44.2x
2023E	60.6x	17.2x	35.4x
Shares Outstanding (mil.)	2,329	71	69
Yield	0.05%	1.12%	0.12%
Dividend per Share	0	10,000	1,000

Note: Stocks are benchmarked against the MSCI Asia Pacific ex Japan Index, which had a closing price of 651.37 as of August 16, 2021

Source: Bloomberg, company reports, and Bernstein estimates and analysis

EXHIBIT 499: **Global Metals & Mining**

	Anglo American AAL.LN	Antofagasta ANTO.LN	Barrick Gold ABX.CN	BHP Group BHP.LN	Newmont Mining NEM.US
Rating	O	O	O	O	O
Prices as of August. 19, 2021	29.12	14.05	24.50	21.64	56.52
Currency	GBP	GBP	CAD	GBP	USD
Target Price	34.60	16.60	35.00	24.00	71.00
52-Week Range	17.60-34.44	9.80-19.25	23.75-40.11	14.90-23.75	54.38-74.38
Market Capitalization (US$ billion)	49.70	18.91	34.03	156.65	45.17
TTM Performance	57%	30%	-38%	25%	-16%
TTM Relative Performance	31%	4%	-68%	-1%	-46%
Bernstein EPS Forecast					
2020A	2.53	0.55	1.15	1.79	2.66
2021E	8.20	1.30	1.33	3.38	4.97
2022E	5.25	1.07	1.49	4.05	5.59
2023E	4.25	1.10	1.62	3.07	5.97
EPS Annual Change					
2020A-2021E	324%	237%	116%	189%	187%
2021E-2022E	64%	82%	112%	120%	112%
2022E-2023E	81%	103%	109%	76%	107%
Consensus EPS					
2021E	7.75	1.44	1.22	3.91	3.40
2022E	5.88	1.38	1.27	2.81	3.54
2023E	4.71	1.29	1.15	2.49	3.22
P/E on Bernstein EPS Forecast					
2021E	3.6x	10.8x	18.4x	6.4x	11.4x
2022E	5.6x	13.2x	16.4x	5.3x	10.1x
2023E	6.9x	12.8x	15.1x	7.1x	9.5x
Shares Outstanding (mil.)	1,239	986	1,778	5,057	804
Yield	2.24%	2.70%	1.70%	4.69%	2.55%
Dividend per Share	1.0	0.5	0.3	1.4	1.5
FX (1 USD to GBP)	0.73	0.73	0.73	0.73	0.73

Note: EPS are adjusted numbers excluding one-off/extraordinary items. For NEM, it's EPS reported. 2021 EPS adjusted for BHP is actual.
The following companies also have secondary listings (closing prices are as of August 19, 2021).
— Barrick Gold: ticker GOLD US, with a closing price of USD19.13, rated Outperform and having a target price of USD28.50
— BHP Group: ticker BHP.AU, with a closing price of AUD44.67, rated Outperform and having a target price of AUD50.00
— BHP Group: ticker BHP.US, with a closing price of USD62.84, rated Outperform and having a target price of USD75.10
— BHP Group: ticker BBL.US, with a closing price of USD58.96, rated Outperform and having a target price of USD66.50

Benchmarks, with closing prices as of August 19, 2021, are:
— Stocks trading in UK are benchmarked against the MSCI Europe Local Index, which had a closing price of 1,865.31
— Stocks trading in Canada and USA are benchmarked against the SPX Index, which had a closing price of 4,405.80

Source: Bloomberg, company reports, and Bernstein estimates and analysis

EXHIBIT 500: **European Industrial & Consumer Chemicals**

	BASF BAS.GR	Umicore UMI.BB
Rating	Outperform	Market - Perform
Prices as of August 16th, 2021	68.27	59.80
Trading Currency	€	€
Target Price	112	53
52-Week Range	€45.80 - €72.90	€29.55 - €56.30
Market Capitalization (US$ billion)	72.8	16.3
TTM Performance	37.4%	49.9%
TTM Relative Performance	2.6%	21.8%
Bernstein EPS Forecast		
2020A	3.21	1.34
2021E	5.80	2.88
2022E	5.82	2.42
2023E	6.92	3.20
EPS Annual Change		
2020A-21E	80.7%	115.3%
2021E-22E	0.4%	-16.2%
2022E-23E	18.8%	32.3%
Consensus EPS		
2021E	5.24	2.75
2022E	5.24	2.49
2023E	5.53	2.59
P/E on Bernstein EPS Forecast		
2021E	11.77x	23.67x
2022E	11.73x	28.25x
2023E	9.87x	21.35x
Shares Outstanding (mil.)	918	241
Yield	4.8%	1.3%
Dividend per Share	3.3	0.8

Note: The stocks are benchmarked against the Stoxx Europe 600 Chemicals Index, which had a closing price of €1322 as of August 16, 2021.

Source: Bloomberg, company reports, and Bernstein estimates and analysis

EXHIBIT 501: **European Oil & Gas**

	BP BP/.LN	Shell RDSB.LN	TOTAL TTE.FP	Equinor EQNR.NO	Galp GALP.PL	Repsol REP.SM	Eni ENI.IM
Rating	O	O	M	O	M	O	U
Prices as of 16 Aug 2021	308.90	1,467.40	37.63	182.00	8.50	9.62	10.35
Currency	GBp	GBp	EUR	NOK	EUR	EUR	EUR
Target Price	540.00	2,400.00	44.00	265.00	12.00	13.00	9.00
52-Week Range	189 - 337	845 - 1,523	25 - 42	116 - 193	7 - 11	5 - 12	6 - 11
Market Capitalization (US$ bil	8,516	15,637	116	5,349	8	17	44
TTM Performance	0.9%	26.1%	11.0%	22.9%	-11.1%	34.9%	25.9%
TTM Relative Performance	-24.5%	0.7%	-14.4%	-2.5%	-36.5%	9.5%	0.5%
Bernstein EPS Forecast							
2020A	-0.28	0.62	1.43	0.12	-0.05	0.39	-0.21
2021E	0.51	2.40	4.85	1.94	0.52	1.26	0.83
2022E	0.58	2.81	5.26	1.83	0.76	1.86	1.27
EPS Annual Change							
2020A-2021E	281%	287%	239%	1517%	1140%	223%	500%
2021E-2022E	14%	17%	8%	-6%	46%	48%	53%
Consensus EPS							
2021E	0.52	2.40	5.03	2.26	0.66	1.50	0.98
2022E	0.57	2.81	5.32	1.91	0.85	1.69	1.22
P/E on Bernstein EPS Forecast							
2021E	826.8x	834.6x	9.1x	846.3x	16.3x	7.6x	12.5x
2022E	727.0x	712.8x	8.4x	897.2x	11.2x	5.2x	8.1x
Shares Outstanding (mil.)	20197	7,807	2640	3258	829	1527	3606
Yield	5.09%	4.70%	6.95%	3.52%	4.10%	6.12%	6.45%
Dividend per Share	15.72	68.97	2.62	6.41	0.35	0.59	0.67

Note: The following companies also have secondary listings (closing prices as of August 16, 2021):
- BP: ticker BP with a closing price of USD 24.73, rated Outperform having a target price of USD41.
- Shell: ticker RDSA.LN with a closing price of GBp 1,425.40, rated Outperform having a target price of GBp2400.
- Shell: ticker RDSB.NA with a closing price of EUR 16.62, rated Outperform having a target price of EUR28.
- Shell: ticker RDSA.NA with a closing price of EUR 16.90, rated Outperform having a target price of EUR28.
- Shell: ticker RDS/B with a closing price of USD 38.94, rated Outperform having a target price of USD67.
- Shell: ticker RDS/A with a closing price of USD 39.71, rated Outperform having a target price of USD67.
- TOTAL: ticker TTE.US with a closing price of 44.37, rated Market-Perform having a target price of USD51.
- Equinor: ticker EQNR with a closing price of USD 20.91, rated Outperform having a target price of USD30.
- ENI: ticker E with a closing price of USD 24.45, rated Underperform having a target price of USD21.

Benchmark indexes (closing prices as of August 16, 2021):
- Stocks trading in Europe are benchmarked against the MSDLE15 Index, which had a closing price of 1,888.53.
- Stocks trading in the US are benchmarked against the SPX Index, which had a closing price of 4,479.71.

Source: Bloomberg, company reports, and Bernstein estimates and analysis

EXHIBIT 502: **India Autos**

Particulars	Maruti Suzuki MSIL.IN	Mahindra & Mahindra MM.IN	Bajaj Auto BJAUT.IN	Hero MotoCorp HMCL.IN	TVS Motor TVSL.IN	Eicher Motors EIM.IN
Rating	O	O	O	M	M	M
Prices as of Aug 16, 2021	6,827	799	3,748	2,747	538	2,496
Currency	INR	INR	INR	INR	INR	INR
Target Price	7,850	900	4,110	3,150	540	2,970
52-Week Range	5,650 - 8,329	493 - 952	2,812 - 4,361	2,468 - 3,629	374 - 666	1,797 - 3,037
Market Cap (US$bn)	27.8	13.4	14.6	7.4	3.4	9.2
TTM Performance	4.0%	23.3%	26.8%	-1.3%	28.7%	17.5%
TTM Relative Performance	-12.3%	7.0%	10.4%	-17.7%	12.3%	1.2%
Bernstein EPS Forecast						
FY21A	140.0	32.7	159.7	147.8	10.8	55.8
FY22E	169.5	41.6	194.3	187.6	15.1	88.0
FY23E	271.9	46.4	242.0	210.3	19.2	106.1
FY24E	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
EPS Annual Change						
FY21A-FY22E	21%	27%	22%	27%	40%	58%
FY22E-FY23E	60%	12%	25%	12%	27%	21%
FY23E-FY24E	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Consensus EPS						
FY22E	197.9	41.3	188.1	164.5	20.3	74.0
FY23E	284.9	46.5	222.1	195.1	29.0	104.0
FY24E	336.8	49.2	252.7	213.6	30.8	119.4
P/E on Bernstein EPS Forecast						
FY22E	40.3x	19.2x	19.3x	14.6x	35.7x	28.4x
FY23E	25.1x	17.2x	15.5x	13.1x	28.0x	23.5x
FY24E	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Shares Outstanding (mil.)	302	1,243	289	200	475	273
Yield	0.7%	1.3%	3.7%	3.8%	0.7%	0.7%
Dividend per Share	45	10	140	105	4	17

Note: The stocks are benchmarked against the MXAPJ Index, which had a closing price of 651.37 as of August 16, 2021.

Source: Bloomberg, company data, and Bernstein estimates and analysis

EXHIBIT 503: **Asian Industrial Technology**

	Estun	Keyence	Hikvision	IPG	Inovance	Cognex	MSCI AC Asia Pacific Excluding Japan Index	MSCI Japan Index	S&P 500 Index
	002747.CH	6861.JP	002415.CH	IPGP	300124.CH	CGNX	MXAPJ	MXJP	SPX
Rating	O	O	O	O	M	M			
Prices as of Aug 16, 2021	32	61,880	57	169	73	83	651	1,180	4,480
Currency	CNY	JPY	CNY	USD	CNY	USD			
Target Price	45	68,000	75	211	92	85			
52-Week Range	15 - 42	42,200 - 59,080	34 - 69	150 - 259	32 - 82	61 - 94	545-744	957-1,225	3,237-4,479
Market Capitalization (US$ billion)	4	137	82	9	30	15			
TTM Performance	88.8%	35.3%	41.7%	4.3%	97.3%	21.2%	14.9%	20.5%	32.5%
TTM Relative Performance	73.9%	20.4%	26.8%	-10.6%	82.4%	6.3%			
Bernstein EPS Forecast									
2020A	0.15	813.47	1.45	2.97	1.22	1.02			
2021E	0.29	1129.70	1.79	5.41	1.70	1.67			
2022E	0.45	1184.20	2.42	6.09	1.92	1.83			
2023E	0.70	1344.36	2.97	6.79	2.33	2.01			
EPS Annual Change									
2020A-2021E	95%	39%	24%	82%	39%	64%			
2021E-2022E	53%	5%	35%	13%	13%	9%			
2022E-2023E	57%	14%	23%	11%	21%	10%			
Consensus EPS									
FY21E	0.31	1095.58	1.80	5.22	1.23	1.62			
FY22E	0.49	1245.82	2.23	6.32	1.56	1.94			
FY23E	0.72	1406.38	2.66	6.97	1.90	2.18			
P/E on Bernstein EPS Forecast									
2021E	110.2x	54.8x	31.7x	31.2x	43.0x	49.5x			
2022E	72.1x	52.3x	23.5x	27.7x	38.0x	45.3x			
2023E	45.9x	46.0x	19.1x	24.8x	31.3x	41.3x			
Shares Outstanding (mil.)	869	243	9,336	53	2,621	177			
Yield	0.0%	0.3%	1.4%	0.0%	0.3%	2.7%			
Dividend per Share	0.00	200	0.80	0.00	0.24	2.23			

Source: Bloomberg, company reports, and Bernstein estimates and analysis

EXHIBIT 504: **Asian Semiconductors and Equipment**

	Infineon Technologies AG IFX GR
Rating	O
Prices as of 16 August 2021	34.26
Currency	EUR
Target Price	39.00
52-Week Range	21.88-37.31
Market Capitalization (US$ billion)	52.7
TTM Performance	51.9%
TTM Relative Performance	25.5%
Bernstein EPS Forecast	
FY2020	0.64
FY2021E	1.13
FY2022E	1.39
FY2023E	1.63
EPS Annual Change	
FY2020-FY2021E	77%
FY2021E-FY2022E	23%
FY2022E-FY2023E	18%
Consensus EPS	
FY2021E	1.12
FY2022E	1.36
FY2023E	1.58
P/E on Bernstein EPS Forecast	
FY2021E	30.4x
FY2022E	24.7x
FY2023E	21.0x
Shares Outstanding (mil.)	1,306
Yield	1.15%
Dividend per Share	0.39

Benchmarks, with closing prices as of 16 August 2021 are:
- Stocks trading in Europe are benchmarked against the MSCI Europe Index, which had a closing price of 1,888.5.
IFX fiscal year ends on Sept 30. IFX EPS is adjusted

Source: Bloomberg, company reports, and Bernstein estimates and analysis

EXHIBIT 505: **Asia Logistics and Travel**

	Trip.com TCOM US
Rating	O
Prices as of Aug 16, 2021	24.9
Currency	USD
Target Price	45.0
Market Capitalization (US$ Bn)	18.4
Bernstein EPS Forecast	
2020A	(1.59)
2021E	2.43
2022E	8.47
2023E	13.72
EPS Annual Change	
2020A-2021E	na
2021E-2022E	248%
2022E-2023E	62%
Consensus EPS	
2021E	3.31
2022E	10.12
2023E	13.02
Bernstein vs. Consensus	
2021E	(27%)
2022E	(16%)
2023E	5%

Note: Benchmarks, with closing prices as of August 16, 2021, are:
— Stocks trading in the US are benchmarked against the S&P 500 Index, which had a closing price of 4479.71
— Stocks trading in Hong Kong are benchmarked against the MXAPJ Index, which had a closing price of 651.37

Source: Bloomberg, and Bernstein estimates and analysis

EXHIBIT 506: **US Machinery**

	CMI US	PCAR US	OSK US	PWR US
Rating	O	M	M	O
Prices as of Aug 16, 2021	239	81	117	97
Currency	USD	USD	USD	USD
Target Price	284	97	134	107
52-Week Range	200 - 277	79 - 103	67 - 137	49 - 102
Market Capitalization (Bn)	33.827	28.329	7.818	13.724
Bernstein EPS Forecast				
2020A	12.00	3.74	4.94	3.83
2021E	15.90	5.64	6.50	4.52
2022E	19.88	6.80	7.98	5.30
2023E	22.53	7.34	9.81	5.97
EPS Annual Change				
2020A-2021E	32%	51%	32%	18%
2021E-2022E	25%	21%	23%	17%
2022E-2023E	13%	8%	23%	13%
Consensus EPS				
2021E	16.28	5.77	6.54	4.57
2022E	18.94	7.06	8.31	5.18
2023E	20.37	7.36	9.72	6.01
P/E on Bernstein EPS Forecast				
2021E	14.80	14.26	17.44	21.58
2022E	11.83	11.83	14.20	18.41
2023E	10.44	10.96	11.55	16.33
Shares Outstanding (mil.)	**148**	**347**	**68**	**141**

Note: Stocks are benchmarked against the S&P 500, which had a closing price of 4,479.71 as of August 16, 2021.

Source: Bloomberg, and Bernstein estimates and analysis

EXHIBIT 507: **US IT Hardware**

	Apple AAPL
Rating	M
Prices as of August 16, 2021	151.12
Currency	USD
Target Price	132.00
52-Week Range	151.12 - 106.84
Market Capitalization (US$ billion)	2,498,039
TTM Performance	32%
TTM Relative Performance	-1%
Bernstein EPS Forecast	
2020A	$3.27
2021E	$5.72
2022E	$5.57
EPS Annual Change	
2020A-2021E	74.9%
2021E-2022E	-2.6%
Consensus EPS	
2021E	$5.55
2022E	$5.60
P/E on Bernstein EPS Forecast	
2020A	46.2x
2021E	26.4x
2022E	27.1x
Shares Outstanding (mil.)	16,530.17

Note: The stock is benchmarked against the S&P 500 Index, which had a closing price of 4,479.71 as of August 16, 2021.

Source: Bloomberg, company reports, and Bernstein estimates and analysis

EXHIBIT 508: **US Natural Gas & MLPs**

	LNG	CQP	ET	EPD	KMI	WMB	PAA	PAGP	OKE	SPX
Rating	O	M	O	O	M	O	M	M	M	
Prices as of Aug 16, 2021	85.00	41.52	9.51	22.42	17.00	24.61	9.73	10.21	51.75	4,479.71
Currency	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
Target Price	94.00	40.00	15.00	32.00	17.00	30.00	10.00	10.00	49.00	
Market Capitalization (US$ bn)	22.0	19.8	25.2	48.5	37.2	29.8	6.9	2.0	23.5	
Bernstein EPS Forecast (US$/share)										
2020A	-0.34	1.79	-0.24	1.71	0.05	0.17	-3.83	-3.05	1.42	
2021E	6.02	2.01	2.20	2.42	1.27	1.13	1.44	0.34	3.16	
2022E	7.79	3.61	1.41	2.39	1.02	1.19	1.40	0.10	3.08	
EPS Annual Change										
2020A-2021E	1887%	12%	1017%	42%	2440%	565%	138%	111%	123%	
2021E-2022E	29%	80%	-36%	-1%	-20%	5%	-3%	-71%	-2%	
Consensus EPS (US$/share)										
2020A	-0.34	2.96	-0.24	1.71	0.05	0.17	-3.83	-3.06	1.42	
2021E	4.36	2.70	2.01	2.21	1.21	1.19	1.03	0.85	3.28	
2022E	6.55	3.31	1.30	2.20	0.99	1.27	1.36	1.02	3.63	

Source: Bloomberg, company reports, and Bernstein estimates and analysis

EXHIBIT 509: **Southern European Utilities**

	NEE	EDF.FP	ENGI.FP	ELE.SM	ENEL.IM	IBE.SM	EDP.PL	EDPR.PL
Rating	O	M	O	O	O	O	O	O
Prices as of Aug. 16, 2021	83.95	11.06	11.95	20.71	7.85	10.21	4.56	20.80
Currency	USD	€	€	€	€	€	US$	€
Target Price	88.00	16.00	15.00	27.00	9.50	13.00	6.00	26.00
52-Week Range	66.8-87.7	8.1-13.6	10.1-13.9	20.2-25.2	6.7-9.1	10.0-12.6	4.1-5.7	13.4-26.4
Market Capitalization (bn)	164	35	29	22	79	65	18	20
TTM Performance	18.7%	24.7%	2.2%	-14.7%	-0.2%	-6.7%	4.1%	50.4%
TTM Relative Performance	-7.3%	-1.3%	-23.8%	-40.7%	-26.2%	-32.7%	-21.9%	24.4%
Bernstein Adj EPS Forecast								
2020A	2.31	0.63	0.63	2.01	0.51	0.57	0.20	0.64
2021E	2.55	1.14	1.04	1.64	0.55	0.60	0.21	0.53
2022E	2.72	1.10	1.05	1.69	0.58	0.65	0.23	0.59
2023E	3.03	1.25	1.16	1.81	0.62	0.72	0.26	0.66
EPS Annual Change								
2019A-20A	10.3%	(50.5)%	(40.3)%	36.5%	9.0%	6.2%	(15.8)%	16.9%
2020A-21E	10.3%	43.6%	53.4%	(18.2)%	6.8%	5.6%	3.6%	(16.8)%
2021E-22E	7.0%	15.4%	10.4%	2.9%	6.3%	7.6%	12.9%	12.2%
2022E-23E	11.4%	16.8%	10.3%	6.9%	7.3%	11.9%	10.7%	11.2%
Consensus EPS								
2021E	2.52	1.03	1.02	1.62	0.55	0.58	0.21	0.53
2022E	2.73	1.11	1.09	1.61	0.57	0.64	0.24	0.60
2023E	2.93	1.28	1.15	1.66	0.63	0.68	0.26	0.67
P/E on Bernstein EPS Forecast								
2020A	36.4x	17.5x	19.1x	10.3x	15.4x	18.0x	23.2x	32.7x
2021E	33.0x	12.2x	12.4x	12.6x	14.4x	17.0x	22.4x	39.3x
2022E	30.8x	10.6x	11.2x	12.2x	13.5x	15.8x	19.8x	35.0x
2023E	27.7x	9.0x	10.2x	11.4x	12.6x	14.1x	17.9x	31.5x
Shares Outstanding (mil.)	1962	3158	2435	1059	10167	6366	3966	961
Yield (trailing)	2%	2%	4%	10%	5%	4%	4%	0%
Dividend per Share (FY1)	1.54	0.33	0.67	1.32	0.38	0.44	0.19	0.08

Note: European stocks are benchmarked against the MSCI Europe Index, which had a closing price of 1888.53 as of August 16, 2021. US stocks are benchmarked against the S&P 500 Index, which had a closing price of 4,479.71 as of August 16, 2021.

Source: Bloomberg, company reports, and Bernstein estimates and analysis

EXHIBIT 510: **Northern European Utilities**

	Orsted ORSTED.DC	SSE SSE.LN	RWE RWE.GR	E.ON EOAN.GR	National Grid NG/.LN	Fortum FORTUM.FH
Rating	O	O	O	O	O	U
Prices as of Aug. 16, 2021	958.80	16.21	31.51	10.94	9.57	0.24
Currency	DKK	£	€	€	£	£
Target Price	1010.00	18.50	45.00	13.30	10.80	18.00
52-Week Range	818-1401	1161-1646	28-39	8-11	805-968	16-25
Market Capitalization (bn)	409	17	22	29	34	22
TTM Performance	8.2%	24.3%	-7.9%	10.0%	8.0%	36.6%
TTM Relative Performance	-17.8%	-1.7%	-33.9%	-16.0%	-18.0%	10.6%
Bernstein Adj EPS Forecast						
2020A	35.14	87.47	1.90	0.63	54.21	2.05
2021E	29.38	94.66	1.41	0.71	58.89	4.61
2022E	16.31	93.82	1.60	0.92	67.22	1.37
2023E	41.08	92.89	1.34	0.94	72.99	1.36
EPS Annual Change						
2019A-20A	126.9%	(4.2)%	10.6%	2.5%	(6.7)%	22.8%
2020A-21E	(16.4)%	7.1%	(25.9)%	13.5%	8.6%	124.8%
2021E-22E	(44.5)%	(3.7)%	13.6%	29.8%	14.1%	(70.4)%
2022E-23E	151.9%	0.6%	(16.2)%	1.1%	8.6%	(0.4)%
Consensus EPS						
2021E	22.49	0.93	1.75	0.83	0.59	1.62
2022E	21.17	0.96	1.79	0.89	0.67	1.61
2023E	21.88	0.93	1.42	0.90	0.68	1.52
P/E on Bernstein EPS Forecast						
2020A	27.3x	0.2x	16.6x	17.4x	0.2x	0.1x
2021E	32.6x	0.2x	22.3x	15.4x	0.2x	0.1x
2022E	58.8x	0.2x	19.7x	11.8x	0.1x	0.2x
2023E	23.3x	0.2x	23.5x	11.7x	0.1x	0.2x
Shares Outstanding (mil.)	420	1043	676	2641	3556	888
Yield (trailing)	1%	5%	3%	4%	5%	5%
Dividend per Share (FY1)	12.37	83.43	0.90	0.49	49.54	1.14

Note: For E.ON and RWE 2019 is proforma. The stocks are benchmarked against the MSCI Europe Index, which had a closing price of 1888.5 as of August 16, 2021

Source: Bloomberg, company reports, and Bernstein estimates and analysis

EXHIBIT 511: **EU Wind OEMs**

	SGRE SGRE.SM	Vestas VWS.DC
Rating	O	O
Prices as of Aug. 16, 2021	24.21	239.10
Currency	€	DKK
Target Price	**28.00**	**285.00**
52-Week Range	20.3-39.4	181.0-321.0
Market Capitalization (bn)	16	241
TTM Performance	10.4%	36.6%
TTM Relative Performance	-16.1%	10.1%
Bernstein Adj EPS Forecast		
2019A	0.21	3.57
2020A	-1.35	3.90
2021E	-0.66	0.74
2022E	-0.06	1.03
EPS Annual Change		
2018A-19A	101.6%	150.1%
2019A-20A	na	9.2%
2020A-21E	na	(81.1)%
2021E-22E	na	39.0%
Consensus EPS		
2020E	0.40	7.42
2021E	0.73	8.23
2022E	1.00	8.54
P/E on Bernstein EPS Forecast		
2019A	121.5x	70.6x
2020A	na	64.6x
2021E	na	341.5x
2022E	na	245.6x
Shares Outstanding (mil.)	679	1,010
Yield (trailing)		
2019 Dividend per Share	0.05	1.06

Note: The stocks are benchmarked against the MSCI Europe Index, which had a closing price of 1888.53 as of August 16, 2021

Source: Bloomberg, company reports, and Bernstein estimates and analysis

EXHIBIT 512: **Asian Renewables, Power and Coal**

	2208 HK Equity	916 HK Equity	601012 CH Equity	002129 CH Equity	DQ US Equity	1799 HK Equity
Rating	O	O	O	O	O	O
Prices as of Aug. 16, 2021	13.28	13.34	84.77	46.53	49.83	18.78
Currency	HKD	HKD	CNY	CNY	USD	HKD
Target Price	**20.50**	**15.70**	**93.00**	**36.00**	**122.00**	**35.00**
52-Week Range	6.1-19.5	4.5-15.8	36.6-95.5	20.1-52.4	18.2-130.3	3.7-31.3
Market Capitalization (US$ billion)	1	6	71	22	4	1
TTM Performance	71.1%	145.2%	111.9%	94.0%	117.8%	336.7%
TTM Relative Performance	56.2%	130.3%	96.9%	79.1%	102.9%	321.8%
Bernstein Adj EPS Forecast	CNY	CNY	CNY	CNY	USD	CNY
2020A	0.67	0.59	1.62	0.38	1.82	0.58
2021E	0.92	0.71	2.09	0.74	7.88	2.34
2022E	0.98	0.81	2.66	0.92	7.11	2.26
EPS Annual Change						
2020A-21E	37.5%	20.3%	29.3%	95.2%	333.4%	303.6%
2021E-22E	6.2%	14.4%	27.2%	25.0%	(9.8)%	(3.4)%
Consensus EPS						
2020A	0.73	0.51	1.35	0.40	0.40	na
2021E	0.79	0.60	2.25	0.46	2.08	0.81
2022E	0.84	0.74	2.29	0.84	9.04	2.47
P/E on Bernstein EPS Forecast						
2020A	16.5x	18.9x	52.3x	123.4x	27.4x	32.4x
2021E	12.0x	15.7x	40.5x	63.2x	6.3x	8.0x
2022E	11.3x	13.7x	31.8x	50.6x	7.0x	8.3x
Shares Outstanding (mil.)	774	3,340	5,413	3,033	74	376
Yield (trailing)	1.0%	0.7%	0.3%	0.1%	0.0%	0.5%
2020 Dividend per Share	0.16	0.12	0.25	0.06	0.00	0.10

Source: Bloomberg, company reports, and Bernstein estimates and analysis

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VALUATION METHODOLOGY

European Autos

We value EU automotive companies based on one/two-year-forward multiples. Based on the point in the cycle, these can vary between PE, EV/sales, and EV/EBITDA. In some cases, we also use sum-of-the-parts valuations. Our EV multiples are for the industrial (autos) operations and we value captive financial services operations separately with their book value. Truck makers and sports car makers are valued with respect to their industrials and luxury goods peer groups.

Asian Autos

We value Chinese automotive companies based on one-/two-year-forward multiples. Based on the point in the cycle, these can vary between P/E, EV/Sales, and EV/EBITDA. In some cases, we also use sum-of-the-parts valuations.

Global Energy Storage

We value Global Energy Storage companies using the sum of the parts valuation and DCF approach. Our DCF model is based on annual free cash flow forecasts until 2050, plus a terminal value estimate to capture the continuing value of the company.

Contemporary Amperex Technology Co Ltd: We value CATL using the DCF approach.

Samsung SDI Co Ltd: We value Samsung SDI using a sum of the parts valuation methodology.

LG Chem Ltd: We value LG Chem using a sum of the parts valuation methodology.

Global Metals & Mining

Our valuation framework for our Global Metals & Mining stocks varies by company, but is driven by: (a) a top down approach using near-term future forecast EBITDA multiplied by the appropriate multiple (EV/EBITDA), and (b) a bottoms-up approach using a set of life-of-asset DCFs for the most important assets in a company's portfolio modeled under our assumptions of commodity prices and asset properties.

We adjust our target multiples and discount to NPV to include the effects of growth, balance sheet strength/weakness, capital efficiency, management premium/discount, FCF yield, and risks especially around ESG.

European Industrial & Consumer Chemicals

We value Umicore shares as the arithmetic average of four metrics: (1) Relative P/E to reflect short-term earnings trends. We use 12-month-forward earnings forecasts relative to the stock's underlying index. (2) Absolute EV/EBIT to reflect medium-term earnings trends. We use two-year-forward earnings forecasts compared to the stock's own history. (3) We use DCF to reflect the long-term value and cash-generative nature of companies. (4) In our sum-of-the-parts analysis, we use DCF for battery materials and battery recycling businesses and NTM EV/EBITDA for other businesses. We increase the arithmetic average from the four methodologies by 4.5% (long-run market return of 7% minus a dividend yield of 2.5%) to calculate our 12-month target prices.

We value BASF shares as the arithmetic average of four metrics: (1) Relative P/E to reflect short-term earnings trends. We use 12-month-forward earnings forecasts relative to the stock's underlying index. (2) We use absolute EV/EBIT to reflect medium-term earnings trends. We use two-year-forward earnings forecasts compared to the stock's own history. (3) We use DCF to reflect the long-term value and cash-generative nature of companies. (4) In our sum-of-the-parts analysis, we use peer multiples on EV/EBITDA NTM+1. We increase the arithmetic average from the four methodologies for each company by 4.5% (long-run market return of 7% minus a dividend yield of 2.5%) to calculate our twelve-month target prices.

European Oil & Gas

Our target prices for the European Integrated Oils are calculated by applying our estimates for 12-month forward cash flow per share (CFPS) to a forward price-to-cash flow (P/CF) multiple. This P/CF multiple is generated through the relationship, and historically strong correlation, between 12-month forward P/CF multiples and Return on Average Capital Employed (ROACE) within the Integrated Oils group. Our calculation utilizes this relationship and an estimated long-term, through-the-cycle ROACE to generate the target P/CF multiple. We use US$60/ bbl Brent in 2021, US$65/bbl, in 2022 and US$63/bbl in 2023.

India Autos

The auto business is an aggregation of several end markets with different growth characteristics and cycles. To understand sector valuations relative to global peers, we use EV/invested capital and compare that with the ROIC/WACC spread. In addition, we overlay that with growth expectations. To arrive at our target prices, we use a combination of discounted cash flow and P/E multiples and benchmark P/E to historical averages.

Asian Industrial Technology

We use EV/EBITDA multiple as the primary valuation method. We set the target multiple referencing previous cycle peaks, but adjust for specific situations of the current cycle, apply it on the upcoming cycle peak to get the enterprise value, and discount it back to derive our price target.

We use DCF as reference for the company's long-term intrinsic value. As we move along the different stages of a cycle, the time-dependent target price may temporarily deviate from the DCF-implied value. Currently, because the 12-month target price date sits in a solid upcycle and approaches the cycle peak, our target prices are higher than the DCF-implied value for most companies.

Asian Semiconductors and Equipment

Infineon Technologies AG: Forward P/E is used as it better reflects Infineon's EPS growth in the next few years. We derive Infineon's 1-year TP using 26x NTM P/E, in line with current valuation.

Asia Logistics and Travel

For the airlines in our coverage, we apply a consistent framework of EV/EBITDA backed by conservative discounted cash flow analysis (DCF). We use MSCI ACWI Airlines Index as our benchmark and apply a premium based on historical trends.

We maintain dual A- and H-share rating when stocks have both categories of shares listed on the relevant exchanges. For airlines listed on multiple exchanges of Hong Kong and China, we derive our A-share target prices by translating the H-share target prices from HKD to RMB, and apply a trading value difference based on historical trends.

Trip.com: We value Ctrip based on the average of SOTP and NTM P/E. The SOTP method values Ctrip's core business using a DCF calculation and adding Ctrip's significant minority investments in other businesses to arrive at a target price.

US Machinery

We calculate 12-month target prices for our coverage using a mix of P/E and EV/EBITDA methodologies based on each company's mode of value creation. We use multiples from the appropriate place in the cycle to triangulate our valuations.

U.S. IT Hardware

We value companies in our coverage using price to forward earnings relative to the S&P 500 and on EV/FCF.

Apple Inc: Our price target reflects a 30 P/FE multiple applied to our FY 21 EPS estimate, in line with a broad set of consumer companies.

U.S. Natural Gas & MLPs

Our valuation framework for midstream and MLP companies in our coverage is based on forecasting 40 years of EBITDA and distributable cash flow (DCF). From this, we allow debt growth in line with the debt to EBITDA coverage required to keep current credit ratings. Any capex needs not funded through debt are therefore funded from DCF, with our valuation based on the remainder, which we consider to be the cash flow available to investors. We value this cash stream at an 8-9% discount rate for our full coverage with the exception of LNG, for which we use a 10% discount rate for cash flows that do not originate from Cheniere Energy Partner (CQP). We adjust our target prices for expected changes to EBITDA, growth capex, interest rate, maintenance capital, and share count.

European Utilities & Renewables

Our main valuation approach is a sum-of-the-parts (SOTP) DCF methodology. We complement the SOTP DCF methodology with an EV/EBITDA multiple approach by segment where applicable (e.g., Engie) and a premium to RAB view for networks. We value our European utilities and renewables coverage using an SOTP DCF methodology.

EU Wind OEMs

We value the European Wind OEMs using an SOTP DCF methodology.

Asian Renewables, Power and Coal

We value Longyuan and Goldwind based on one-year forward price-to-earnings (P/E) multiples. We use forward EPS estimates of 2022 to set our one-year target prices.

We value LONGi Green, Zhonghuan, and Daqo New Energy based on DCF. We forecast growth until 2040 and calculate a terminal value for years beyond 2040. For WACC, we use Bloomberg equity beta, market return, and risk free rate. Debt and cash portion are based on our forecast of debt/cash balance as of 2021-year-end and the equity portion is based on current market capitalization.

RISKS

European Autos

The risks to our views on our European auto stocks and our share price targets are mainly macroeconomic in nature. Earnings, liquidity, and equity value could be severely tested in the event of economic contractions in major end markets and a slowdown in vehicle demand. Individual companies are at risk of specific product and project failure, while the ability of financial services businesses to remain viable could also be tested if the global financial system deteriorates, restricting capital market access. Our forecasts are also sensitive to moves in the euro versus the US dollar and the UK sterling, as well as Latin America and Asian currencies.

Asian Autos

The risks to our views on our Chinese auto OEM stocks and our share price targets are mainly macroeconomic in nature. Auto sales in China correlate well with liquidity growth and earnings, and equity value could be severely tested in the event of economic contractions in major end markets such as China, the US, Europe, and emerging markets. The individual companies are at risk of specific product and project failure, while the ability of financial services businesses to remain viable could also be tested in an environment where liquidity becomes very scarce, and/or access to capital markets becomes restricted.

The highly politicized nature of the Chinese auto industry creates a number of risks, both external (e.g., anti-Japan protests in China in 2012 and anti-Korean sentiment in 2017) and internal (e.g., Chinese government intervention in policy or company strategy). Unclear inter-company relationships and politicized corporate governance also represent potential risks for some of our coverage companies.

Our forecasts are also sensitive to moves in global exchange rates and commodity prices (e.g., steel and aluminum).

Global Energy Storage

Risks to Global Energy Storage companies include increasing market competition globally, which could negatively impact growth and price outlook. In addition, further raw material cost increases could put additional pressure on the EV value chain. Given the industry is still in a nascent stage, positive or negative changes in government policy and subsidy programs will impact the growth outlook.

Contemporary Amperex Technology Co Ltd: Key risks include: (1) stronger-than-expected competition in the space, (2) raw material costs increase further, putting additional pressure on the EV value chain, and (3) CATL's battery costs fall slower than expected due to either poor execution or higher input costs (from suppliers).

Samsung SDI Co Ltd:

Samsung SDI's earnings growth depends on the adoption of EVs and energy storage systems (ESS) to boost battery revenues and profits. Any change in strategy by automakers or lack of cost declines would reduce this upside. In addition, display still plays a large role in the equity income line. Small battery profit recovery depends on the utilization of polymer lines improving which, in turn, depends on orders from customers, including parent Samsung Electronics. Risks to display (driving equity income) include supply/demand balance pressuring pricing and, hence, margins.

Upside risks include better-than-expected EV battery/ESS sales and faster-than-expected technology breakthroughs.

LG Chem Ltd: Key risks include: (1) increasing competition within the EV battery industry, (2) raw material costs increase further, putting additional pressure on the EV value chain, and (3) battery quality issues that could lead to battery recalls, etc.

Global Metals & Mining

The primary risk to our target prices for Global Metals & Mining equities is lower/higher-than-expected commodity prices over the next few years.

Commodity prices are negatively impacted by demand weakness (driven by GDP trends and structural efficiency improvements), supply strength (driven by poor capital discipline or technology breakthroughs), and the strength of the dollar.

Operational, strategic, and capital allocation errors negatively impact company stock prices.

Additional risks fall into various ESG buckets. Mining has a significant environmental footprint that needs focus. Social issues involve host governments and large labor forces. Governance issues involve the risk of poor governance, mismanagement and even corruption.

European Industrial & Consumer Chemicals

Our financial forecasts are based on our forecasts for economic growth and assume prevailing exchange rates remain unchanged in the future. The performance of chemicals companies can be significantly influenced by changes in demand, in turn driven by changes in industrial growth and consumer spending.

For Umicore specifically, the primary upside risk to our target price would be for EV market adoption rates to be greater than initially expected or for the company to build a truly dominant market share to perpetuity. We also see risk from a faster-than-anticipated ramp in its recycling business and technological development in its catalysis business leading to share gains. Conversely, downside risks to our target price would be for EV adoption to stall, the recycling business to have production issues, and the catalysis business losing share.

For BASF specifically, downside risks to our target price could arise from a reversal of the recovery in demand in key end-markets, particularly industrial production. Potential raw material headwinds through petrochemical cost inflation and the inability to pass on higher costs to customers could hurt BASF's margins. Additionally, unexpectedly large dilutive acquisitions could have a downward effect.

European Oil & Gas

For the European Majors, the greatest risk to our target prices is a significant decline in crude oil prices, as the Majors commonly trade in line with commodity prices. Additionally, downward revisions to production volume targets could adversely impact share prices. Upside risks include higher oil prices and capex reduction below what we carry currently.

India Autos

After weak auto sales for the last two years, we think PV and 2W growth rates will resume from 2H FY2022 as demand normalizes post Covid-19 impact. There could be risk of continued weakness if Covid-19-related disruption reemerges. A faster-than-expected regulatory pressure and stiff targets for EVs, which is currently not the case, could also present risks for ICE vehicle sales. Conversely, for CV, a further delay in recovery could be a risk as we are taking a cautious view on the cycle while tractor upcycle could have challenges from the ongoing farmer protest.

Asian Industrial Technology

The risks to our coverage names are mainly associated with the global macroeconomy, including industrial capex cycles, trade frictions, and currency. US companies' share prices are sensitive to their quarterly results relative to management guidance and consensus forecasts. Japanese and Chinese companies are much less so.

As IPG has >50% of global share in fiber laser, potential changes in the competitive landscape would be a bigger risk to them than to other companies.

Asian Semiconductors and Equipment

Infineon Technologies AG: Downside risks to our price target for Infineon include slower automotive demand or EV penetration, unexpected direction and timeline changes to technology transitions such as SiC, lower semiconductor demand broadly as well as valuation multiple compression.

Asia Logistics and Travel

The Asia Pacific Transportation and Logistics companies we cover are subject to macroeconomic risks, including exposure to overall economy growth, trade volume, interest rates, and foreign exchange rates, as well as competitive landscape changes brought about by new entrants and new technology that may disrupt the market game.

Trip.com

Upside risks: Growth and profitability from overseas businesses better than expected, pick up in overall travel consumption, change in competitive dynamics that leads to less-than-expected sales and marketing expense, margins better than expected, improvement in travel ticketing take rate, result from offline shops better than expected.

Downside risks: Growth and profitability from overseas businesses worse than expected, slowdown in overall travel consumption, further deterioration of margins due to competitive pressure, accelerated sales and marketing expense from expansion in lower tier cities, regulatory risks.

US Machinery

Upside/downside risks include: (1) a better-/worse-than-expected cyclical recovery; (2) higher/lower market share gains/losses; (3) higher/lower product penetration; (4) better/worse cost structure management; and (5) more/less aggressive deployment of balance sheet.

U.S. IT Hardware

The biggest risks to U.S. IT Hardware are (1) that an accelerated migration to the Cloud could undermine on premise spending; (2) that the macro and IT spending environment is weaker than expected in 2021; or (3) that PC and tablet demand was "pulled forward" during the pandemic, triggering weaker than expected spending in 2021 and/or 2022.

Apple Inc

The biggest risks to the downside on Apple and to our price target are that: (1) iPhone replacement cycles extend as successive generation product differentiation becomes less pronounced, undermining growth; (2) the iPhone 12 cycle is weaker than expected; or (3) earnings stall out post FY 2021.

The biggest risks to the upside are that: (1) the current iPhone cycle is stronger than we think, as depressed purchase levels from last year rebound; (2) Apple is able to sustain or accelerate services growth through myriad new offerings; or (3) the stock continues to rerate, potentially due to an ongoing market preference for quality or technology based names.

U.S. Natural Gas & MLPs

The greatest risks to the natural gas & MLP sector are from: (1) Commodity prices. Lower commodity prices would directly impact segments tied with price exposure (e.g., percent of proceeds contracts in the natural gas processing segment). In the medium term, lower price may lead to lower production (through lowered investment) or immediately (through bankruptcy). Higher-than-expected commodity prices may lead to greater production and would benefit pipeline volume throughput and processing plant utilization. (2) Commodity volumes. Reduced production or demand for these products hurts the midstream MLP companies that transport them, leaving pipelines empty and companies unable to earn back their investments. Higher-than-expected production benefits existing assets while providing companies with more growth opportunities. (3) Overcapacity. If midstream MLP players build more capacity than suppliers can fill or than demand-side customers are willing to receive, they are at risk of being unable to recoup their initial investment in the project. We believe that this may play out in the near-to-medium term in several US producing regions. Upside risk may come if additional infrastructure is required and MLPs are able to construct it at good returns. (4) Regulatory bottlenecks. If state and federal regulators do not grant the necessary permits to construct and operate new midstream assets, the industry will not be able to grow in the medium-long term. On the other hand, if regulatory processes are streamlined significantly, the industry may see additional upside from lower compliance costs, faster approval processes, and/or greater certainty of approval.

European Utilities & Renewables

Risks common to all companies in our coverage include:

Regulation: All companies in our coverage are at risk of regulatory impacts. A country's general attitude and policy toward the energy & utilities industry (e.g., renewables, regulated return for networks, and energy taxes) will have significant influence stoward the future earnings stream of companies operating in this space.

Adverse credit conditions limiting access to credit.

Prevailing macroeconomic conditions: In each of the territories our coverage companies operate in, the demand for electricity and gas is correlated to prevailing economic conditions. Thus, any unexpected deterioration or improvement in the macroeconomic conditions in these countries will impact the growth assumptions applied to those operations. Changes in commodity prices — power, gas, coal, and carbon — will also impact the profitability of our coverage with merchant power generation/upstream/midstream activities.

EU Wind OEMs

Key downside risks to our thesis include:

Slowdown in onshore wind market due to regulatory/policy hiatus

Excessive competitive pressure on offshore wind, leading to lower orders beyond 2025

Product quality issues leading to a significant drawdown on warranty claims/liquidated damages

Vestas Wind Systems A/S

Key downside risks to our target price include:

Failure to capture scale and market share in offshore wind

Failure to hit long-term margin expansion targets

Slow-down in onshore wind market due to regulatory/ policy hiatus

Product quality issues leading to a significant draw-down on warranty claims/ liquidated damages

Siemens Gamesa

Key downside risks to our target price include:

Failure to turnaround the onshore wind division and slowdown in onshore wind market due to regulatory/policy hiatus

Excessive competitive pressure on offshore wind, leading to lower orders beyond 2025

Product quality issues leading to a significant drawdown on warranty claims/liquidated damages

Asian Renewables, Power and Coal

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Ticker	Rating Changes		
002129.CH	O (RC) 09/24/20	U (IC) 11/26/19	
002202.CH	O (IC) 11/26/19		
002415.CH	O (IC) 04/20/17		
002747.CH	O (IC) 10/27/20		
006400.KS	M (IC) 06/21/21	O (DC) 02/12/21	O (IC) 06/11/14
051910.KS	O (IC) 06/21/21		
1114.HK	M (RC) 10/16/18		
175.HK	O (RC) 01/07/20		
1799.HK	O (IC) 07/22/21		
1958.HK	M (RC) 01/07/20		
2208.HK	O (IC) 11/26/19		
2238.HK	M (RC) 04/08/20		
2333.HK	O (RC) 12/04/20	M (RC) 02/22/19	
300124.CH	M (IC) 04/17/19		
300750.CH	O (IC) 06/21/21	O (DC) 02/12/21	O (IC) 06/11/18
600104.CH	M (RC) 12/04/20	O (RC) 05/19/17	
601012.CH	O (RC) 09/24/20	U (IC) 11/26/19	
6861.JP	O (IC) 06/06/16		
8TRA.GR	U (IC) 09/08/20		
916.HK	O (IC) 11/26/19		
AAL.LN	O (RC) 07/02/21	M (IC) 01/12/21	O (DC) 02/07/20
AAPL	M (RC) 02/02/18		
ABX.CN	O (IC) 01/12/21		
ANTO.LN	O (IC) 01/12/21	O (DC) 02/07/20	
BAS.GR	O (RC) 01/12/21	M (IC) 09/24/18	
BBL	O (IC) 01/12/21	M (DC) 02/07/20	
BHP	O (IC) 01/12/21	M (DC) 02/07/20	
BHP.AU	O (IC) 01/12/21	M (DC) 02/07/20	
BHP.LN	O (IC) 01/12/21	M (DC) 02/07/20	
BJAUT.IN	O (RC) 01/11/21	M (IC) 09/25/19	
BMW.GR	O (IC) 09/08/20	M (DC) 02/28/20	
BP	O (RC) 09/10/15		
BP/.LN	O (RC) 09/10/15		
CGNX	M (RC) 04/30/19		
CMI	O (IC) 09/22/20	O (DC) 07/16/10	

CQP	M (RC) 10/08/19
DAI.GR	O (IC) 09/08/20 M (DC) 01/13/20
DQ	O (IC) 02/01/21
E	U (RC) 01/04/21 O (RC) 04/07/20
EDF.FP	O (RC) 12/03/20 M (IC) 05/01/19
EDP.PL	O (RC) 09/04/19
EDPR.PL	O (IC) 05/01/19
EIM.IN	M (RC) 10/28/20 O (RC) 06/15/20
ELE.SM	M (IC) 07/23/18
ENEL.IM	O (IC) 11/15/17
ENGI.FP	O (IC) 10/15/18
ENI.IM	U (RC) 01/04/21 O (RC) 04/07/20
EOAN.GR	O (IC) 05/08/14
EPD	O (IC) 05/10/16
EQNR	O (RC) 06/01/21 M (RC) 01/04/21 O (RC) 04/07/20
EQNR.NO	O (RC) 06/01/21 M (RC) 01/04/21 O (RC) 04/07/20
ET	O (RC) 05/10/17
FORTUM.FH	U (IC) 06/15/20
GALP.PL	M (RC) 01/04/21 O (RC) 02/23/17
GOLD	O (IC) 01/12/21
HMCL.IN	M (RC) 01/09/20
IBE.SM	O (RC) 09/10/18
IFX.GR	O (IC) 06/19/19
IPGP	O (IC) 04/18/18
KMI	M (RC) 03/09/21 O (RC) 06/26/18
LNG	O (RC) 03/26/18
MM.IN	O (RC) 06/15/20
MSIL.IN	O (IC) 03/21/19
NEE	O (IC) 03/02/21 M (DC) 02/26/16
NEM	O (IC) 01/12/21
NG/.LN	O (RC) 06/14/19
OKE	M (RC) 01/08/19
ORSTED.DC	O (RC) 05/18/21 M (RC) 09/03/19
PAA	M (RC) 06/18/18
PAGP	M (RC) 06/18/18
PAH3.GR	M (RC) 01/05/21 U (IC) 09/08/20 O (RC) 04/09/14
PCAR	M (IC) 09/22/20
PWR	O (IC) 09/22/20
RDS/A	O (RC) 12/03/20 M (RC) 03/09/20
RDS/B	O (RC) 12/03/20 M (RC) 03/09/20
RDSA.LN	O (RC) 12/03/20 M (RC) 03/09/20
RDSA.NA	O (RC) 12/03/20 M (RC) 03/09/20
RDSB.LN	O (RC) 12/03/20 M (RC) 03/09/20
RDSB.NA	O (RC) 12/03/20 M (RC) 03/09/20
REP.SM	O (RC) 04/07/20
RNO.FP	O (IC) 09/08/20 M (DC) 02/28/20
RWE.GR	O (RC) 01/09/18
SGRE.SM	O (IC) 03/24/21
SSE.LN	O (RC) 01/09/19
TCOM	O (IC) 02/24/21 M (DC) 08/31/20 M (RC) 01/21/20
TTE	M (RC) 01/04/21 O (RC) 03/25/20
TTE.FP	M (RC) 01/04/21 O (RC) 03/25/20
TVSL.IN	M (IC) 09/25/19
UMI.BB	U (IC) 09/24/18
VOLVB.SS	O (IC) 09/08/20
VWS.DC	O (IC) 03/24/21 U (DC) 07/13/13
WMB	O (RC) 03/12/20

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