ELECTRIC CARS

AN OVERVIEW OF THE ELECTRIC CAR INDUSTRY AND ASSOCIATED TECHNOLOGY

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Executive Summary

The history of motor vehicle manufacturing can be compared to a long and winding road which began in the second half of the 19th century. Although the early 20th century saw the electric car accounting for about one third of road vehicles in operation in the United States and Europe, this type of vehicle quickly became marginalized by diesel and gasoline-powered automobiles, including Ford's Model T. The so-called Tin Lizzy was built at such an exceptionally low cost that it became hard for electric vehicles (EVs) to compete. The superior driving range of the internal combustion engine (ICE) used in gasoline and diesel-powered cars, coupled with a growing number of gas stations which made refueling quick and easy, added further to the decline in the electric car's popularity.

However, the love for diesel and gasoline-powered vehicles among customers in Europe and North America still took some unexpected turns between 1973 and 2011. During these four decades, several instances of fossil fuel shortages roiled the world's leading economies and affected the prices of petroleum products. Additionally, some countries began to introduce higher taxes on fuel to incentivize ecological sustainability. Since the first United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties was held in 1995, the rise of greenhouse gas (GHG) emissions has raised concerns among the United Nations member states that greenhouse gases will increase surface temperature levels and thus lead to the destruction of the earth's ecosystem. Considering that the transportation sector is one of the leading producers of greenhouse gases, cutting GHG emissions from car travel has emerged as an effective way to curb emission growth.

In light of these efforts to tackle GHG emissions, passenger electric vehicles have made a comeback: If electricity from renewable energy sources is used to fuel them, EVs have the potential to play a vital role in the reduction of carbon dioxide and nitrogen oxide emissions. This is an even more important undertaking today, as the light vehicle market has increased tremendously over the past two decades, approaching the 100 million vehicle sales mark.

Batteries remain the electric car's greatest vulnerability. Recharging will have to become easier, and range will have to improve. In the end, EVs can only be environmentally benign if the industries providing the commodities used in electric vehicle batteries are able to reduce their impact on the planet.

Electric vehicle timeline

1832	Robert Anderson creates the first crude electric carriage
1900	Ferdinand Porsche develops the world’s first hybrid
1935	Gasoline-powered cars force EVs out of the market
1996	General Motors launches the EV1
1997	Toyota releases the Prius - the first mass-produced hybrid car
2008	Tesla Motors launches its Roadster, an all-electric luxury sports car
	BYD releases the F3DM - the world’s first plug-in hybrid compact sedan
2010	General Motors introduces the Chevy Volt - the first mass-produced plug-in hybrid;
	Nissan releases the all-electric Leaf
2014	Nissan Leaf sales surpass the 100,000 unit mark
2018	The Model 3 becomes Tesla’s best-selling model

01 Technology: The road to greater range and faster charging

- Batteries
- Range
- Charging infrastructure

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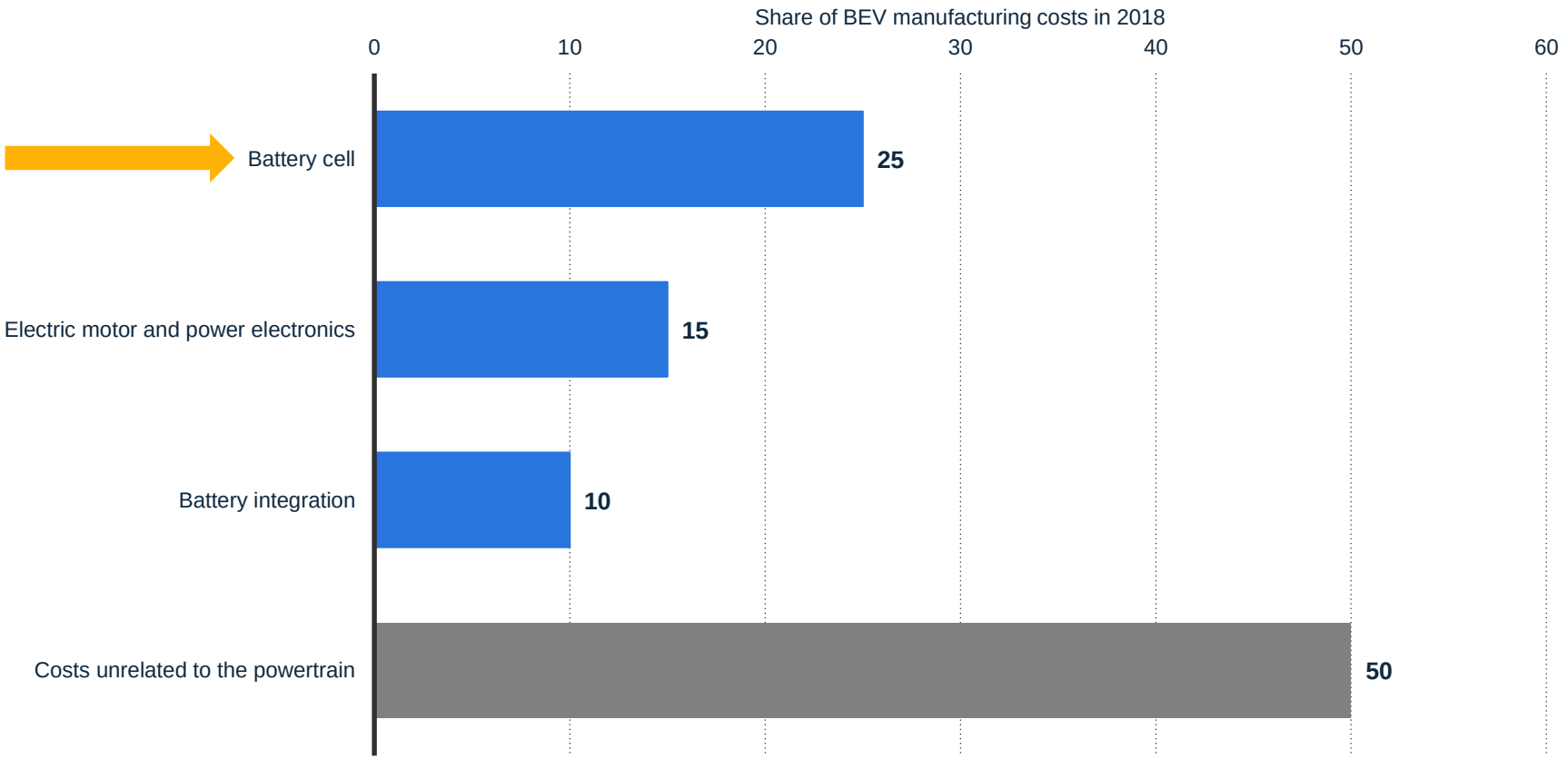
Improved battery technology is the key to competitiveness

While Toyota is betting big on fuel cell electric vehicles (FCEVs), many other carmakers are focusing on battery technology. There are two major categories of batteries holding the potential to power EVs: solid-state batteries and liquid electrolyte batteries. While solid-state batteries for EVs have not yet reached market commercialization, the latter have been used in EVs for many decades.

In 2016, the lithium-ion batteries in some Samsung Galaxy Note 7 devices caught fire and exploded. This incident shows how difficult it is to manufacture lithium-ion batteries that are both efficient and stable. When the EV battery industry began to add nickel to their battery cells to increase the range of electric vehicles, the inclusion of cobalt and manganese was required to prevent the battery from losing stability by controlling how nickel and lithium ions move between the battery cell's anode and cathode.

- Research into electric vehicle battery technology aims to achieve the following:
  - low costs
  - high capacity and stability
  - quick and easy recharging
- 50 percent of BEV manufacturing costs are powertrain-related
- Declining battery costs are expected to push electric vehicle sales
- Finding the right material mix will be key to winning the EV battery race
- Consumers demand higher range, lower costs, and easier access to charging infrastructure
- Electric vehicle energy charging demand will push electricity use in the United States – and probably across all other markets too

50 percent of BEV manufacturing costs are powertrain-related

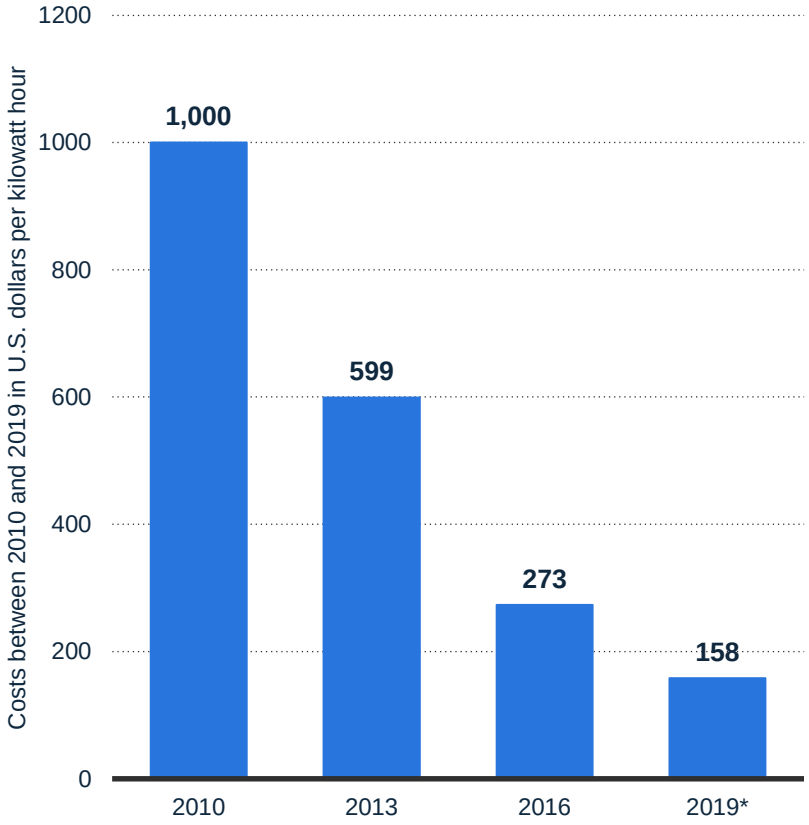


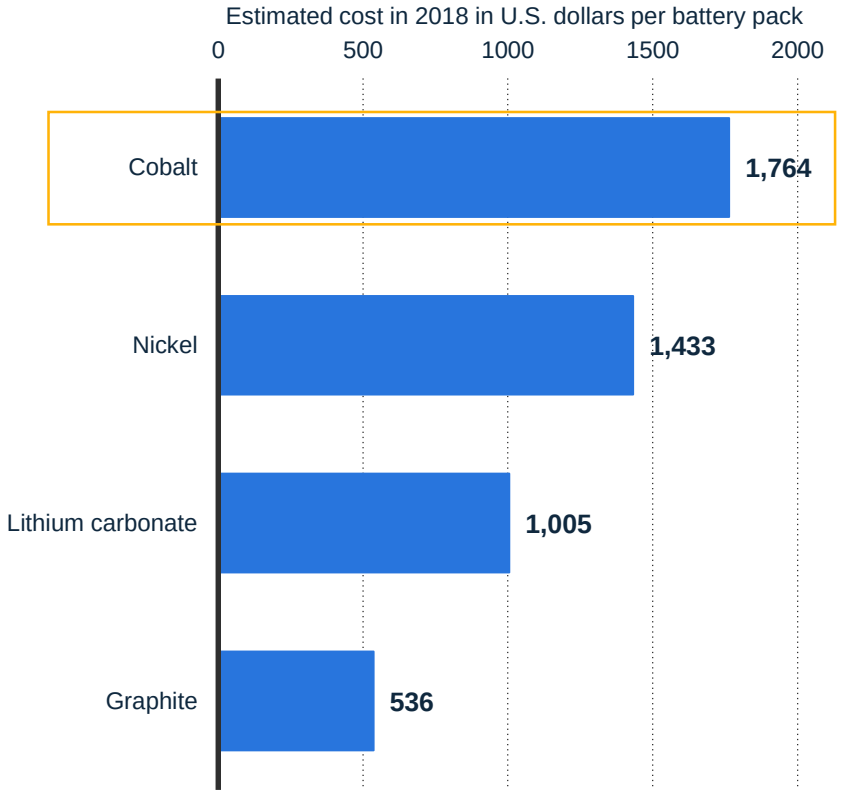
As of 2018, the costs unrelated to the electric powertrain in a battery electric vehicle (BEV) only account for about 50 percent of the overall manufacturing costs.

Battery cells currently account for around 25 percent of costs attributed to the manufacturing of all-electric vehicles, and thus hold the greatest potential for cost reduction.

Note: Worldwide
Source(s): JPMorgan Chase; BCG

Lithium-ion battery pack costs are set to reach a record low in 2019





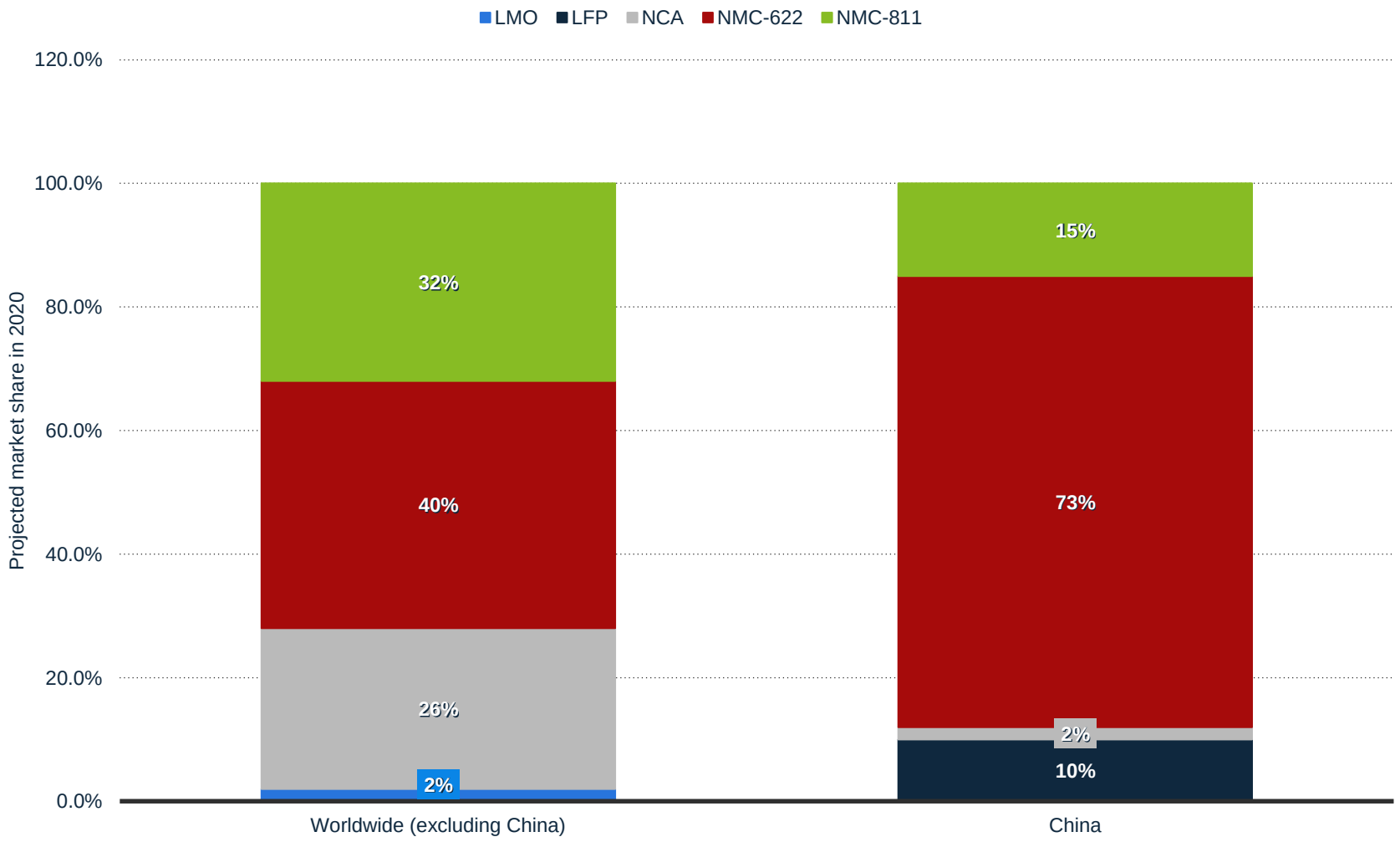
This year, lithium-ion battery pack costs are expected to drop to 158 U.S. dollars per kilowatt hour.

Battery pack costs are driven by size, production volumes, and costs attributable to the commodities used in the manufacturing process.

Electric vehicles may be less vulnerable to fossil fuel prices, but they continue to be susceptible to a volatile commodity market. As a result of cobalt's contribution to EV battery pack costs in 2018, automotive manufacturers and suppliers are now seeking alternatives to this commodity and other expensive materials.

Note: Worldwide
Source(s): Bloomberg New Energy Finance; Bloomberg; PwC; Strategy&; Various sources

Battery chemistry trends diverge between China and the rest of the world

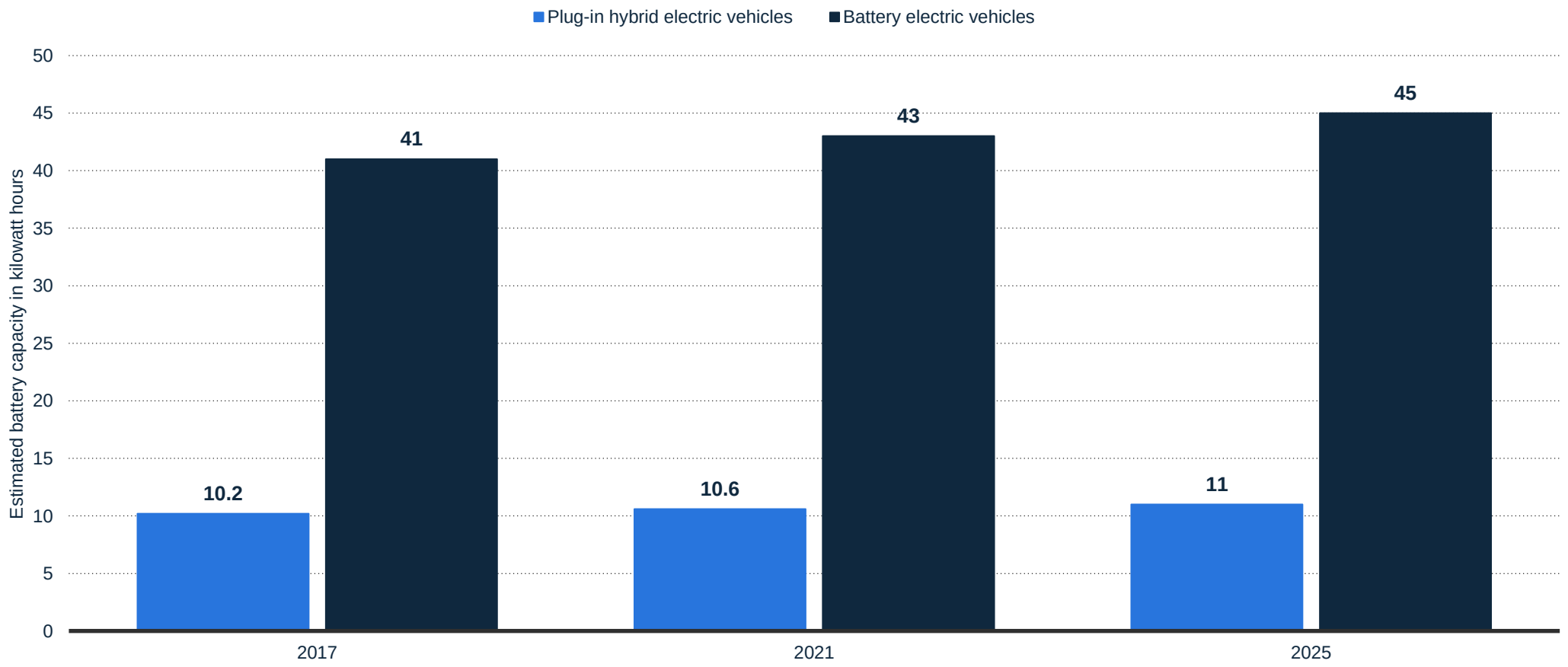


Note: Worldwide
Source(s): McKinsey

By 2020, natrium-manganese-nickel (NMC) battery cathodes are expected to include more nickel than today's batteries and the cobalt content in the more novel NMC-622 and NMC-811 types is projected to be significantly lower than in the NMC-111 batteries that are used most commonly today. Taking into consideration that cobalt prices rose fourfold between 2016 and 2018, the trend towards lower cobalt levels may make EV batteries more cost-effective in the long run.

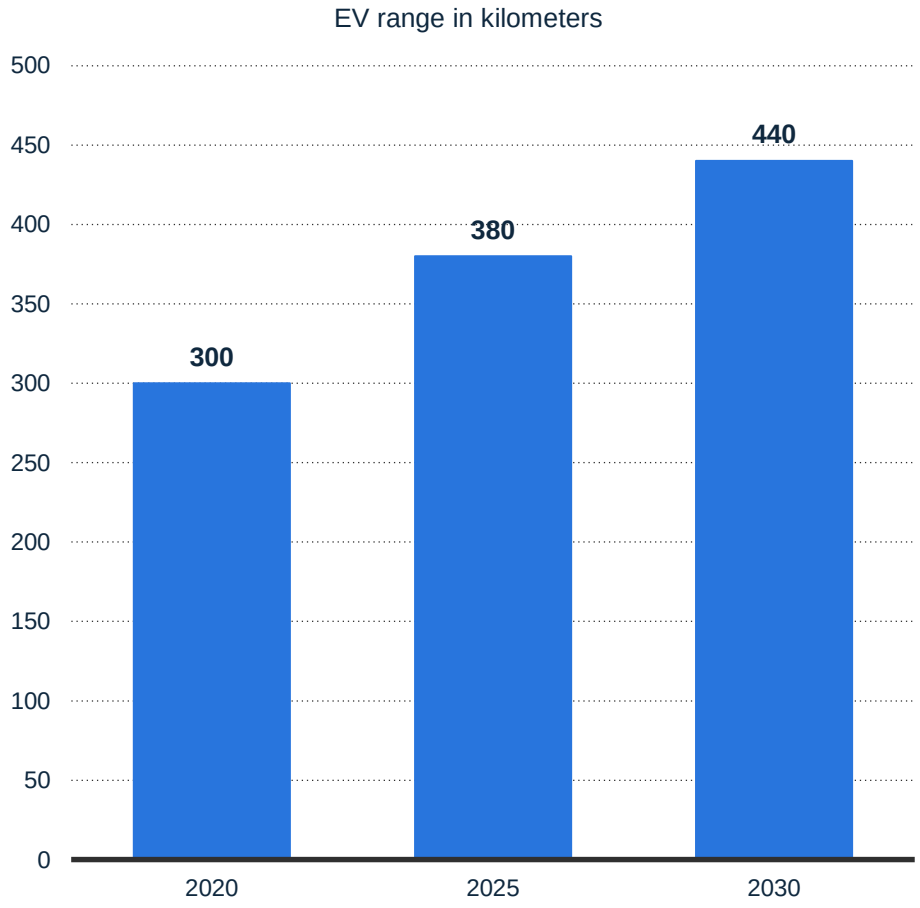
Concurrently, the level of nickel in the NMC-811 and the nickel-cobalt-aluminum (NCA) variants is set to exceed the 80 percent mark, leading to enhanced battery capacity.

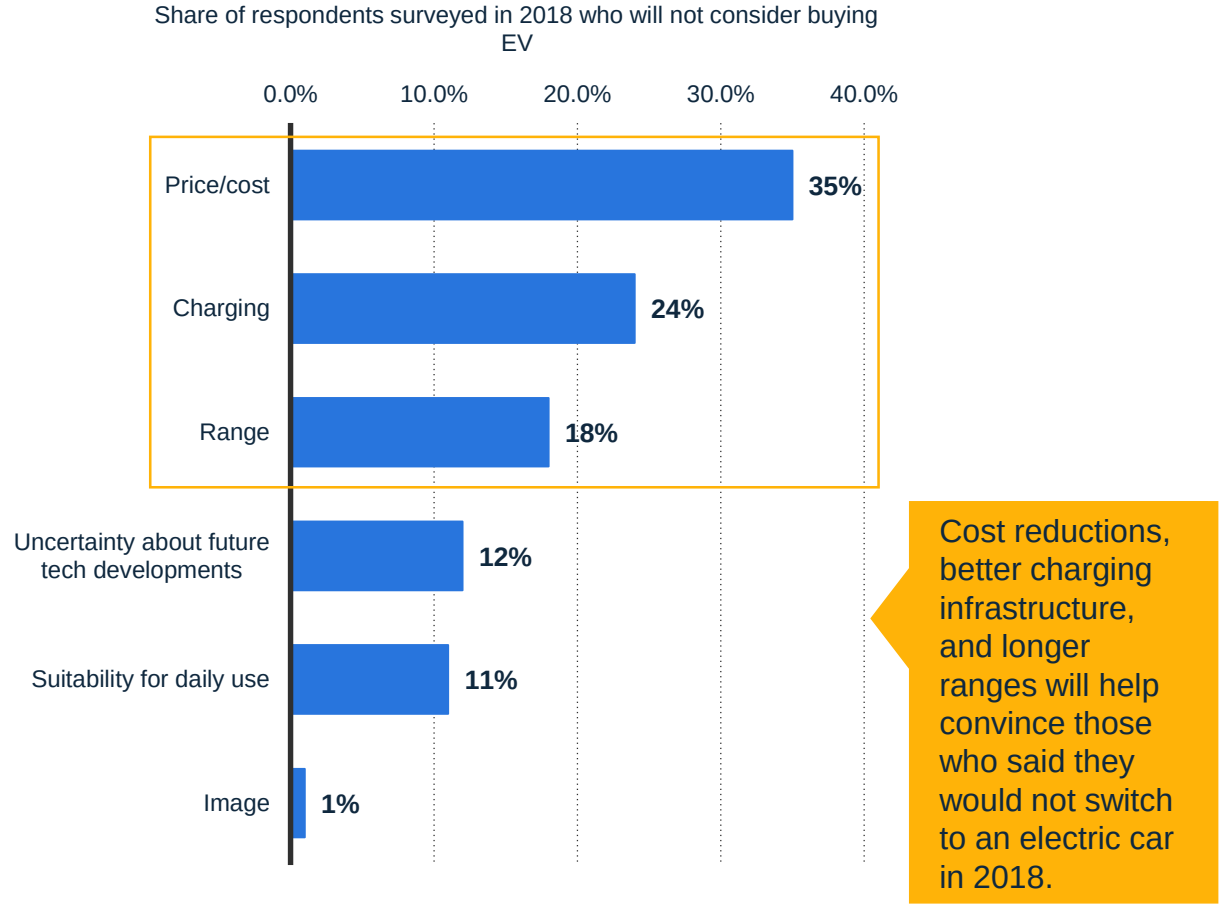
Battery chemistry composition is expected to drive mild increases in battery capacity levels



Note: Worldwide
Source(s): Various sources; BMO Capital Markets

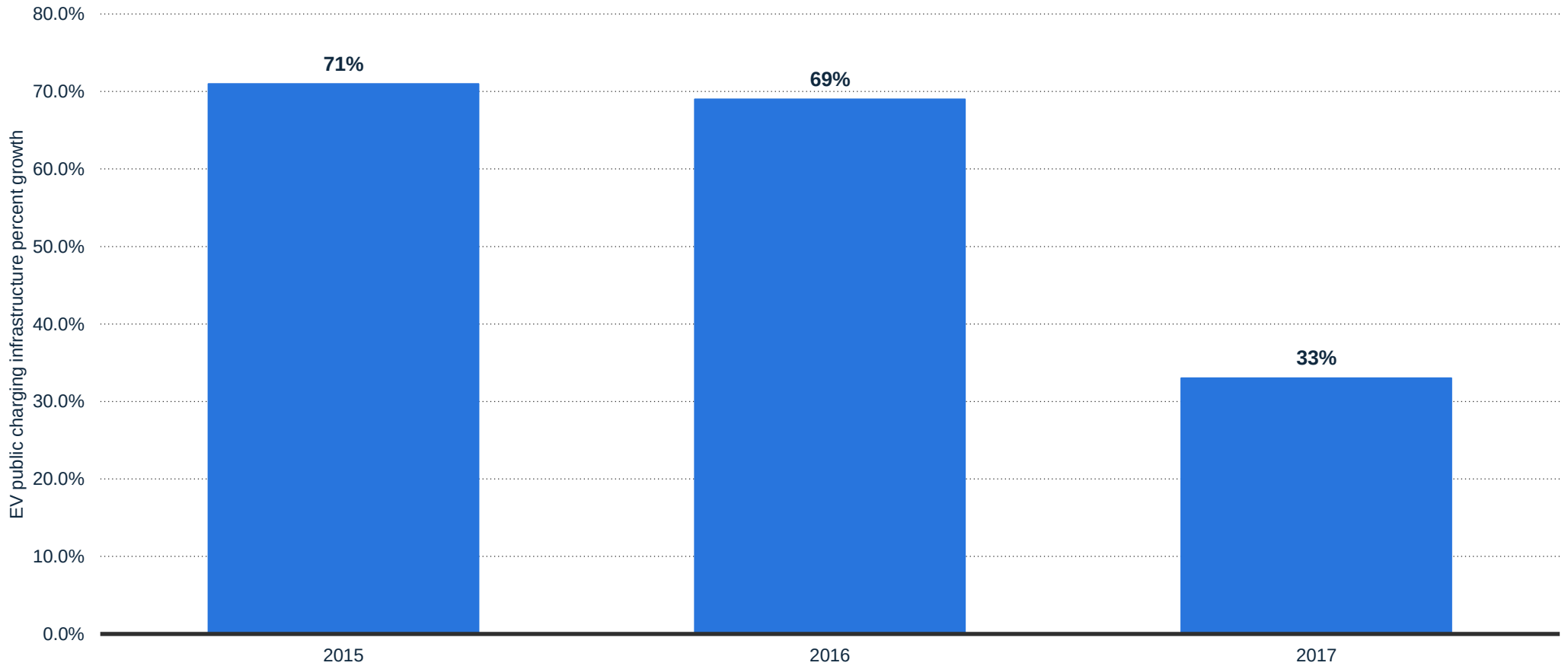
Consumers are expected to welcome the converging range gap between electric and ICE cars



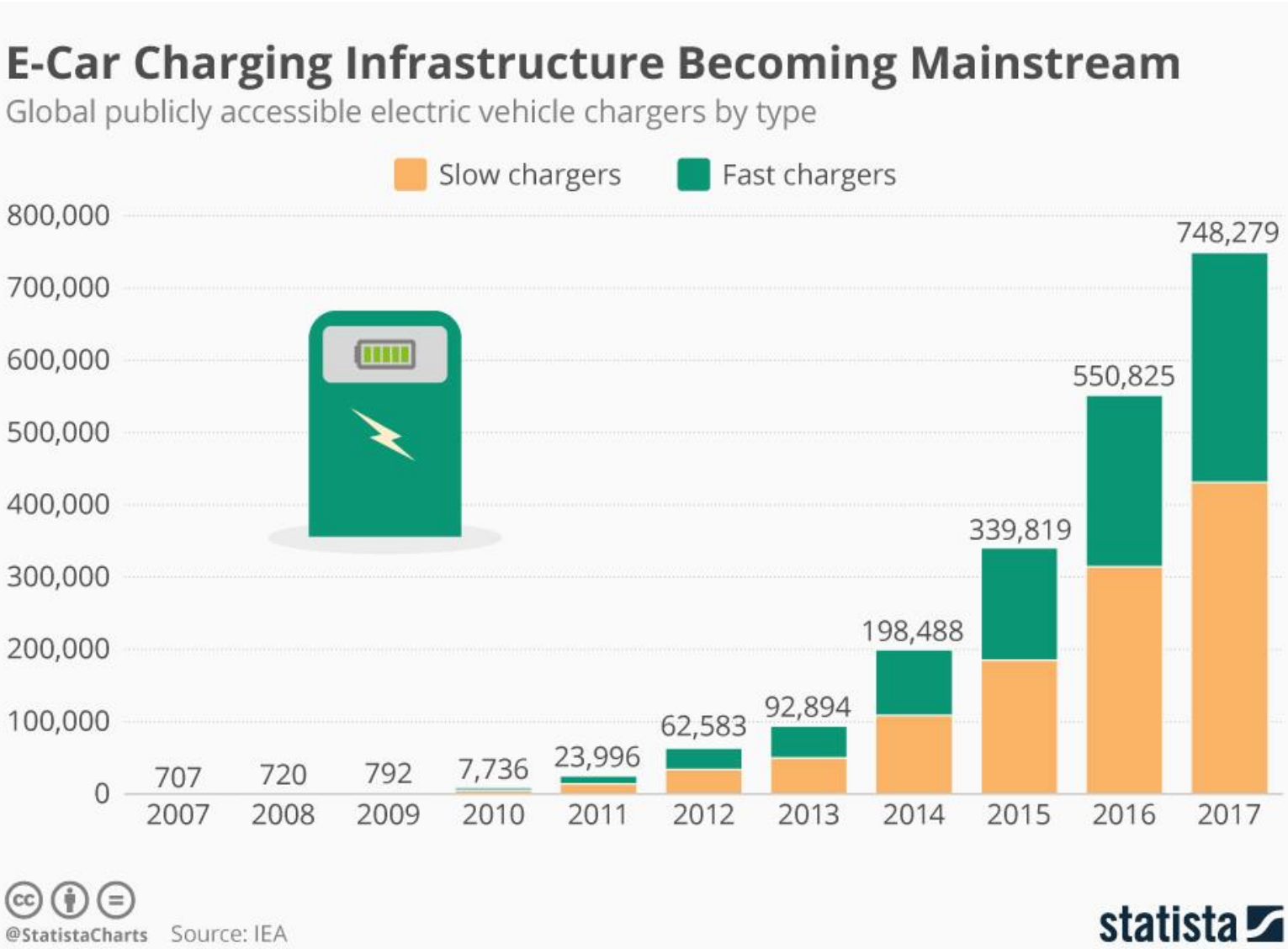


Note: Worldwide; 18 years and older; 2,028 Respondents;
Source(s): Oliver Wyman; VDA; Merrill Lynch; KPMG

Electric vehicle public charging infrastructure growth is waning globally



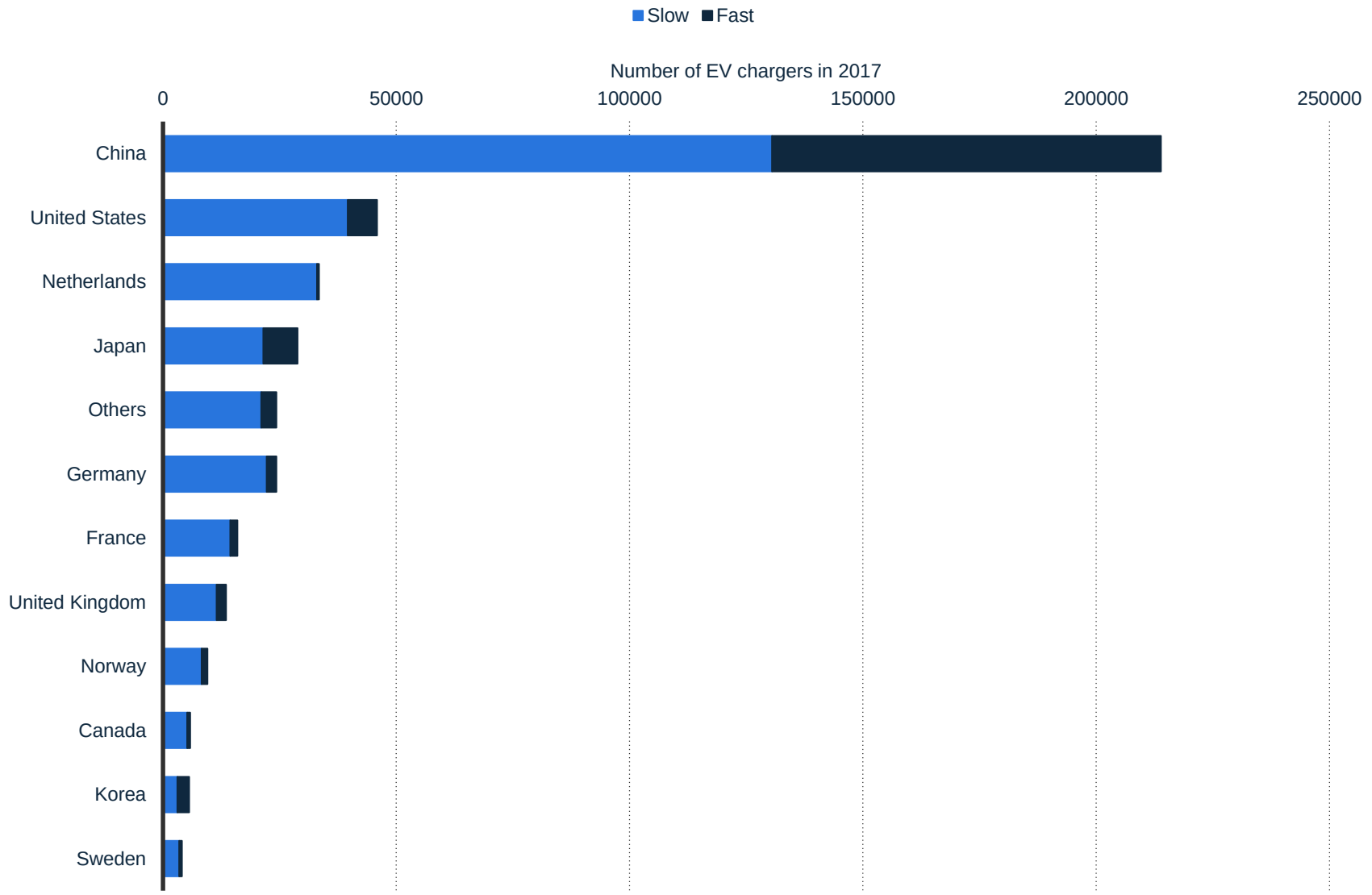
Note: Worldwide
Source(s): AlixPartners



Range anxiety remains a common concern among those consumers who are hesitant to purchase an electric car.

In addition to this, consumers are concerned that the electric car charging infrastructure in place today is not yet sufficient for widespread, carefree recharging.

No matter how much the number of charging outlets has grown over the past decade, consumers want to be able to recharge whenever their battery is low – and they want to do it fast.

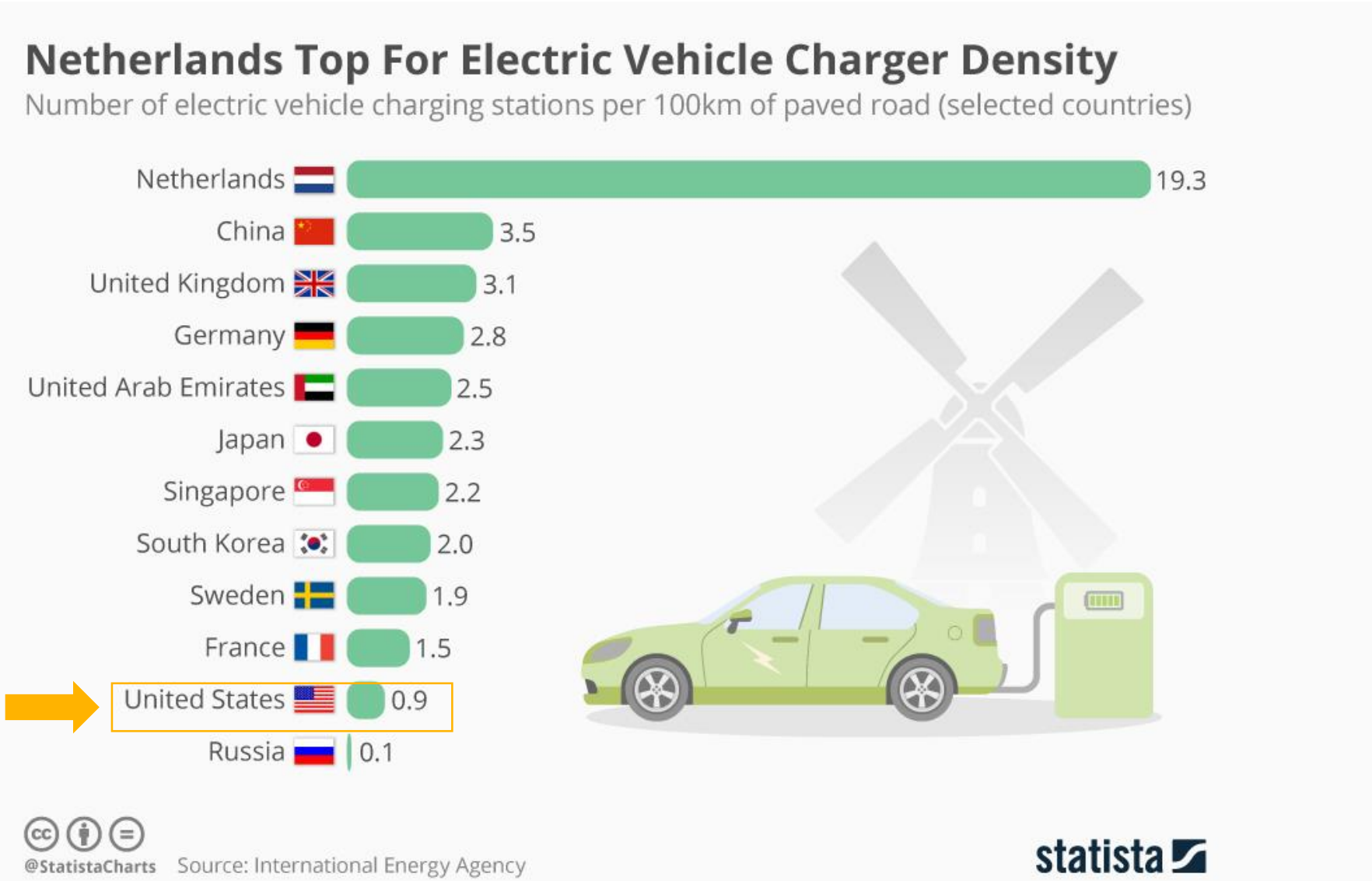


Number of chargers was not equally distributed across markets in 2017

Consumers cannot yet expect to find a charging outlet whenever they need it although the number of electric vehicle supply equipment (EVSE) chargers grew a thousandfold between 2007 and 2017.

Moreover, there is a distinction between slow and fast chargers, different socket standards, and payment methods, making it even more difficult for consumers to find the charging point they need.

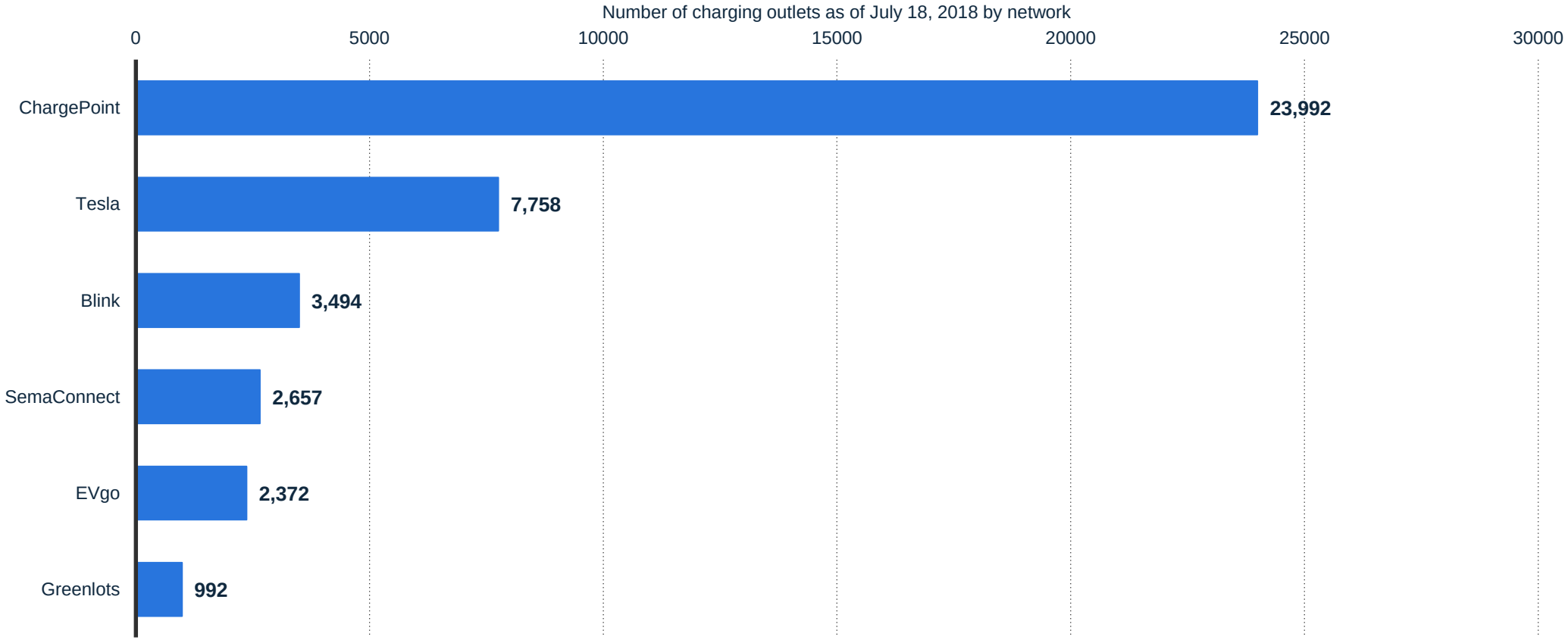
Note: Worldwide
Source(s): IEA; EAFO



Despite being the second largest sales market for electric vehicles, the United States trailed most countries in terms of electric vehicle charging density in 2017.

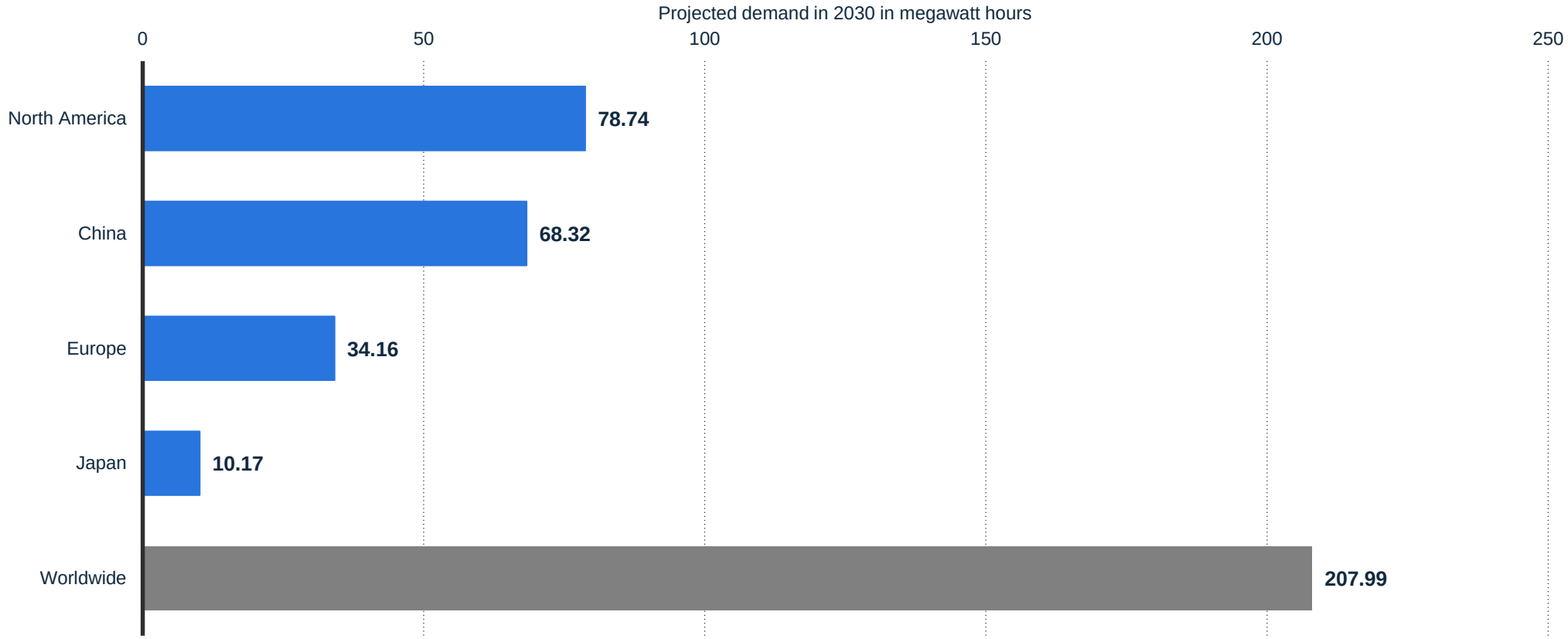
In addition to this, the charging outlets that do exist are provided by a number of charging networks using varying standards in terms of plug size and power limits.

Electric vehicle charging infrastructure fragmentation left consumers confused in 2018



Note: United States
Source(s): Alternative Fuels Data Center; Automotive News

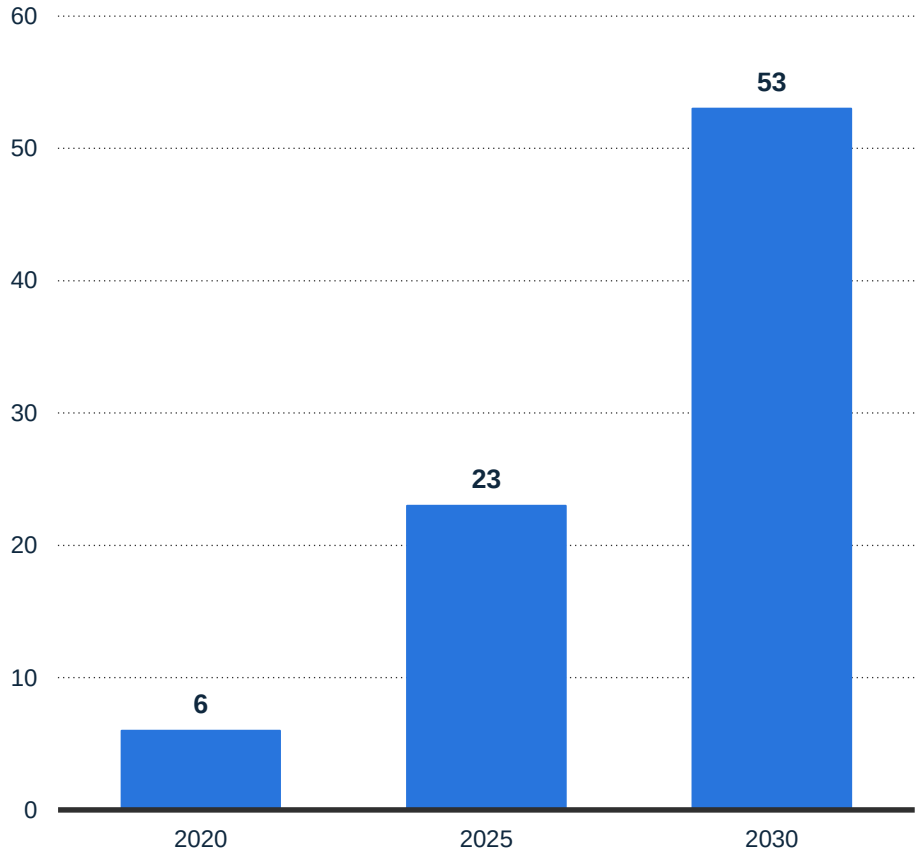
Energy demand for electric vehicle charging is expected to be highest in North America by 2030



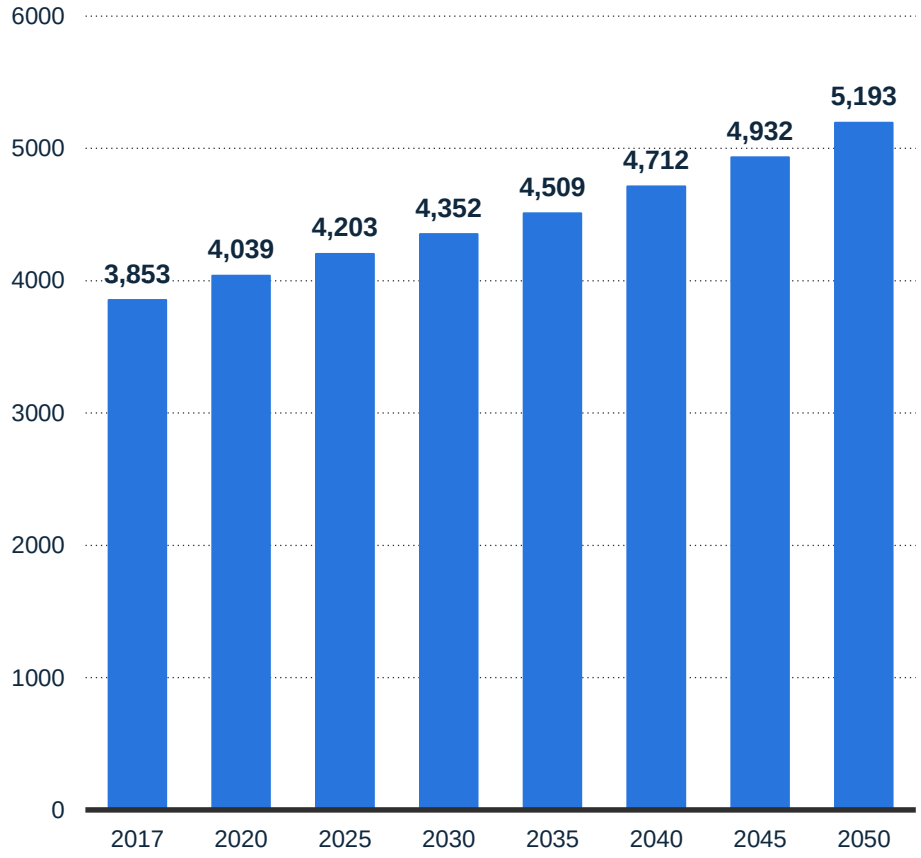
Note: Worldwide
Source(s): Wood Mackenzie; Bloomberg

Electric vehicle energy charging demand will push electricity use in the United States

EV charging demand in billion kilowatt hours



Electricity use in billion kilowatt hours



Note: United States
Source(s): McKinsey; EIA

02 Investment: The ideas leading to innovation

- Auto industry R&D
- EV investments
- Patents

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Investments are the foundation on which the industry stands

Investments need to be made not only in the field of electric vehicle-related battery technology, but also with regards to the sufficient provision of charging outlets. Providing the infrastructure for all the various types of electric vehicles proves to be a difficult task, after an entire industry had focused on diesel and gasoline-propelled motor vehicles for almost a century.

The tightening of environmental regulation puts pressure on carmakers and suppliers alike to invest in emerging electric vehicle technologies. The shift away from internal combustion engines may not come without risks, but the introduction of new technologies offers additional opportunities for automotive suppliers and manufacturers.

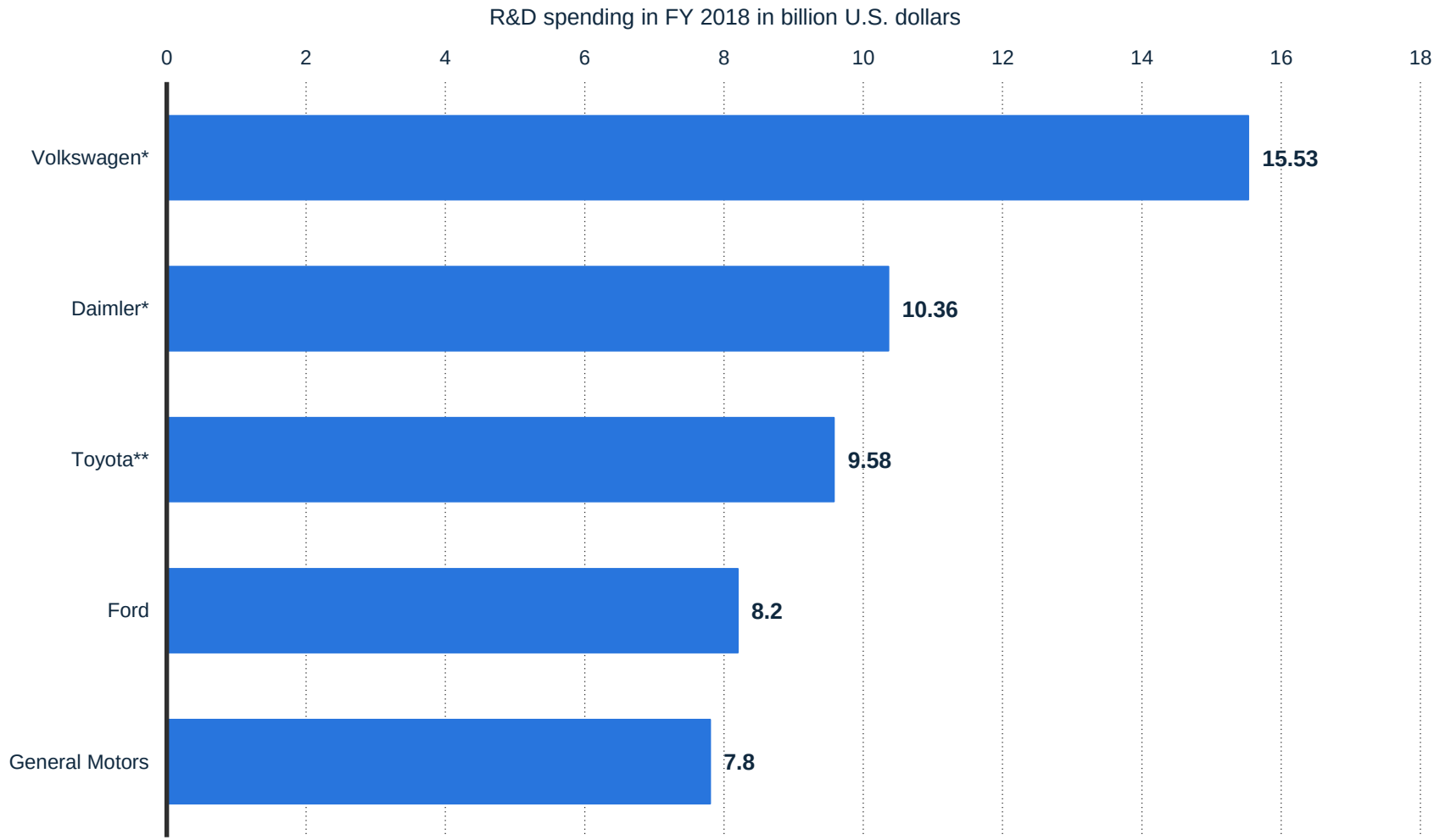
While some original equipment manufacturers (OEMs) in the motor vehicle manufacturing and parts industry started shifting their attention towards the connected driving and mobility services realms, others have made it paramount to invest in green vehicles:

- Globally operating traditional automakers invest most heavily in R&D activities
- Tesla has the highest R&D intensity in the industry
- France is the leading European nation in terms of electric vehicle-related technology

“I hope you will still recognize us as being the inventor of the car, but we should be defined by our future, not by our past.”

– Dieter Zetsche,
Chairman of Daimler AG and Head of Mercedes-Benz Cars

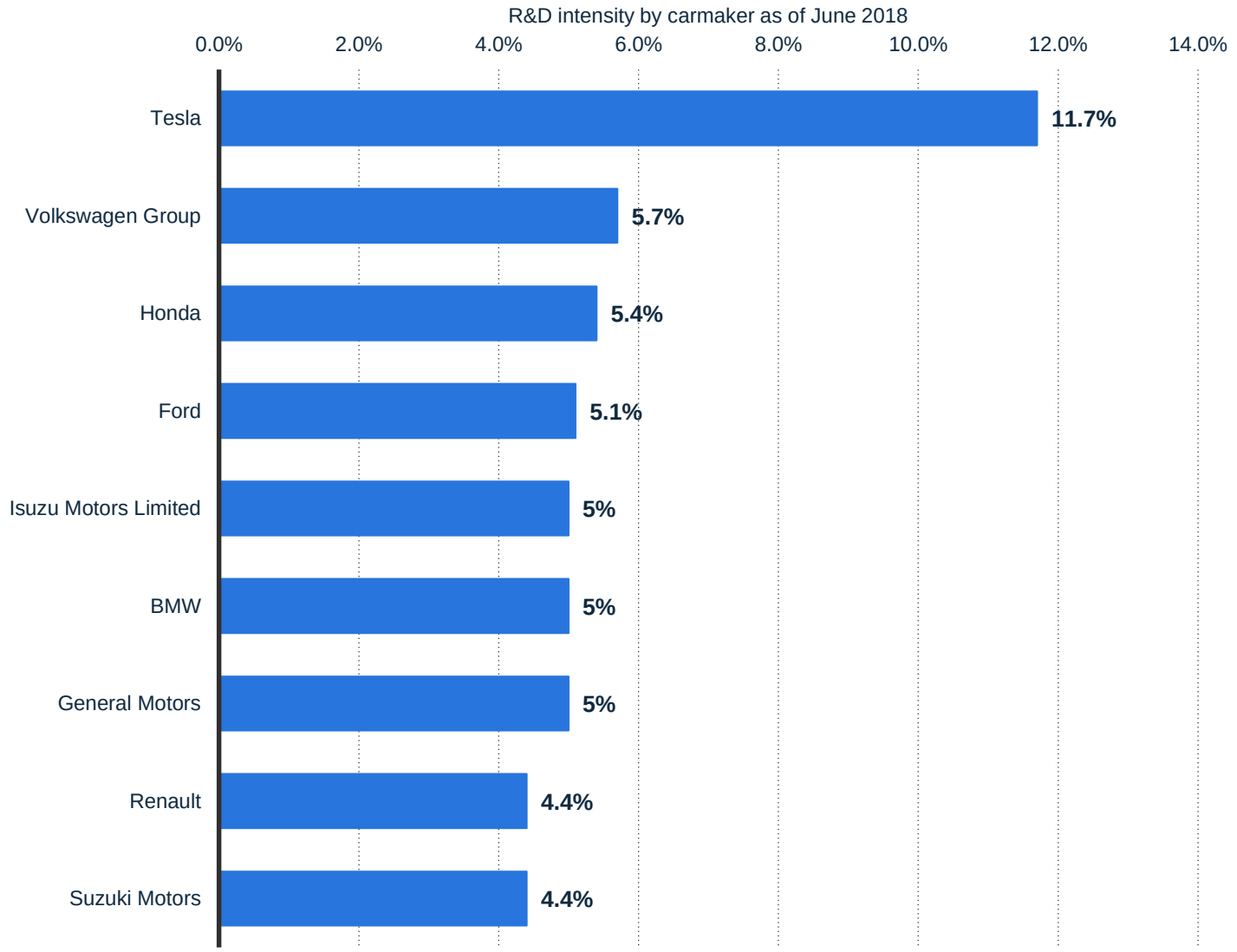
Traditional OEMs invest most heavily in R&D activities



Note: Worldwide
Source(s): Statista; Volkswagen; Daimler; Toyota; Ford; General Motors
* VW: the value refers to R&D costs in the automotive division; VW & Daimler: These figures have been converted at the following rate, correct as of March 1, 2019: 1 euro = 1. 13835 U.S. dollars; ** this figure has been converted at the following rate, correct as of March 1, 2019: 1,000 Japanese yen = 9. 00558 U.S. dollars; the figure is for FY ended March 31, 2018.

Traditional automotive OEMs were the ones investing most heavily in research and development (R&D) activities during the 2018 fiscal year.

That said, the highest ratio of R&D spending to revenue was yielded by a firm with a comparatively small sales base: Tesla.



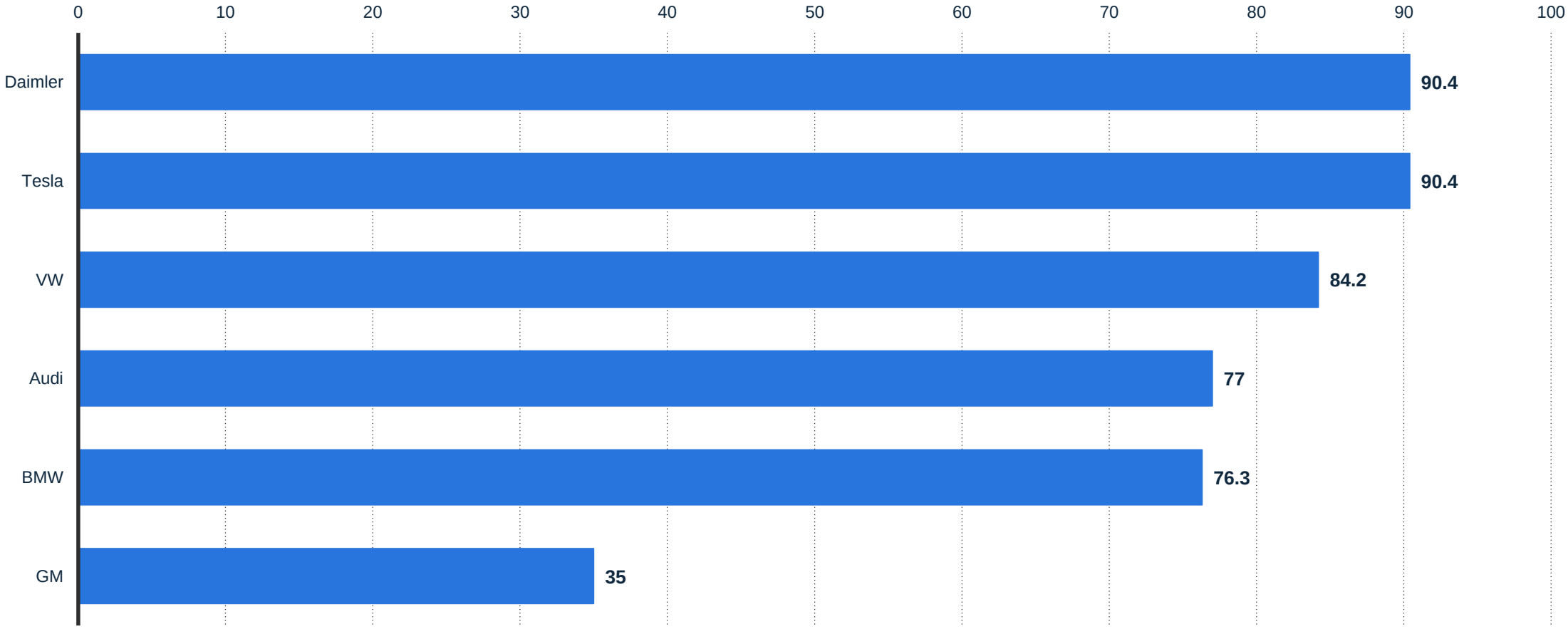
Tesla outperformed its larger competitors in terms of R&D to sales ratio in 2018

The following list includes a selection of investments and partnerships:

- Daimler: invests in ChargePoint, collaborates with BYD, is part of IONITY
- BMW: invests in ChargePoint, is part of IONITY, collaborates with Umicore, Northvolt
- VW: invests in ChargePoint , is part of IONITY
- Ford: is part of IONITY
- GM: invests in Evgo
- Hyundai: collaborates with Hawtai
- Delphi: is owner of NuTonomy
- Shell: is owner of NewMotion, invests in Sonnen
- BP: invests in PowerShare, FreeWire, StoreDot, Chargemaster
- Total SA: is owner of G2mobility, Saft SA, collaborates with Nexans

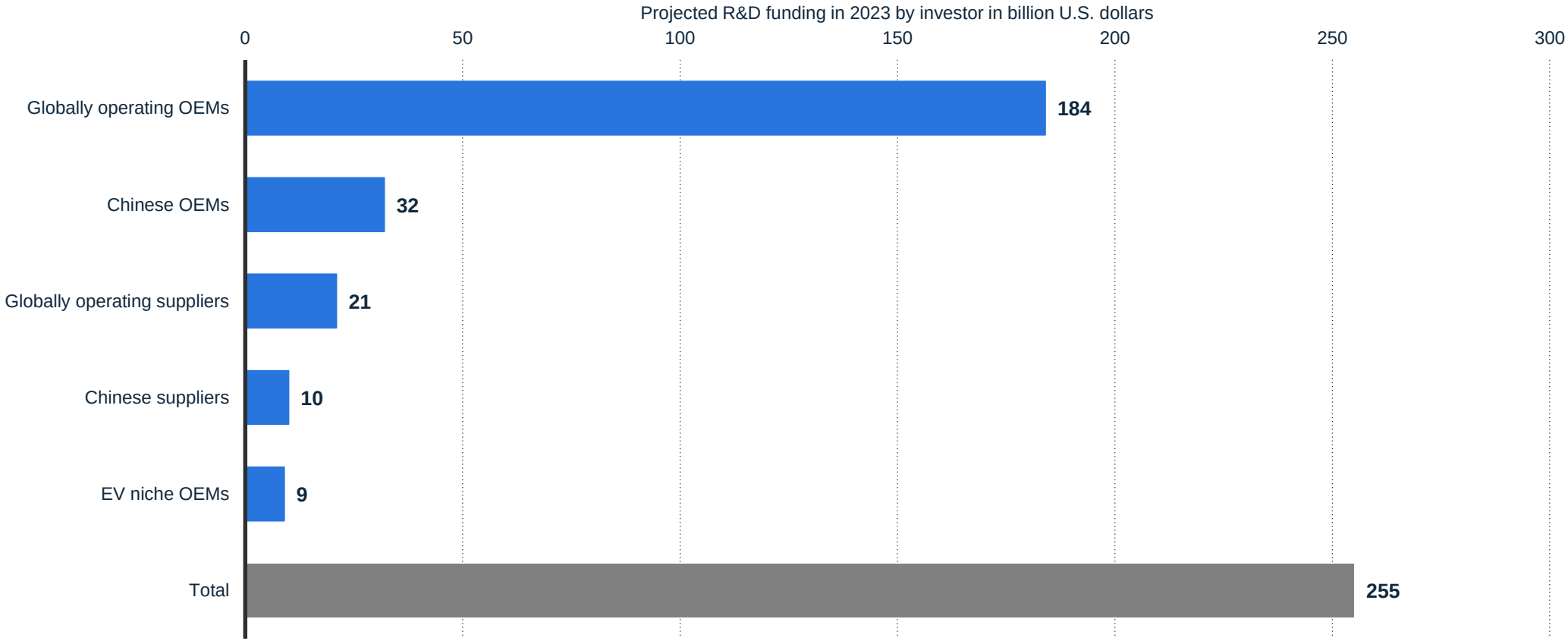
Note: Worldwide
Source(s): PwC; Strategy&; Various sources
According to the source, all sales and R&D expenditure values in foreign currencies were converted into U.S. dollars at an average of the exchange rate over the relevant period; all figures are for the last fiscal year, as of June 30, 2018.

Daimler and Tesla dedicated ~ 90 percent of patents to green vehicles between 2012 and 2016



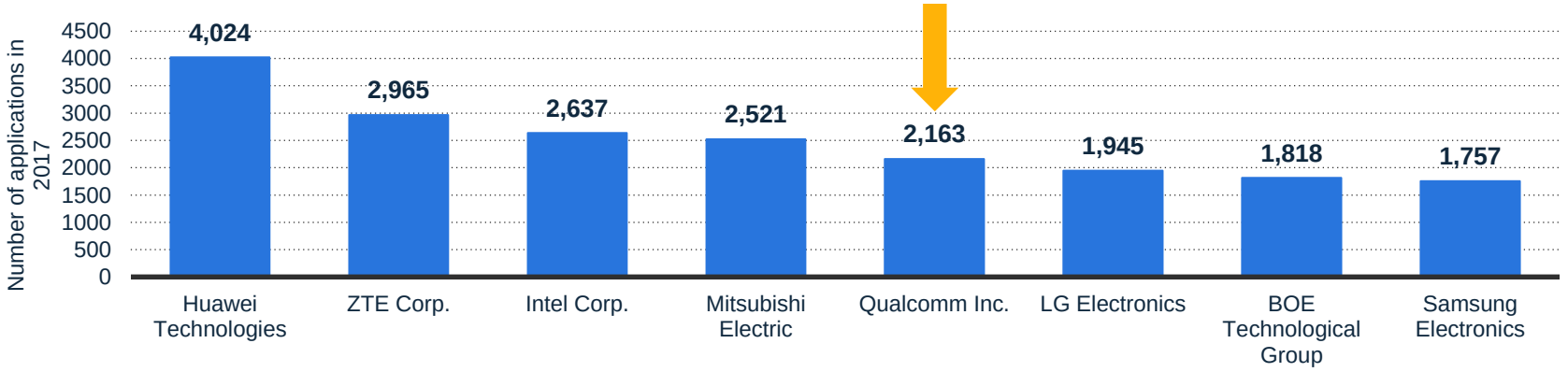
Note: Worldwide
Source(s): Oliver Wyman; WIPO

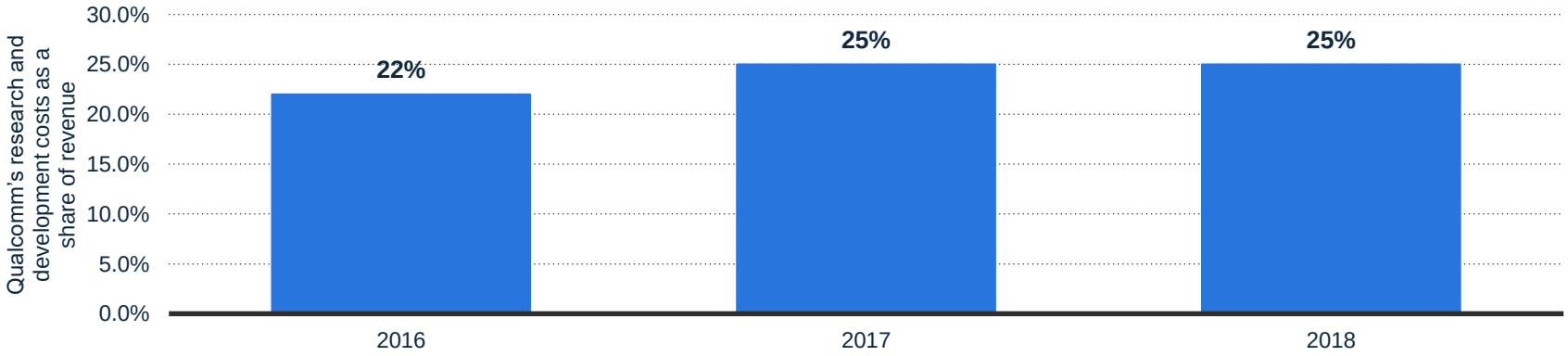
Globally operating carmakers are projected to account for almost two thirds of investments in 2023



Note: Worldwide
Source(s): AlixPartners

Qualcomm has filed one of the most valuable patents in the field of EVs



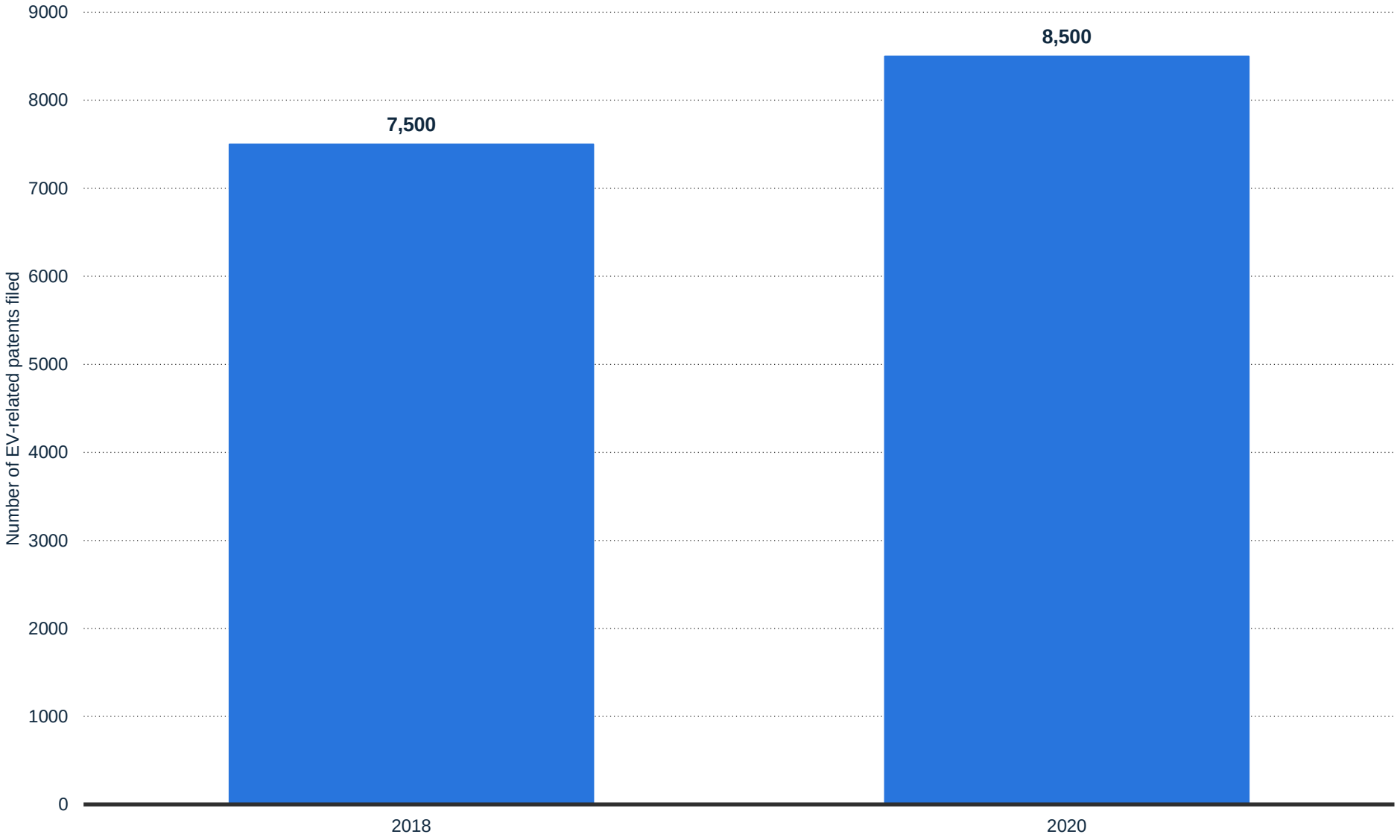


Qualcomm's 2017 R&D costs-to-revenue ratio was comparatively high with around 25 percent. The company filed some 2,163 patents in 2017.

In 2018, an EV wireless charging patent application was submitted on behalf of Qualcomm and approved by the USPTO.

It was considered a scientific breakthrough and acquired by WiTricity in 2019.

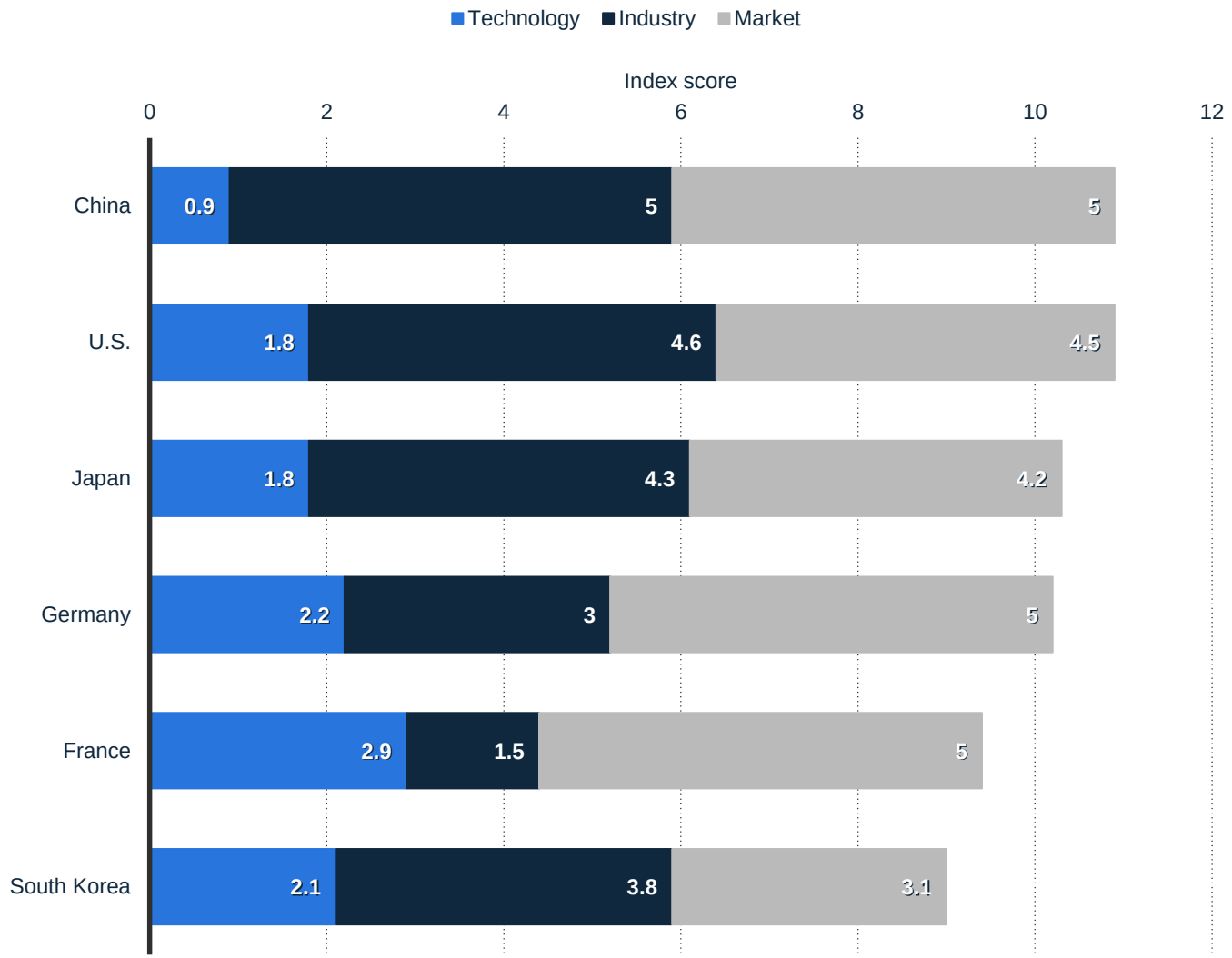
Note: Worldwide
Source(s): WIPO; Qualcomm



Moderate growth in EV-related patent filings can be anticipated

Most electric vehicle-related patents were granted in the electric propulsion and secondary cell manufacturing segments, with most of the activity occurring in China and the United States.

Note: Worldwide
Source(s): Power Electronics World (powerelectronicsworld.net)



Note: Worldwide
Source(s): Roland Berger; fka

The indicators are defined by the source as follows:
Technology: Current status of electric vehicle-related technology developments made by domestic OEMs, and national subsidy program support
Industry: National vehicle, system and component production industry added value
Market: National electric vehicle market size based on current customer demand

France seemed better equipped in terms of technology than other European markets in 2018

Not only is France home to some of the world's leading automotive manufacturing groups, such as Groupe Renault and Groupe PSA, but the country is also the domestic market of Total SA-owned Saft Groupe SA, one of the few battery manufacturers in Europe with an international presence.

France's carmakers offer a range of electric vehicles in the non-premium segment, including Europe's second-best-selling all-electric car, the Renault Zoe.

03 Production: The leading regions, companies, and models

- Production volume
- Models
- OEMs

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“The first step is to establish that something is possible;
then probability will occur.”

– Elon Musk,
CEO of Tesla, Inc. and SpaceX

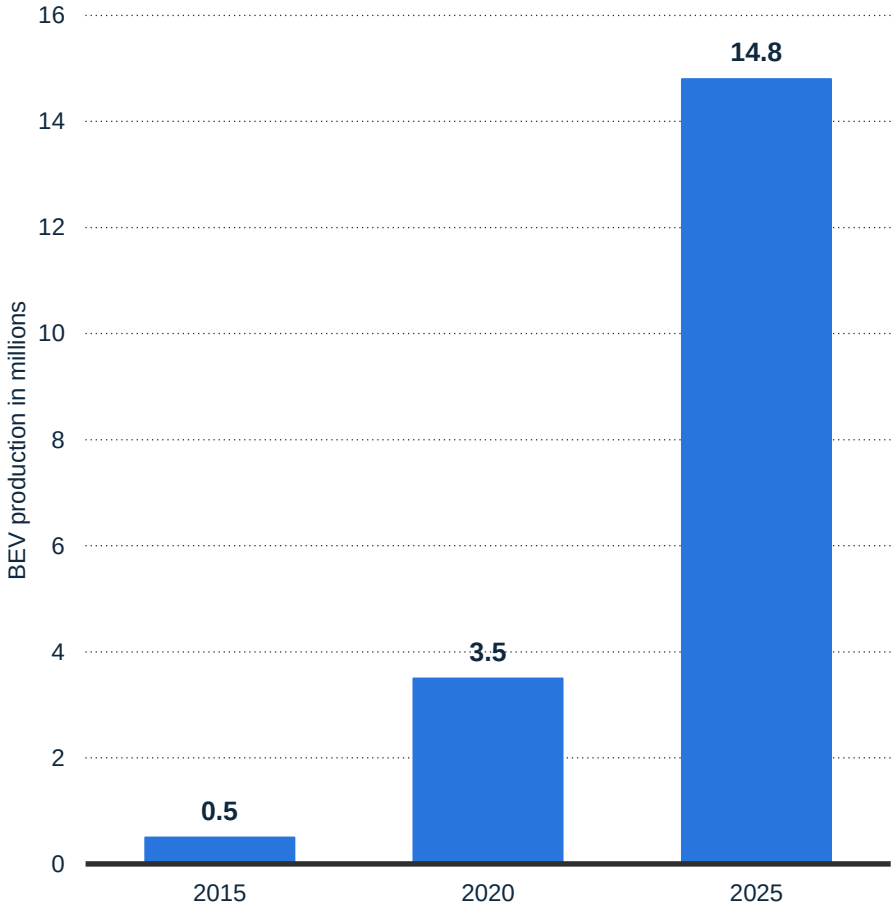
Production volumes are beginning to pick up after a slow start

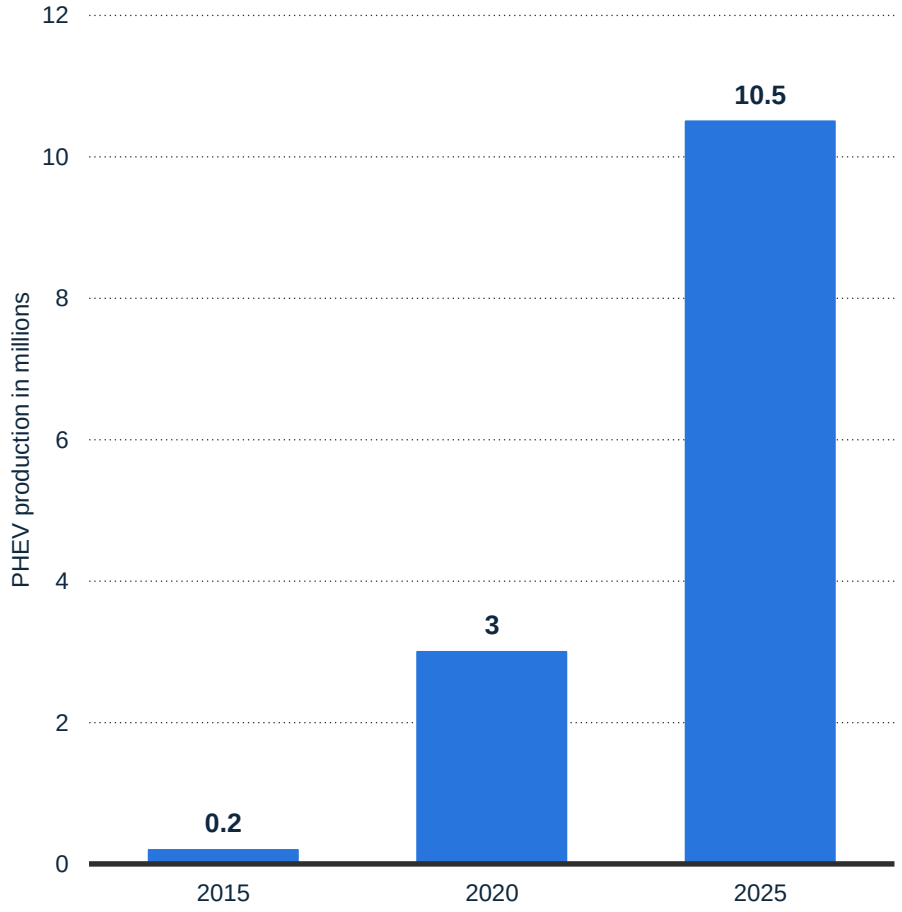
Policymakers saw the opportunity to replace ICE cars with electric vehicles as soon as the effects of road transportation on air quality became apparent. However, the CEOs of traditional carmakers, such as Volkswagen or General Motors, seemed to lack the imagination to believe in the electric vehicle's success for the best part of two decades. Some 16 years after Tesla's founding, traditional automotive manufacturers have likely turned a corner, and, along with new entrants from the Chinese mainland - including BYD, Chery, and Hawtai - they are now hot on Tesla's heels.

It is expected that over 30 million hybrid cars and plug-in electric vehicles will be produced by 2025, with battery electric vehicles accounting for almost 50 percent of total production.

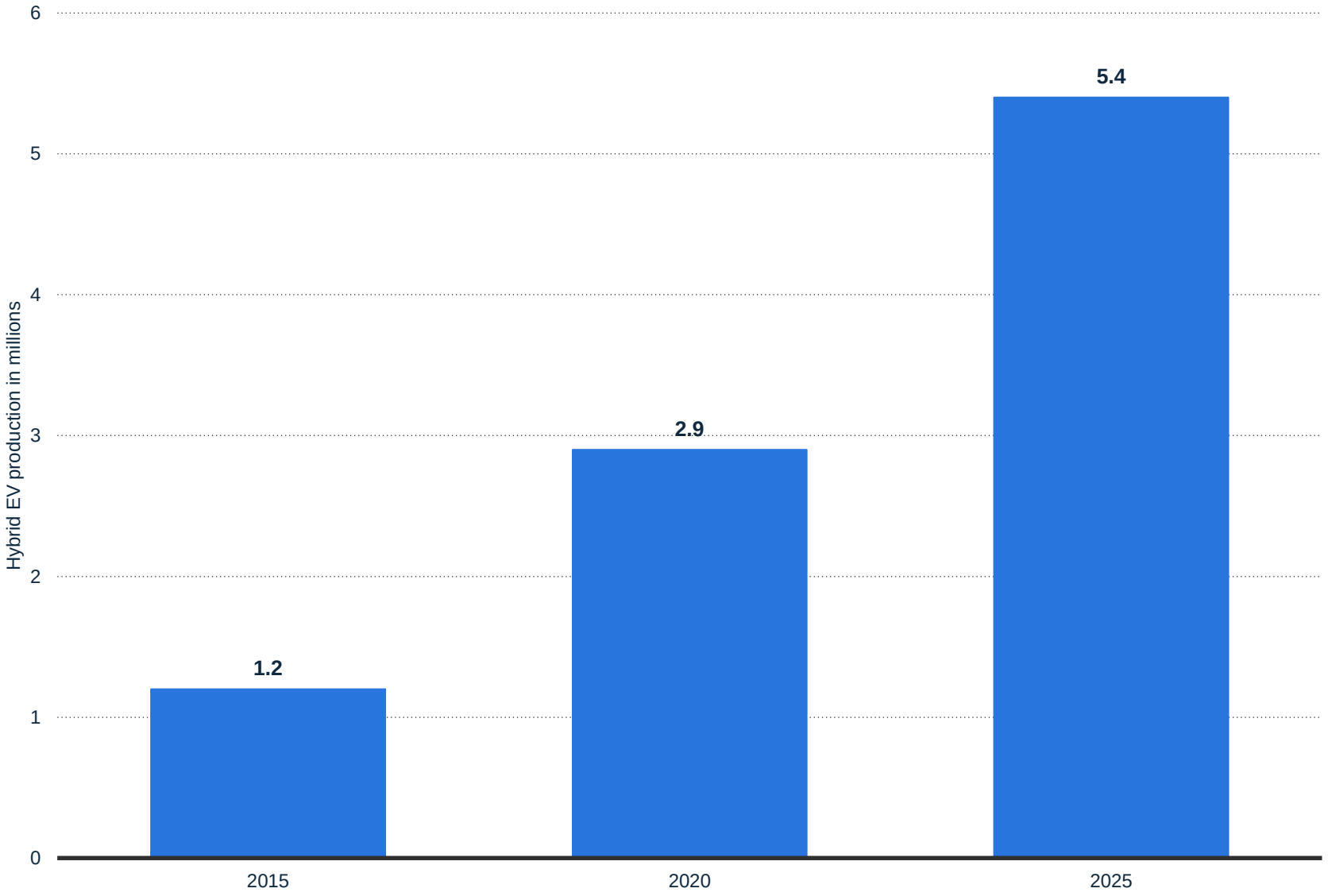
- Worldwide production volume of all-electric vehicles is expected to grow fourfold
- Growth is expected to be highest in the plug-in electric vehicle segments, but hybrid production will continue to rise
- China is predicted to remain the largest market in terms of electric vehicle production by country
- Additional model launches are expected to trigger consumer demand

Battery and plug-in hybrid vehicles are projected to experience the highest growth





Note: Worldwide
Source(s): McKinsey



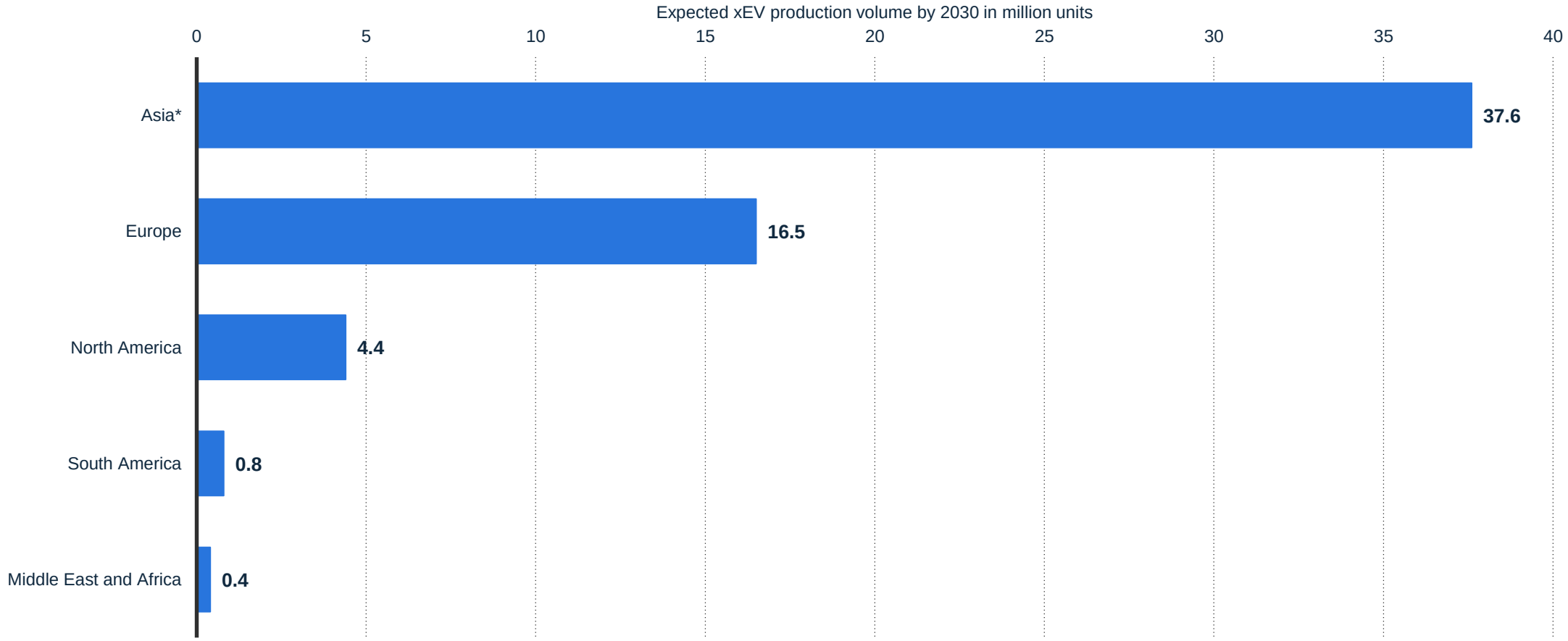
Hybrid production will continue despite smaller output levels

The production of hybrid electric vehicles is projected to grow to about 5.4 million units globally by 2025.

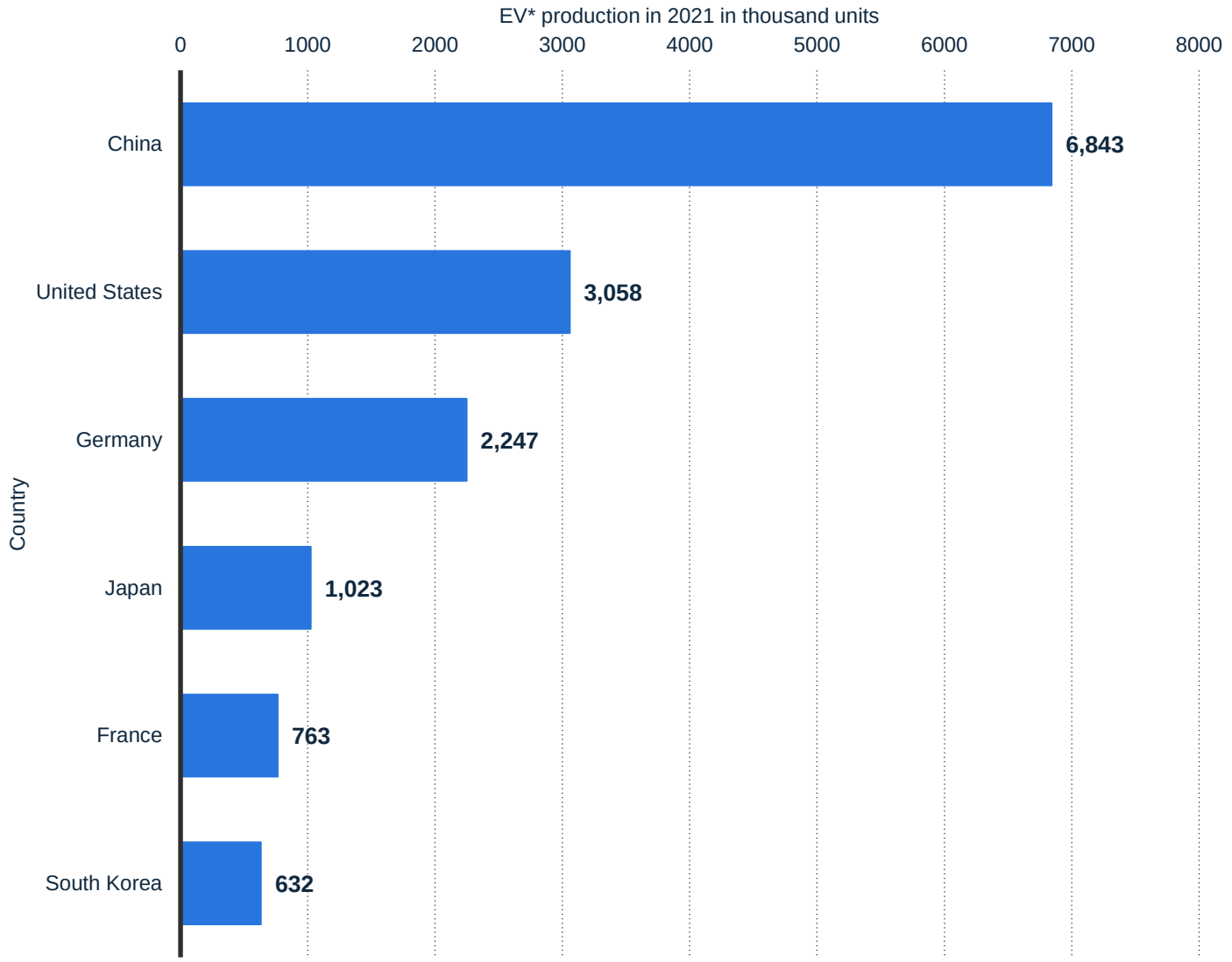
This volume is significantly lower than the anticipated 10.5 million units in the plug-in hybrid electric vehicle segment and the 14.8 million units in the battery electric vehicle segment but the market is still likely to grow.

Note: Worldwide
Source(s): McKinsey

Asia will remain the leading producer of electric vehicles throughout 2030



Note: Worldwide
Source(s): IHS Markit
* The figures for India, China, Japan, South Korea, and the ASEAN region have been added up.
The term xEV refers to battery and plug-in hybrid vehicles.



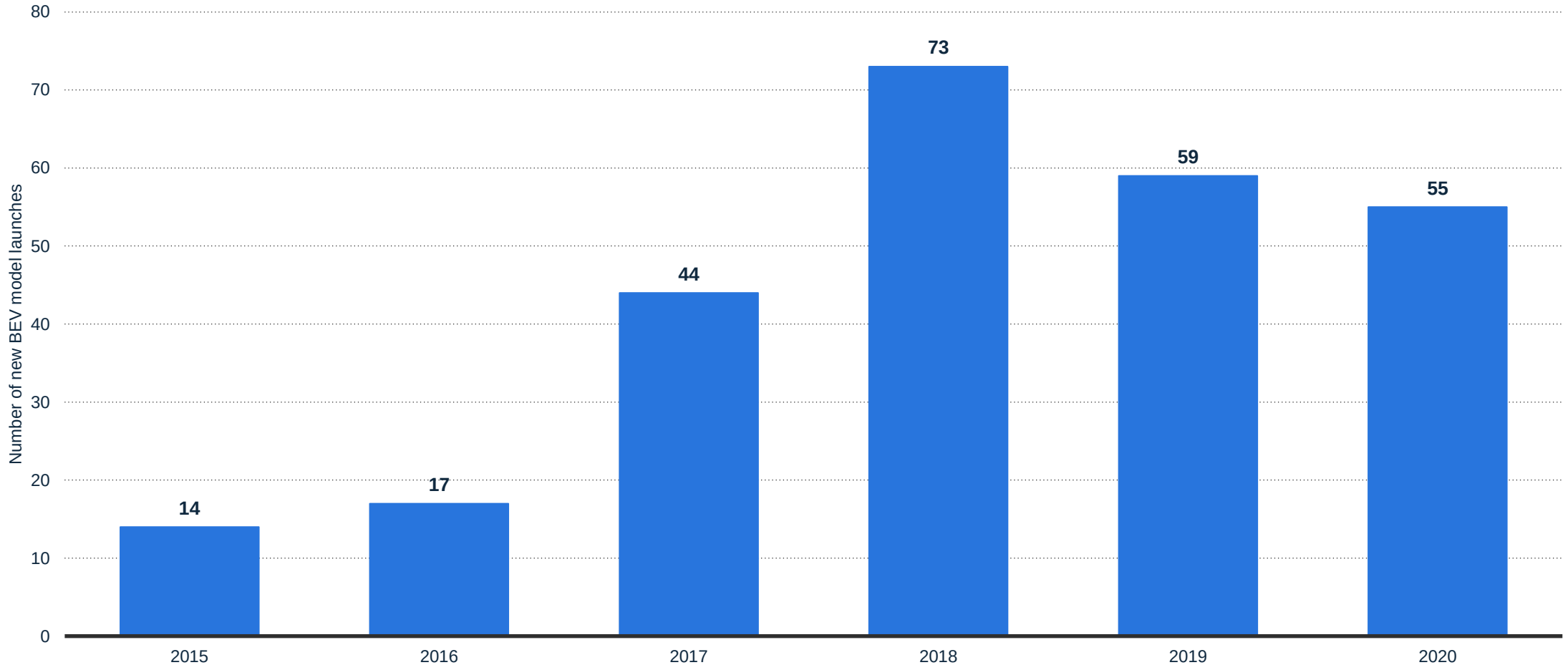
Note: Worldwide
Source(s): Forschungsgesellschaft Kraftfahrwesen Aachen; Roland Berger
* Numbers refer to battery-powered and plug-in hybrid vehicles.

China will continue to lead on a country-by-country level through ‘21

The following list presents a selection of announcements on EVs made by OEMs:

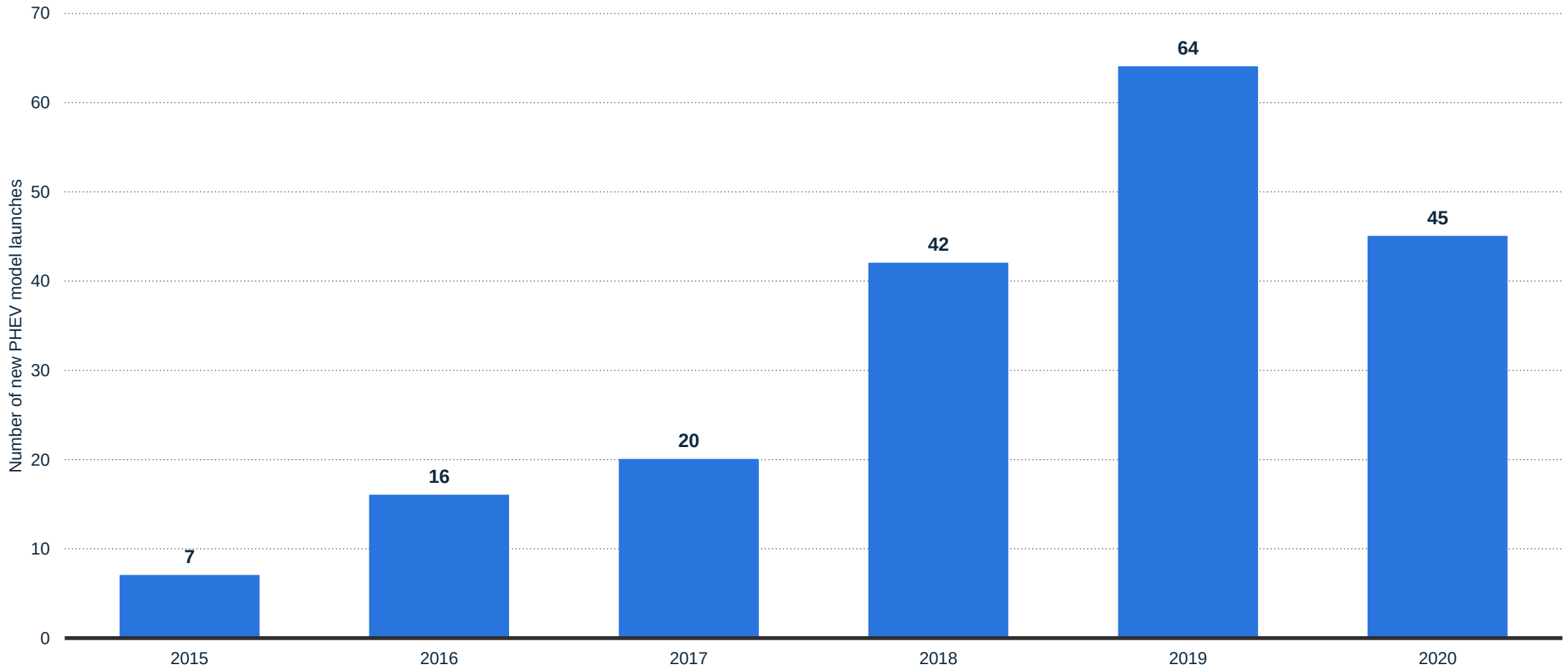
- Toyota is expected to release 10 EV models by 2020
- VW is committed to launch more than 50 BEV models by 2025
- Renault-Nissan wants EVs to account for 20 percent of sales by 2023
- GM will launch two EV models in 2019
- PSA is to launch 27 EV models by 2023
- Ford plans to release 40 EV models by 2022
- By 2022, Daimler plans to release 10 EV models
- BMW is expected to launch the Mini E, the i5, and the X3 i between 2019 and 2021
- BAIC intends to add 10 EV models to its portfolio by 2025
- Geely plans to launch two more models under its Polestar brand by 2025

Global number of battery electric vehicle model launches between 2015 and 2020



Note: Worldwide
Source(s): LMC Automotive; Citigroup

Global number of plug-in hybrid electric vehicle model launches between 2015 and 2020



Note: Worldwide
Source(s): LMC Automotive; Citigroup

04 Adoption: The drivers behind demand

- Sales
- Penetration rate
- Forecasts

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Demand is affected by cost competitiveness and mobility trends

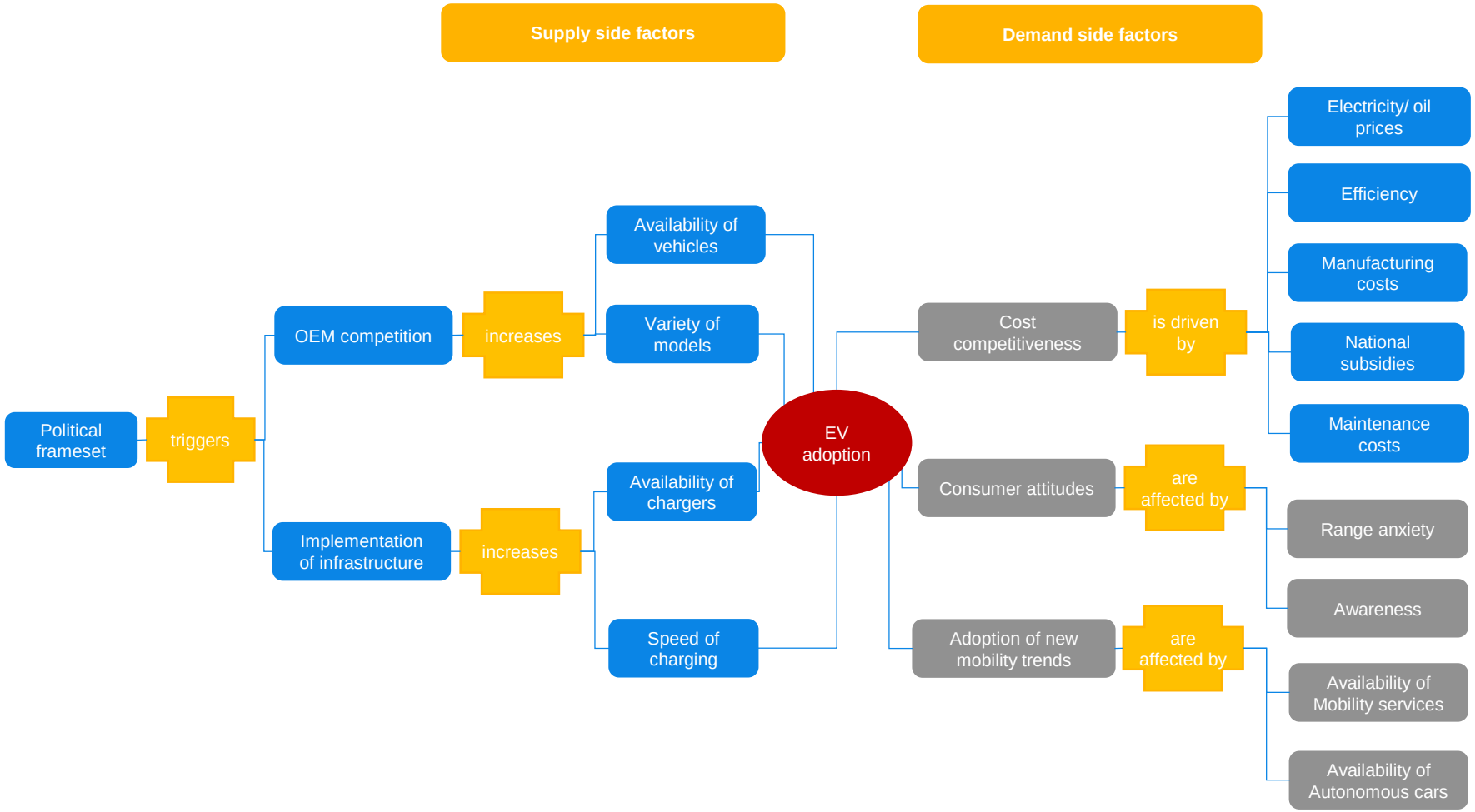
Ten years from now, plug-in electric vehicles are expected to account for close to half of all vehicle sales. It is also projected that electric vehicle adoption will be driven by growing access to public charging infrastructure in tandem with increased vehicle model availability.

Furthermore, electric vehicles are projected to pique consumers' interest, once the cost of ownership reaches parity with ICE vehicles; this is predicted to happen over the course of the next two to four years.

Innovative trends in the field of mobility services such as car-sharing, ride-sharing, and ride-hailing are forecast to raise consumer awareness and help users familiarize themselves with EV technologies.

- The share of ICE cars in overall light vehicle sales is forecast to fall to almost 50 percent by 2030
- As adoption levels pick up, the electric vehicle market is projected to gain traction
- Mobility service fleets are set to fuel electric vehicle demand
- Tesla has emerged as the market leader in battery electric vehicle sales
- The Model 3 has become Tesla's best-selling model

Key drivers of electric vehicle adoption



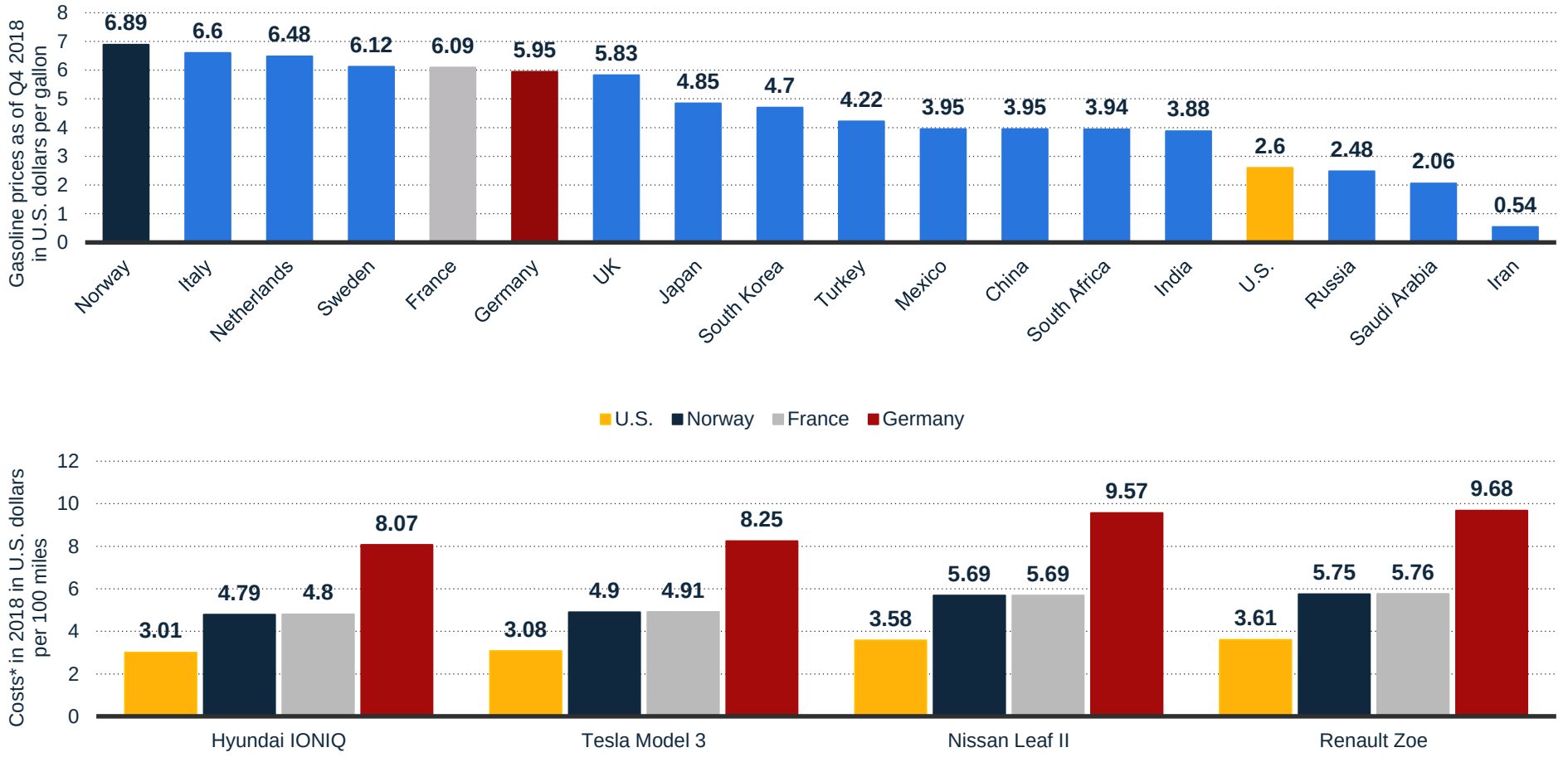
It is predicted that EV buyers want the total cost of ownership in tandem with potential government subsidies to be within the range of what they would normally have to pay for a comparable ICE car.

New mobility trends are projected to help consumers familiarize themselves with EV technologies.

As soon as consumers are satisfied with the availability of suitable models and a sufficient charging infrastructure, adoption levels can be expected to pick up speed.

Note: Worldwide
Source(s): Statista; Nytimes.com; ICCT; Consumer Affairs; Renew Economy; L.E.K.

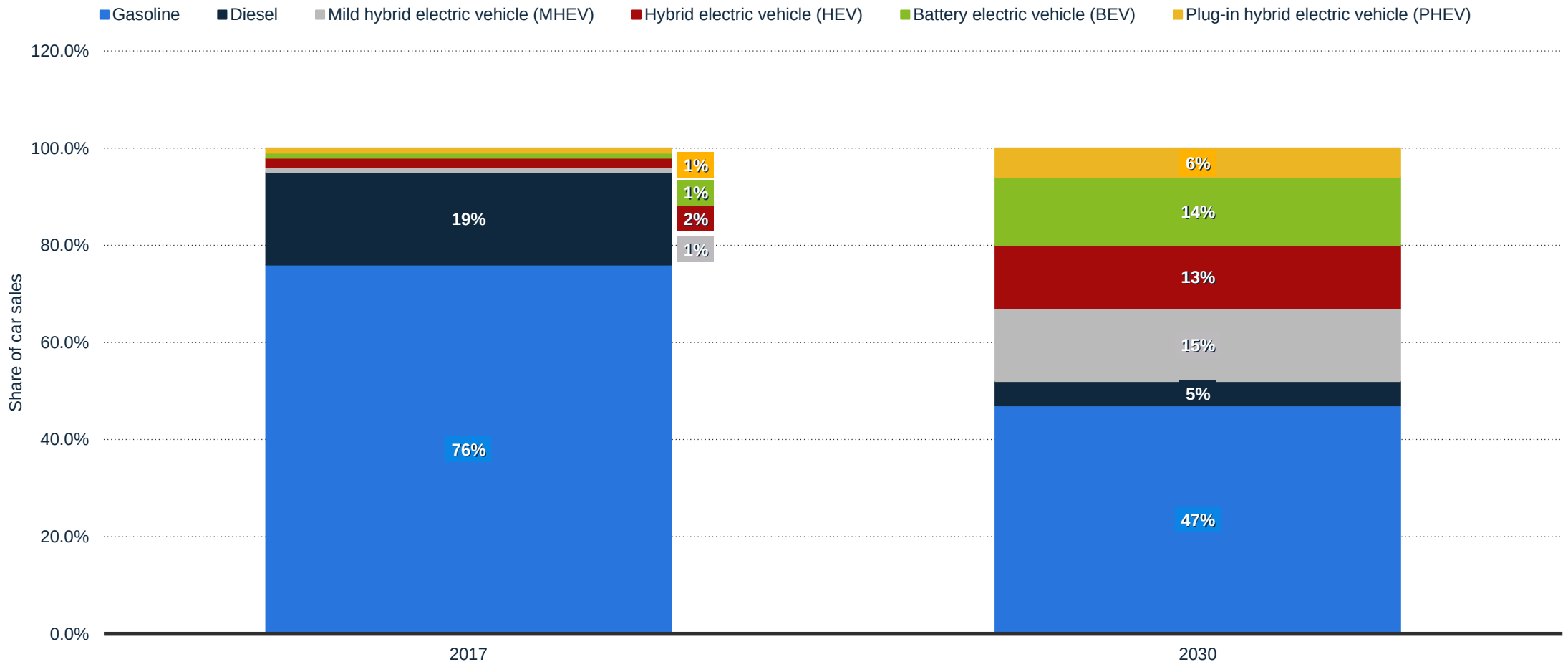
The cost of refueling ICE cars is often higher than the running costs of electric vehicles



Assuming that an average ICE sedan has a fuel economy of 30 mpg, and thus a consumption level of about 3.3 gallons per 100 miles, low power rates may help convince consumers to switch to an electric car, especially in markets where gas prices are high.

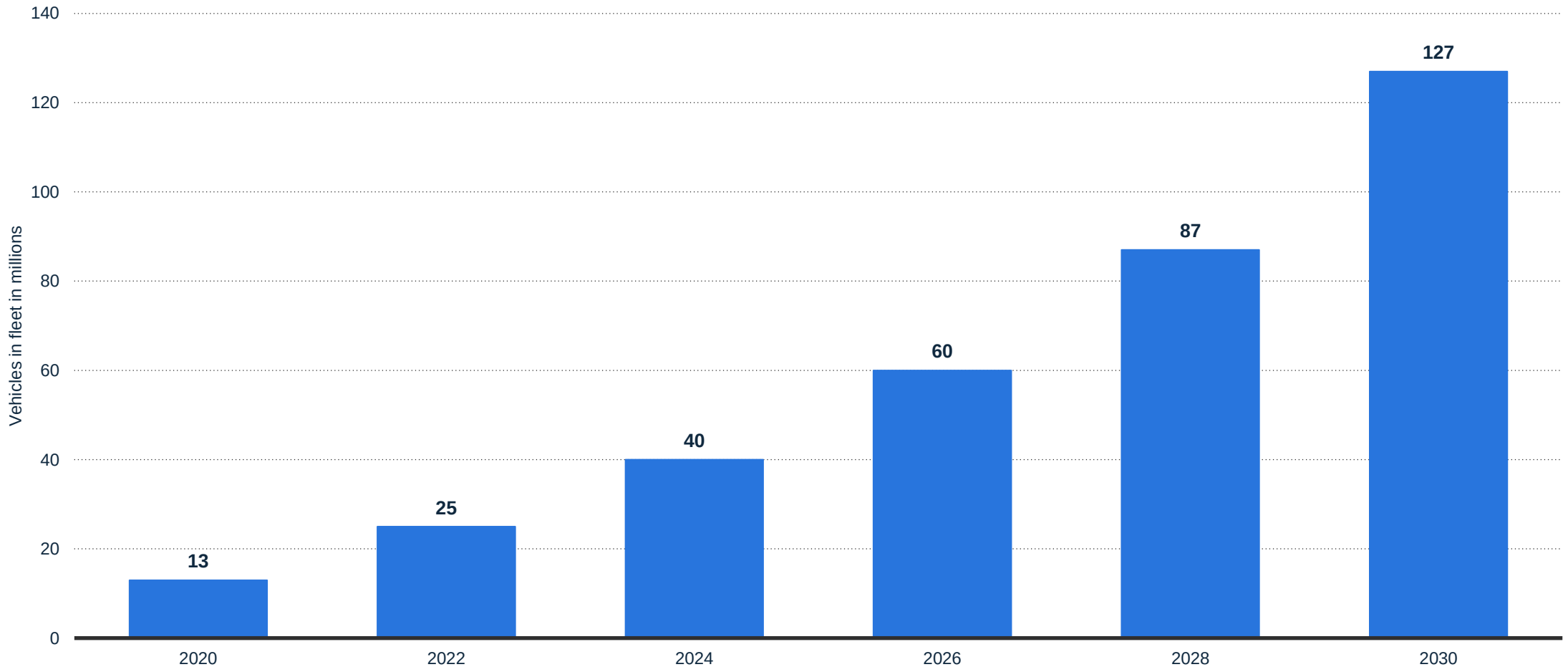
Note: Worldwide
Source(s): Bloomberg; IMF; UN; World Bank; CleanTechnica; nextmove.de; Eurostat; chooseenergy.com
* The results are based on estimated consumption rates by model and average residential electricity prices by country. The values have been converted from euros to U.S. dollars at an average annual rate of 1 euro = 1.18 U.S. dollars, as retrieved from the ECB.

The sales share of ICE vehicles continues to decline globally



Note: Worldwide
Source(s): BCG

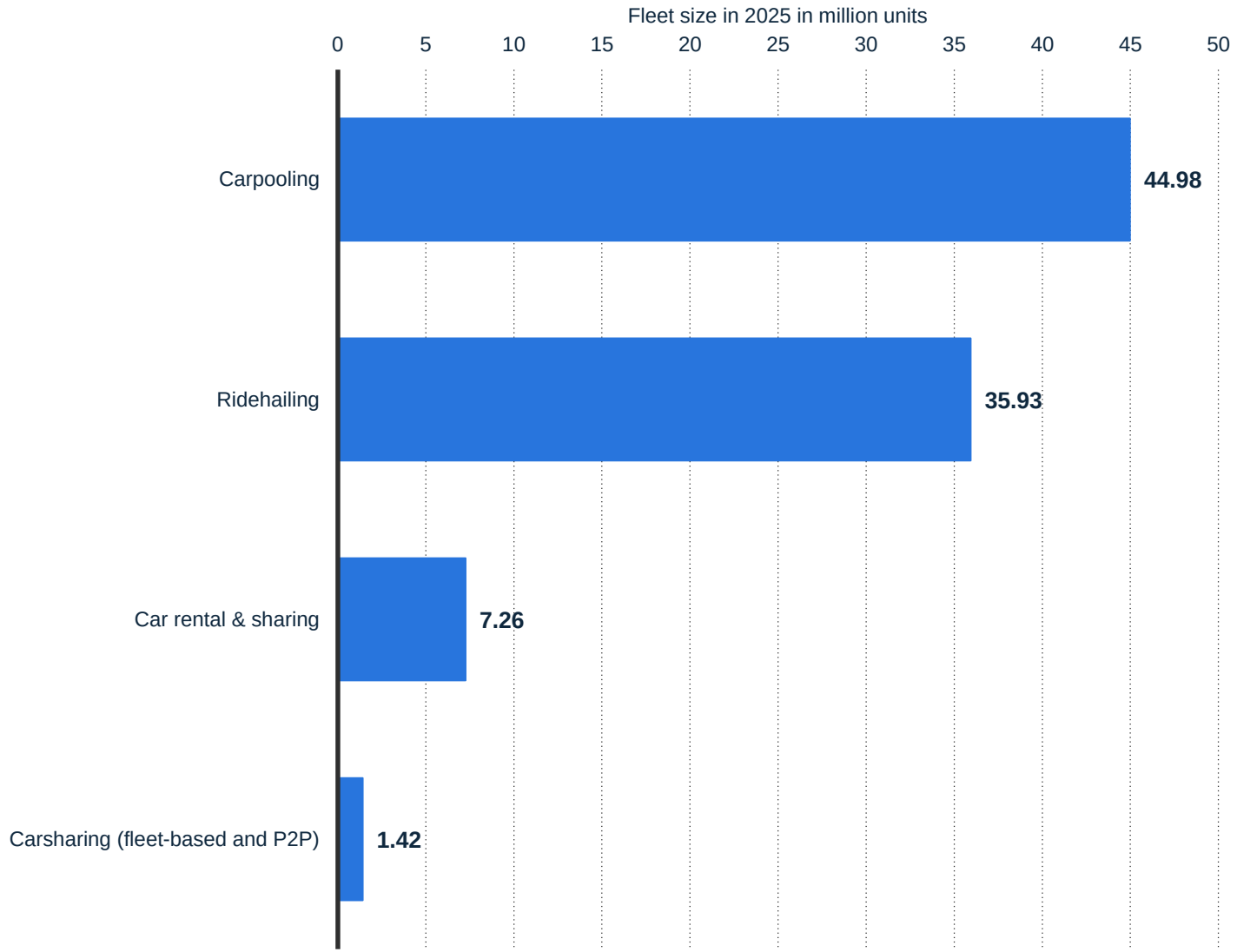
Projected size of the global electric vehicle fleet between 2020 and 2030



Note: Worldwide
Source(s): Business Insider

“We are convinced that the future of carsharing is electric.”

– Olivier Reppert,
CEO of Share Now



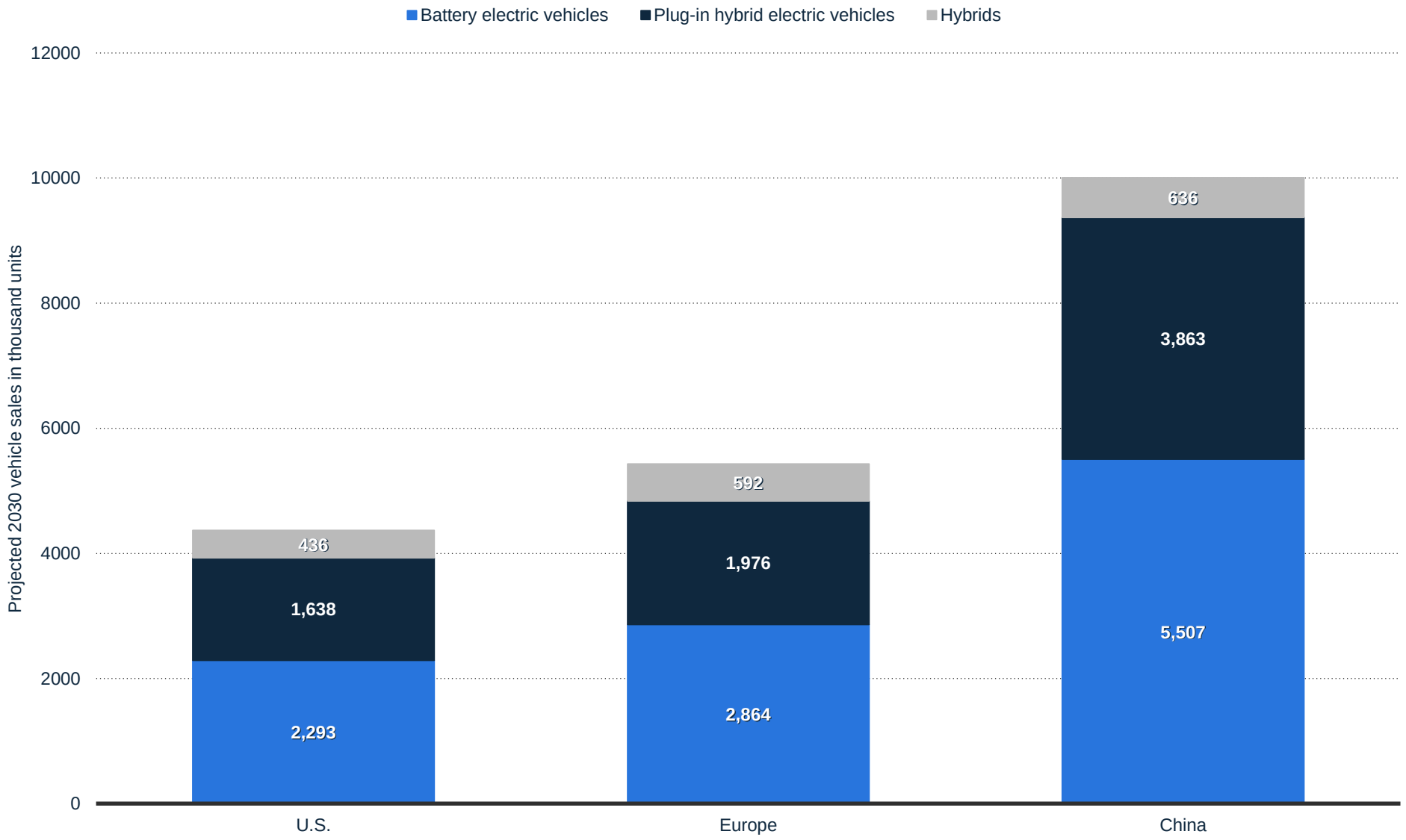
Mobility fleet electrification is set to spark EV adoption

Electrification will be key to other mobility areas due to growing environmental commitments and lower maintenance costs associated with the parts in battery electric vehicle motors.

Some firms have begun to unlock the value of mobility services:

- Daimler: is owner of Share Now, ViaVan
- BMW: is owner of Share Now, Moovit
  - Share Now has 3,200 BEVs in fleet[1]
- VW: is owner of Moia
  - Moia has 100 BEVs in fleet[2]
- GM: is owner of Maven, BOOK, invests in Lyft
  - Maven has 20 BEVs in fleet[3]
- Hyundai-Kia: invests in Grab
- Avis: is owner of Zipcar
- Uber: collaborates with Daimler, Toyota, VW
- Didi: collaborates with VW

Note: Worldwide
Source(s): Bank of America; Merrill Lynch



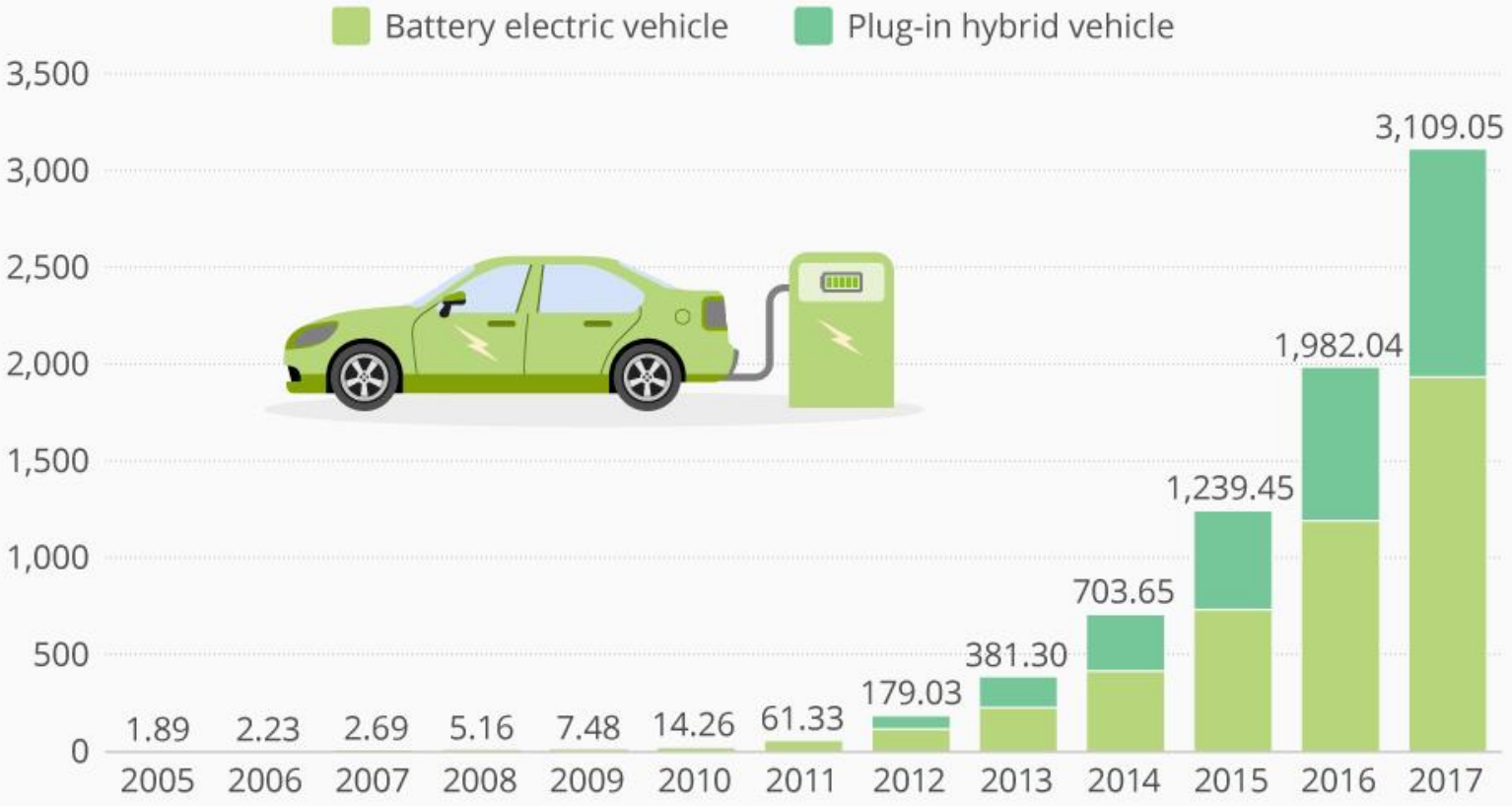
China holds the potential to extend its lead with regards to EV sales throughout 2030

It is expected that sales to customers in China will continue to be crucial for EV manufacturers throughout 2030. This is true for the hybrid and plug-in electric vehicle segments.

Note: Worldwide
Source(s): Citigroup

Electric Car Stock Ramping Up at a Fast Pace

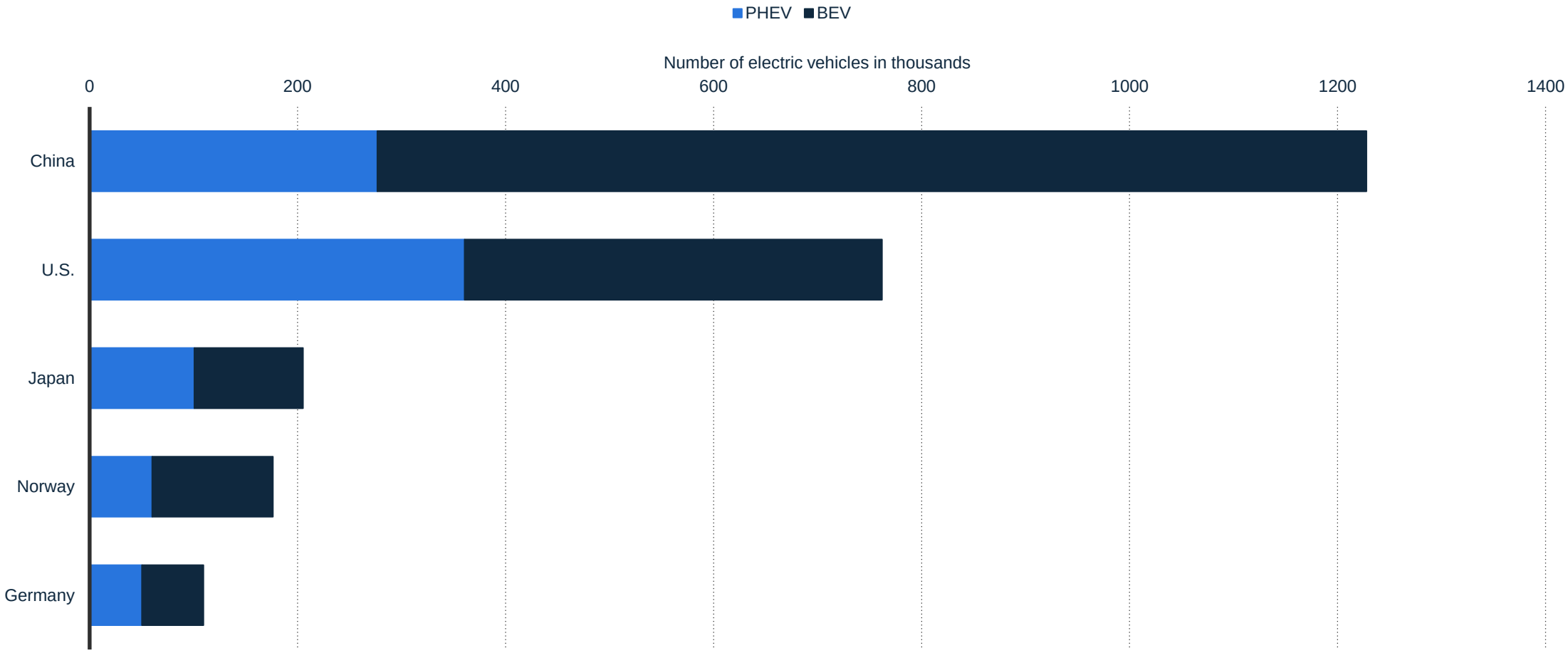
Global electric vehicle stock by year and engine type (in 1,000)



@StatistaCharts Source: IEA

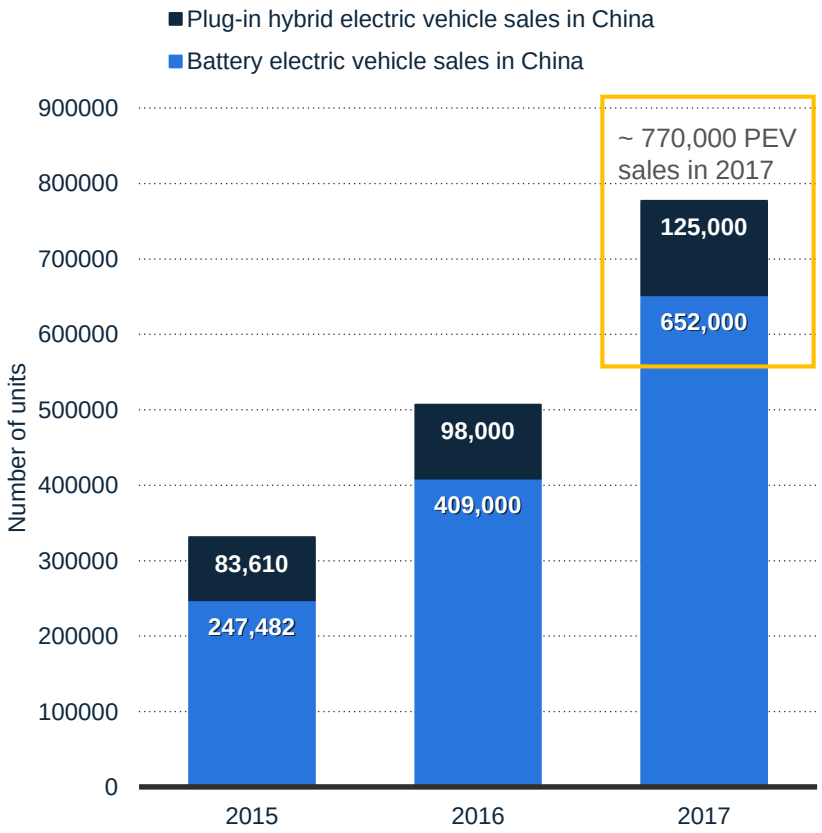
statista

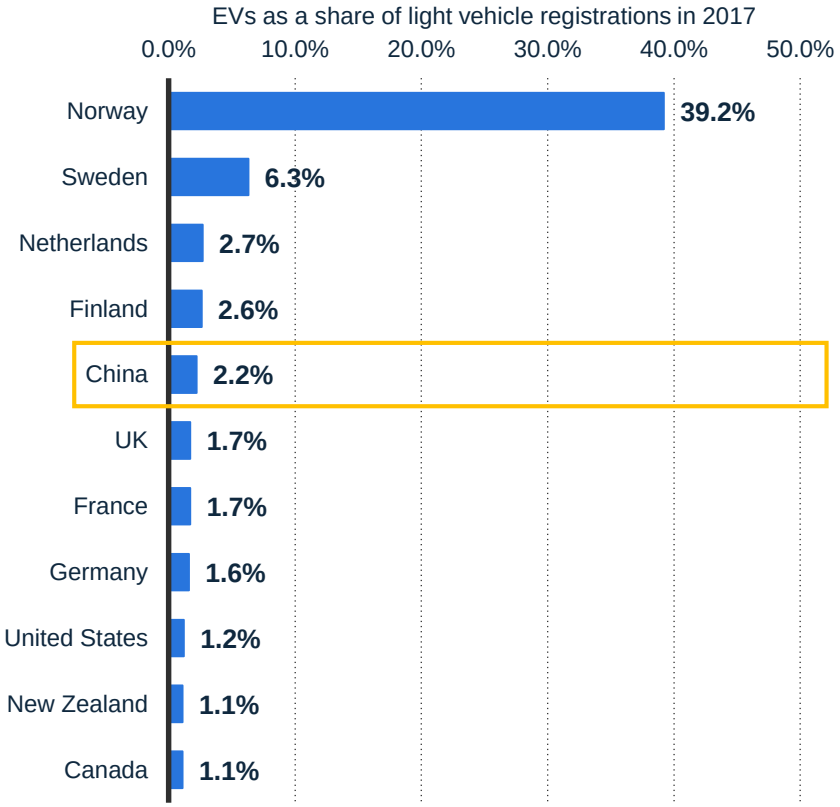
Estimated electric vehicles in use in selected countries as of 2017



Note: Worldwide
Source(s): IEA

China’s electric vehicle registration share is expected to grow



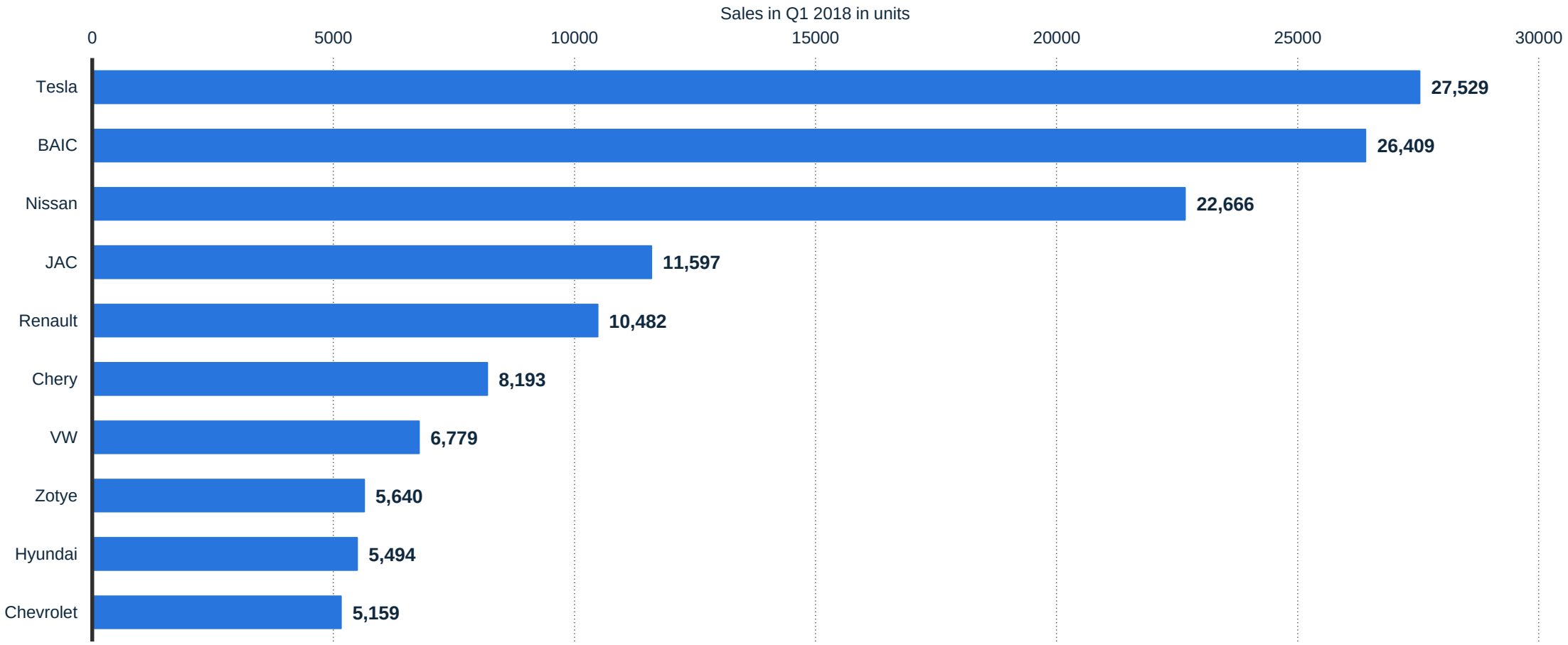


While historical light vehicle registration data shows that Norway might reach an electric vehicle sales share of 50 percent soon, several experts’ outlook figures show that China has the potential to become the undisputed leading market in terms of EV sales by 2030.

The country has great potential with combined battery and plug-in electric vehicle sales of around 770,000 units and a registration share of 2.2 percent in 2017.

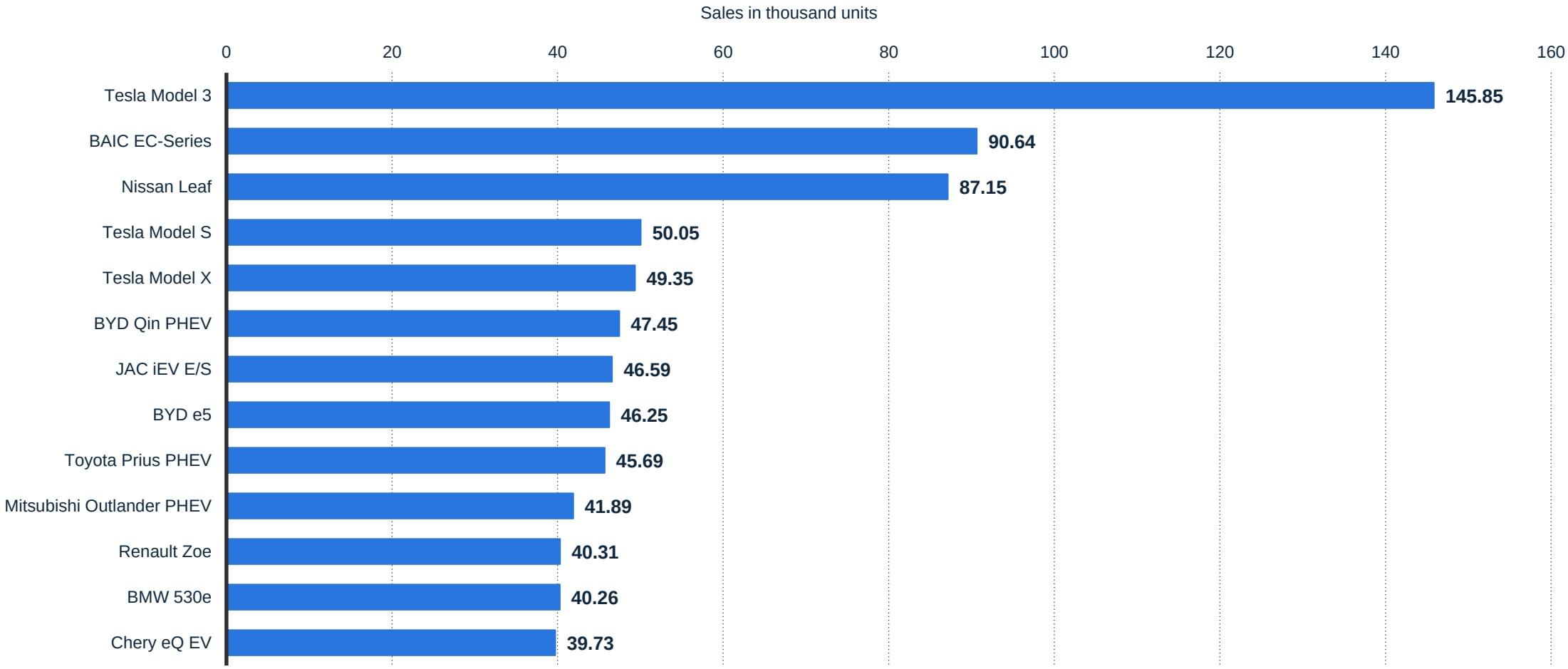
Note: Selected countries
Source(s): CAAM; IEA

Battery-electric vehicle sales worldwide in the 1st quarter 2018, by brand



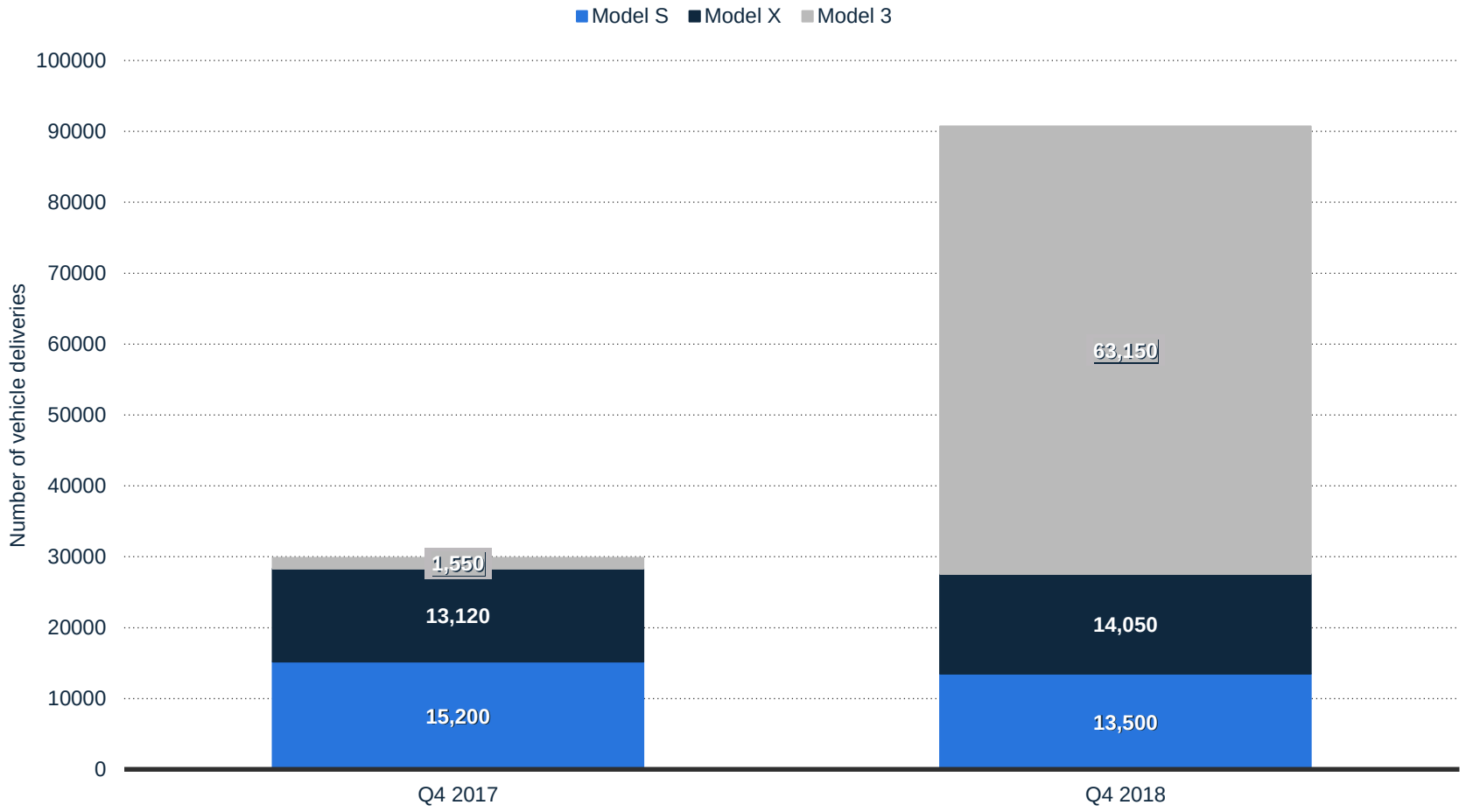
Note: Worldwide
Source(s): JATO

Worldwide plug-in electric vehicle sales in 2018, by model



Note: Worldwide
Source(s): EV Sales; insideevs.com

Tesla has ramped up its Model 3 deliveries after a slow start



After production and delivery volume targets were missed in late 2017 and early 2018, the Model 3 has turned into Tesla's best-selling model during the fourth quarter of 2018.

As of February 2019, the Model 3 is Tesla's most recent model addition, as the first units rolled off the assembly line in 2017. It comes at a price tag of 35,000 U.S. dollars (and up), thus targeting broader customer segments than the Model S and Model X, both of which are aimed towards the high-end market segments. Tesla's new Model Y was unveiled in March 2019; production is expected to start in 2020.

05 Revenue: The segments and regions of growth

- Market growth
- Electric vehicle market size
- EV battery market size

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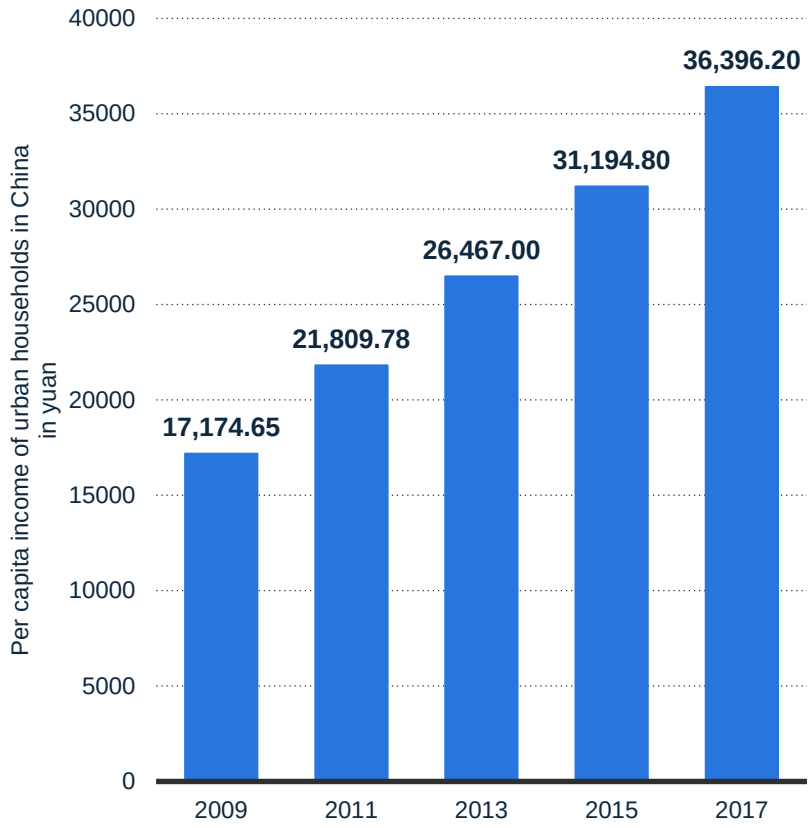
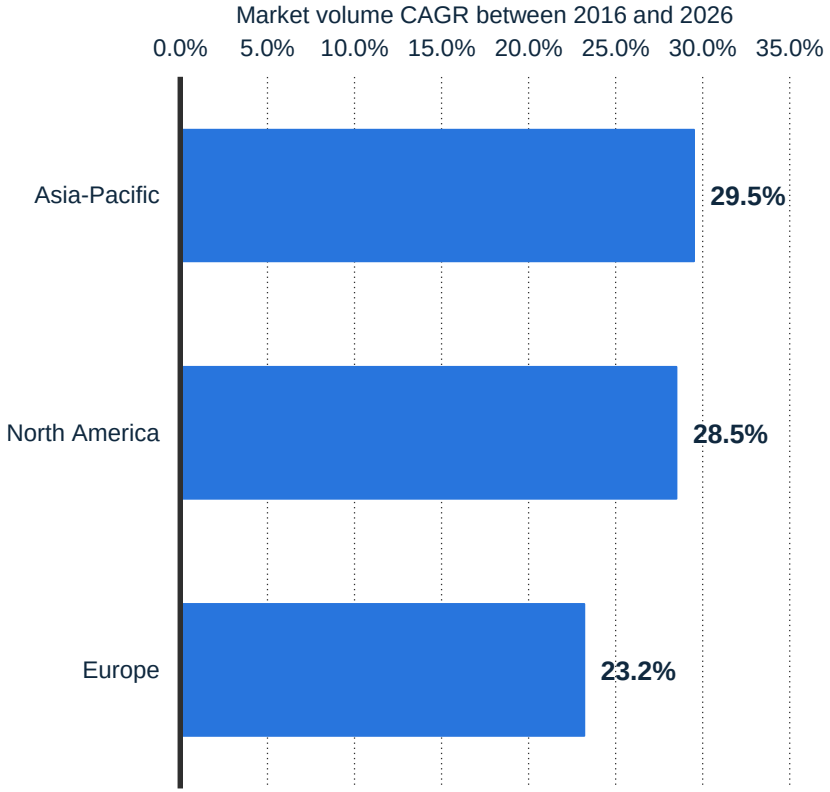
The electric vehicle market is beginning to gain momentum

The fact that electric car sales accounted for about two to three percent of overall light vehicle sales leaves great opportunities for growth for carmakers and automotive suppliers alike. Charging equipment manufacturers emerge as a third group of beneficiaries who can expect a golden age of electrified transportation.

- The United States and China are market leaders in terms of market growth, while Europe lags behind
- The electric vehicle battery market has enormous potential
- Wireless electric vehicle charging is set to revolutionize the sector

China’s rising affluence correlates with electric vehicle market growth



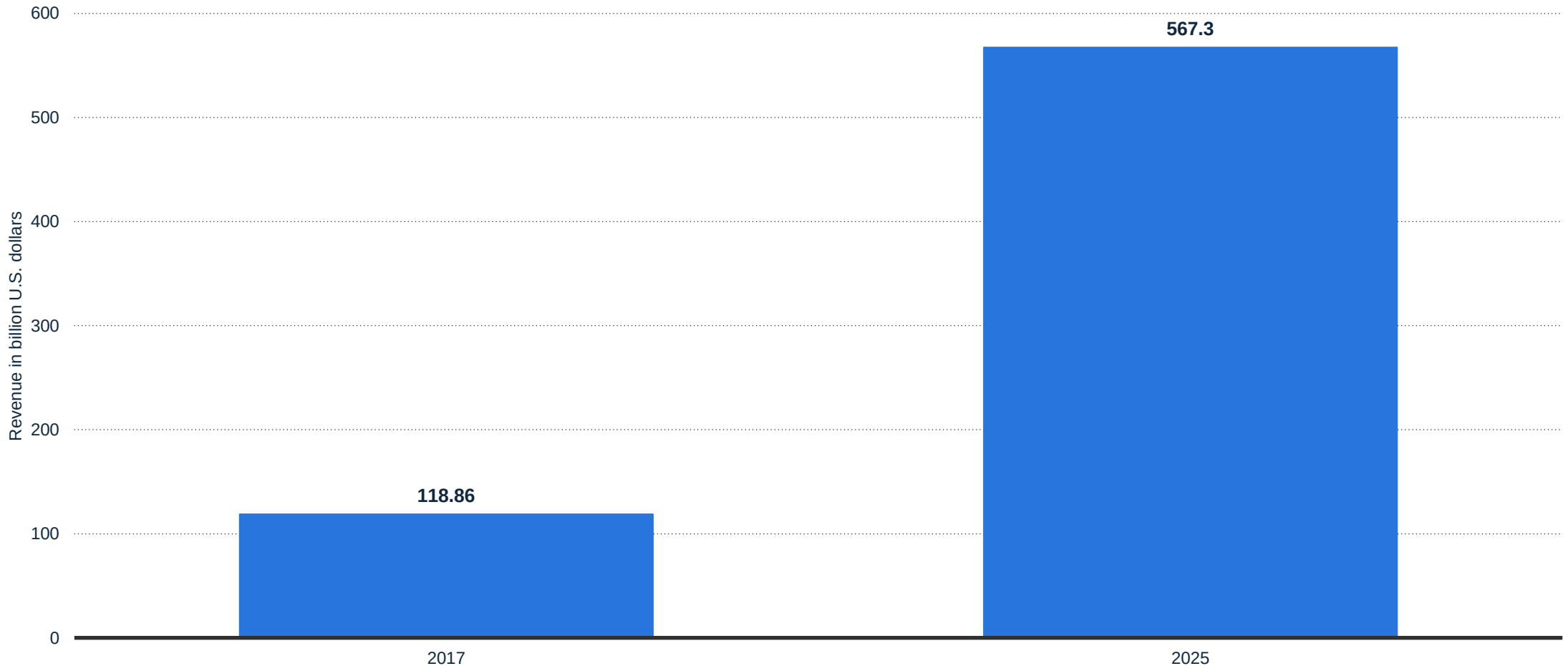


The electric vehicle market in the Asia-Pacific region is expected to expand its volume at a compound annual growth rate of almost 30 percent between 2016 and 2026.

This comes as no surprise considering the vast number of potential buyers in this populous region, coupled with the rising affluence of its growing middle class.

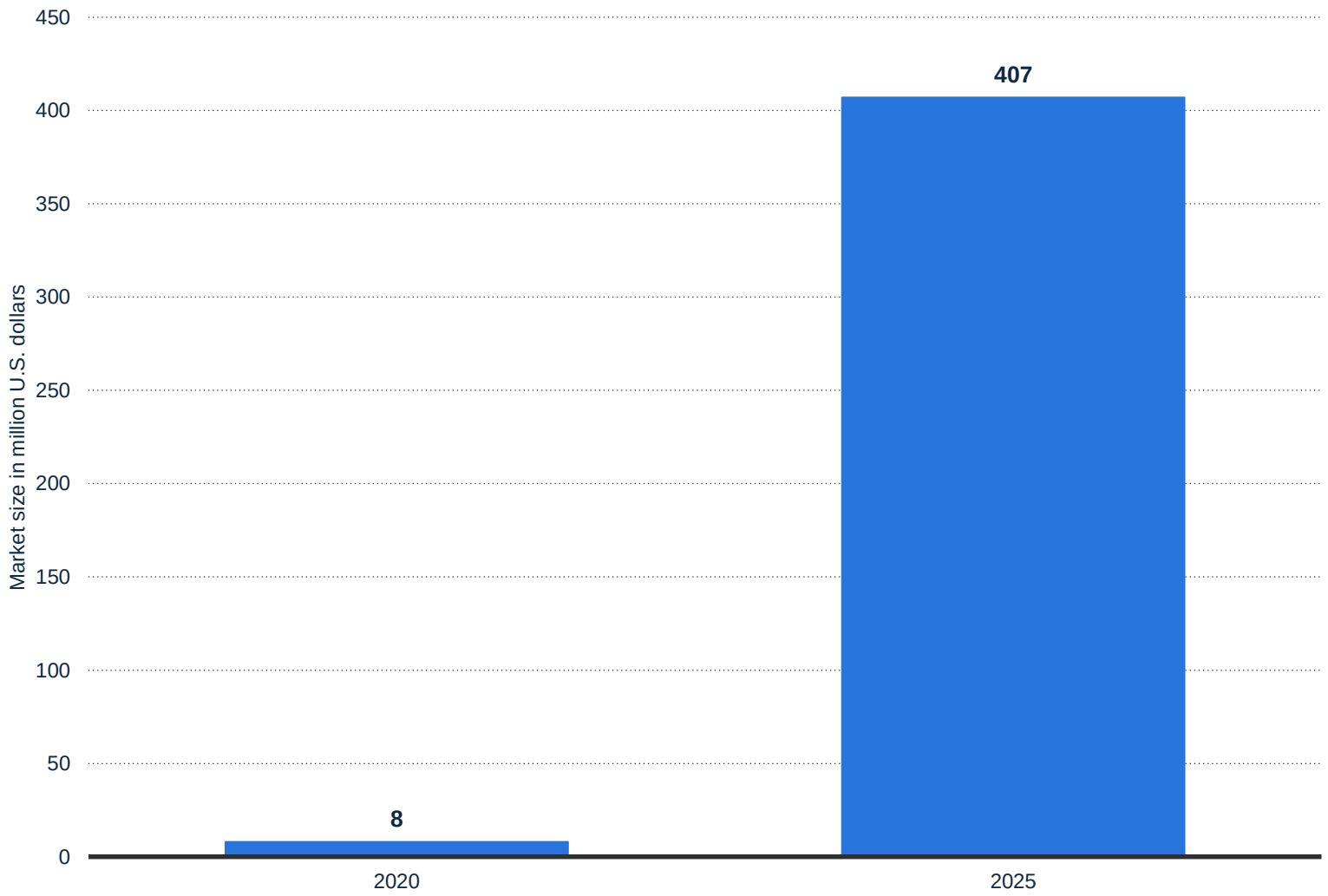
Note: Selected countries or regions
Source(s): National Bureau of Statistics of China; BIS Research

Size of the global market for electric vehicles in 2017 and 2025



Note: Worldwide
Source(s): Allied Market Research; PR Newswire

Projected global wireless EV charging market size in 2020 and 2025



Note: Worldwide
Source(s): MarketsandMarkets

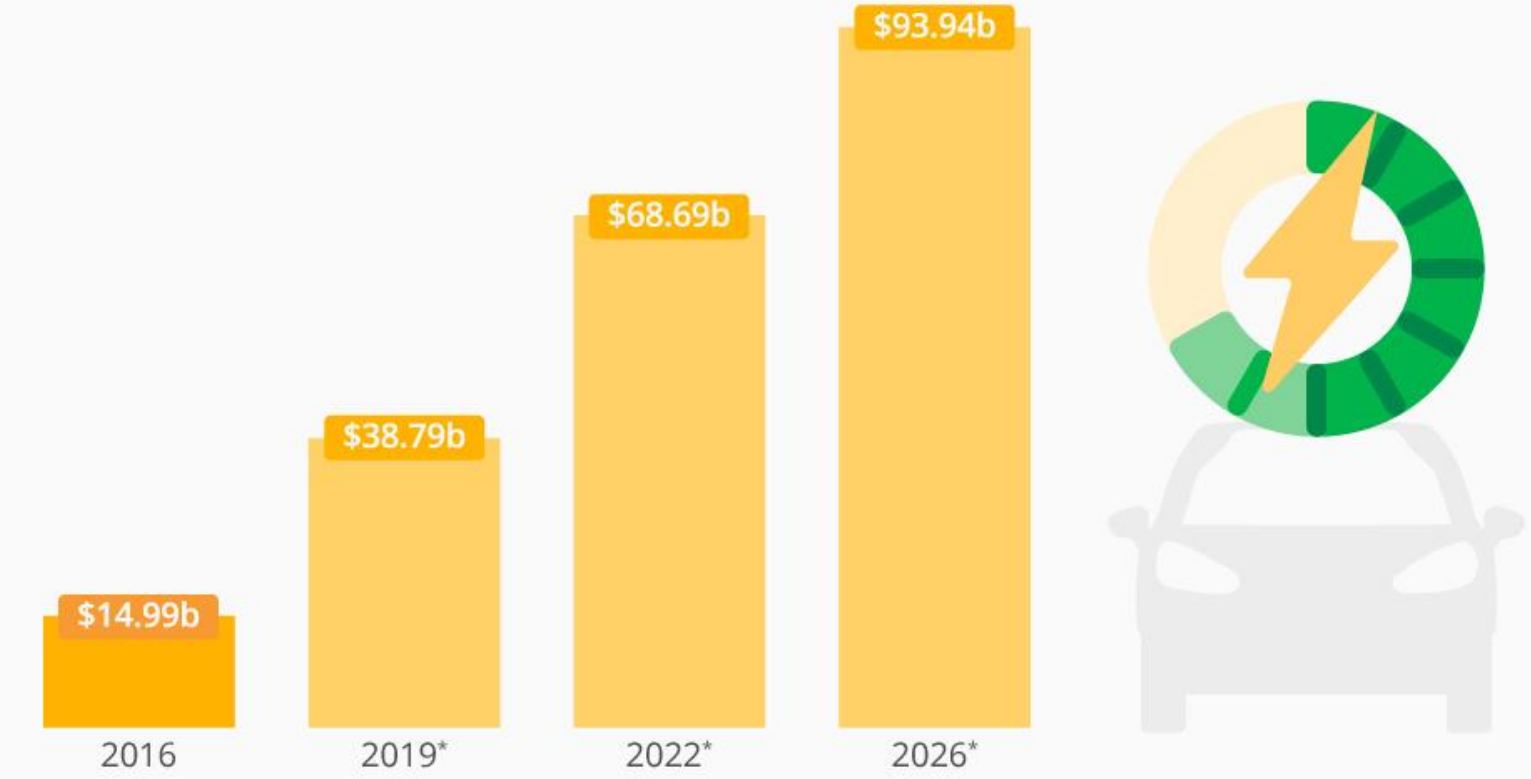
Wireless charging infrastructure is slated to be a game changer

The wireless technology is set to facilitate the charging process, and customers are expected to welcome the seamlessness that will accompany wireless charging.

Evatran and WiTricity are the leading providers in this field.

The Electric Vehicle Battery Market's Enormous Potential

Size of the global electric vehicle battery market from 2016 to 2026 (in USD)



* Forecasts

@StatistaCharts Source: BIS Research

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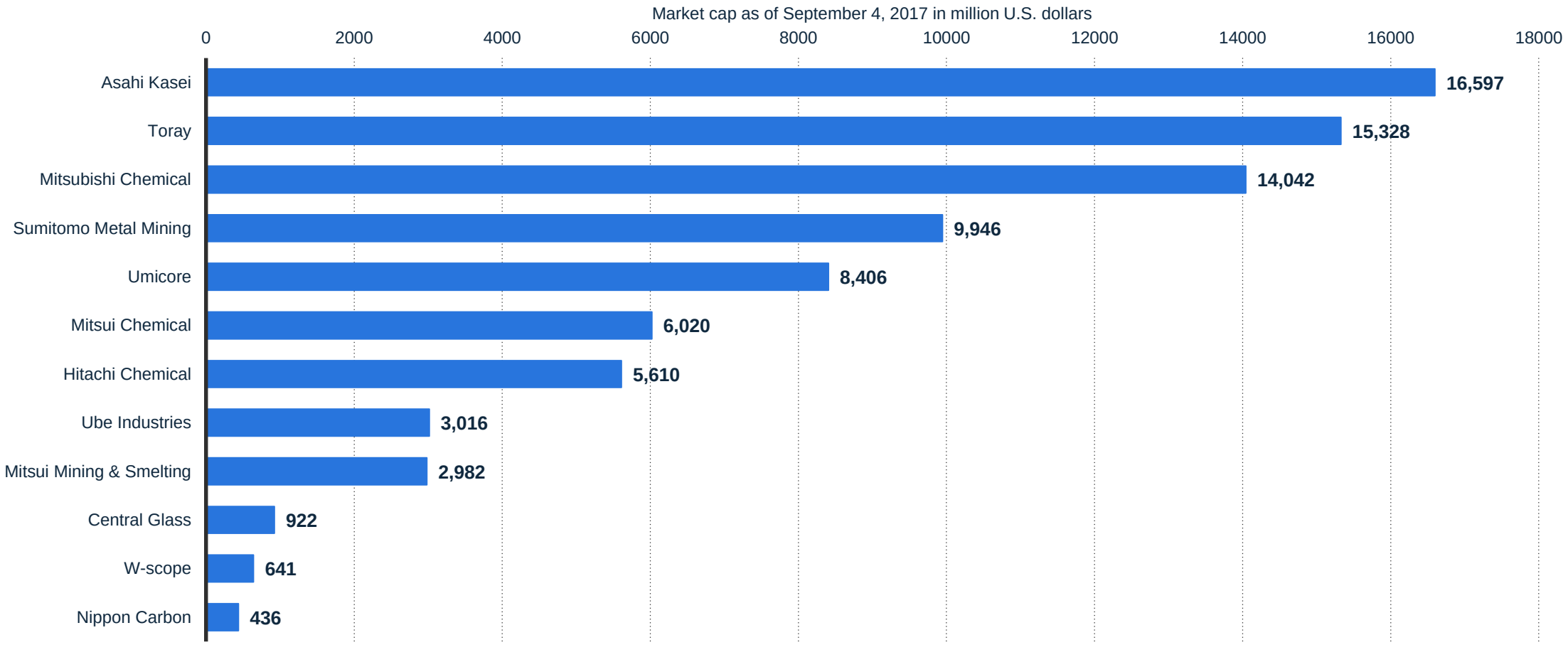
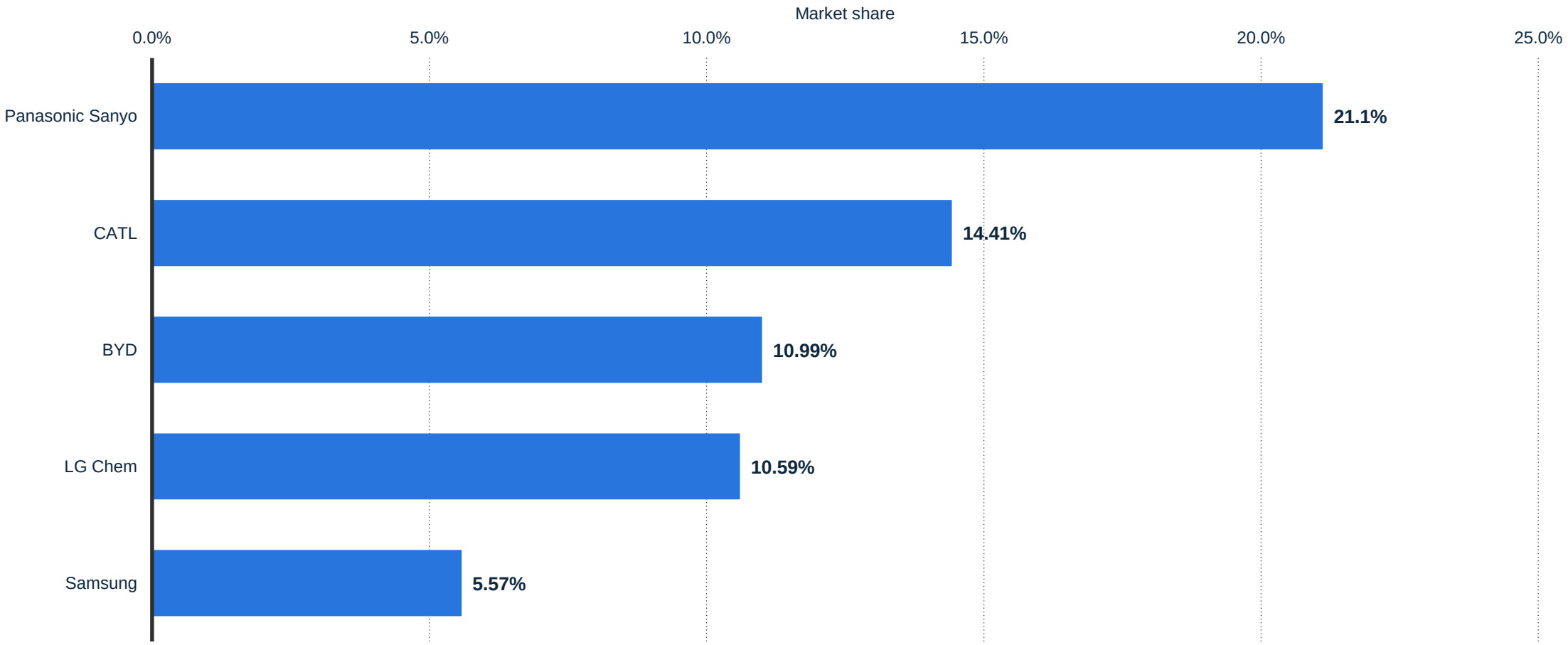
Market cap of lithium-ion battery component manufacturers worldwide as of September 2017



Note: Worldwide
Source(s): Goldman Sachs; Various sources

Global market share of lithium ion battery makers in the 1st quarter of 2018



Note: Worldwide
Source(s): electrive.com

06 Sustainability: The issues that need to be tackled

- Transportation-related emissions
- Renewable sources in power generation
- Materials used in batteries

statista

Today’s electric vehicles fall short of sustainability goals

While EVs clearly have the potential to outperform ICE cars in terms of fuel-related emissions, it is not easy to ascertain if electric vehicles are environmentally sustainable, or not. There is no denying in the fact that all motor vehicles have an impact on the environment, though.

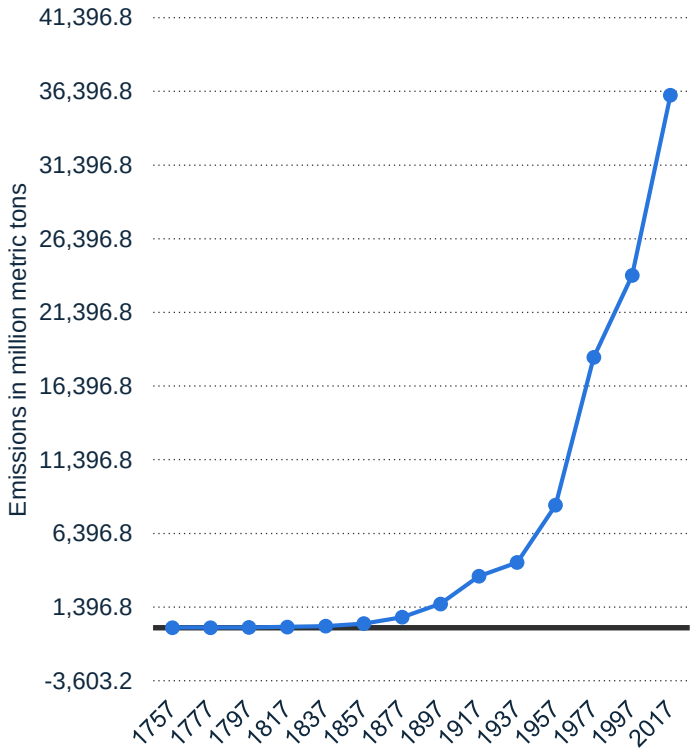
- Questions about EVs financial sustainability aside, the key factors in gauging the sustainability of EVs include the following:
  - type of energy used as a source of power
  - battery material types
- Although electric cars have a smaller carbon footprint than gasoline or diesel-powered automobiles, a shift away from coal power will be necessary to soften the transportation sector’s carbon footprint
- To date, battery supply chain sustainability has not been achieved due to the continued unsustainable mining of key materials, including cobalt, lithium, and nickel
- The growing demand for those commodities that are used in the manufacture of electric vehicle batteries is likely to have an impact on spot prices

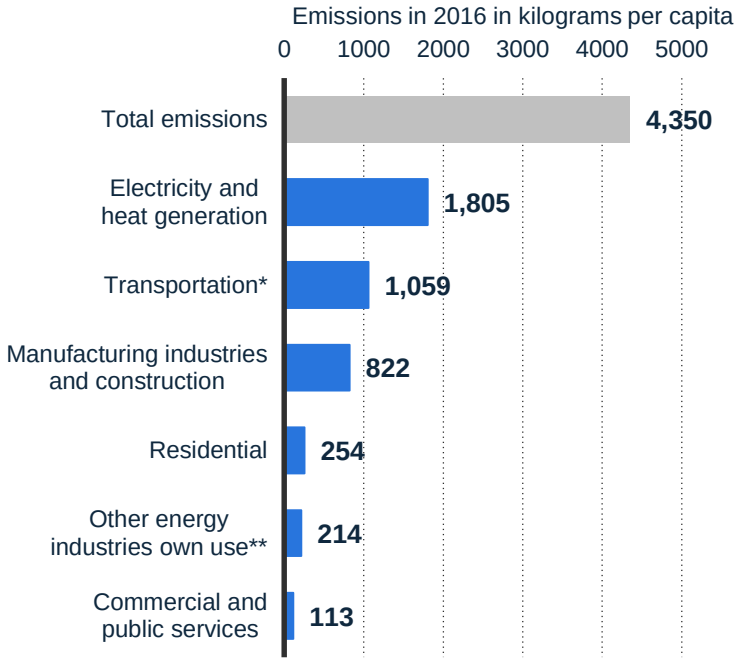
“(…) [E]lectromobility alone is not effective climate protection. We need an energy transition alongside the transport transition to truly improve our carbon footprint”

– Herbert Diess,

CEO of Volkswagen Group

Rise in anthropogenic CO^2 emission levels requires mitigation





Since the second half of the 20th century, the combustion of fossil fuels has led to the release of unfettered volumes of carbon dioxide (CO^2) emissions into the atmosphere. The resulting concentration of CO^2 in the atmosphere continues to exacerbate what has been dubbed the greenhouse effect: The earth's surface temperature rises because solar heat is absorbed by molecules of carbon dioxide and other greenhouse gases, including nitrous oxide, methane, and water vapor.

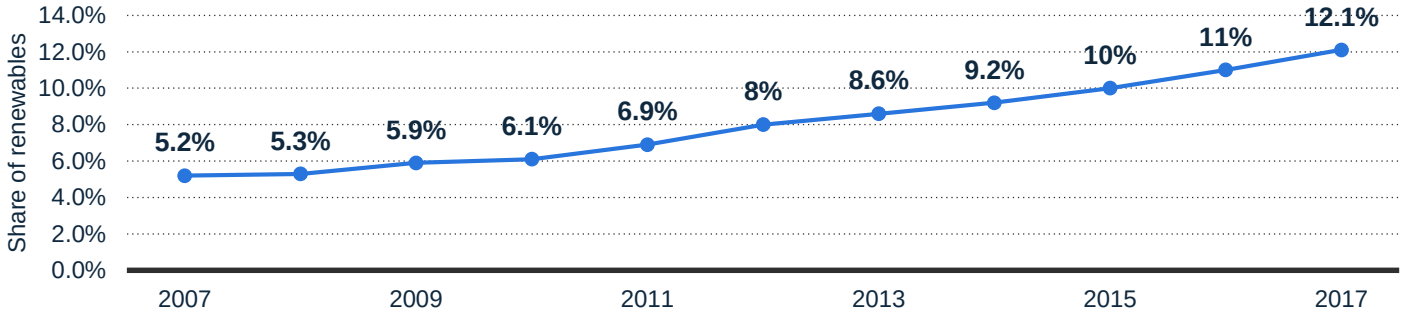
Higher surface temperatures have been linked to rises in sea levels, stronger hurricanes, and changes in precipitation patterns.

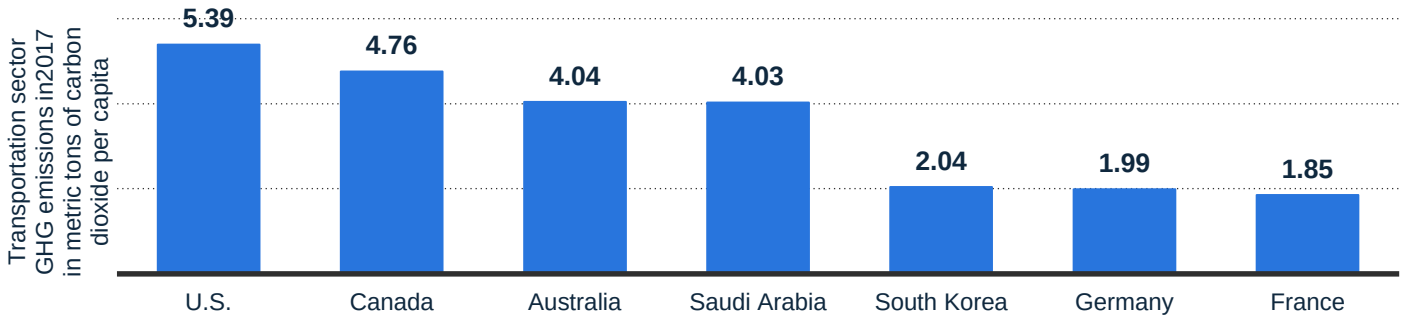
The transportation sector contributes some eight gigatons of carbon dioxide equivalents worth of emissions globally[4]. Under the auspices of the UN, 197 ratifiers have thus agreed to mitigate vehicle-related fuel combustion CO^2 emissions by replacing ICE vehicles with EVs.

Note: Worldwide
Source(s): IEA, Global Carbon Project

* Includes international bunkers in transport sector. ** Includes emissions from own use in petroleum refining, the manufacture of solid fuels, coal mining, oil and gas extraction and other energy-producing industries.

Conventional sources represent ~ 90 percent of the power mix





Note: Worldwide
Source(s): Enerdata; Climate Transparency; UNEP; Bloomberg New Energy Finance; FS-UNEP Collaborating Centre
Large hydro is not considered a renewable energy source in this data set.

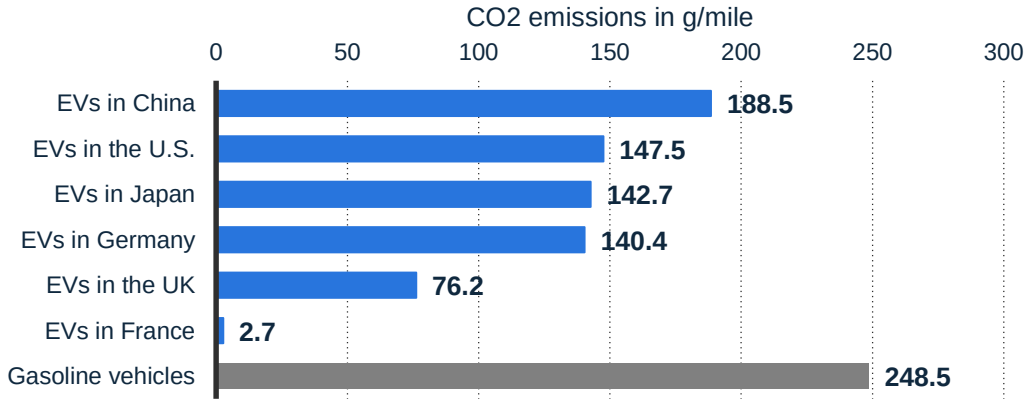
About 40 percent of electricity generation worldwide comes from the combustion of coal. In order to be environmentally benign, EVs need to make use of as little coal power as possible because of the severe health effects caused by its combustion. If renewable sources are used as the primary source of power though, the widespread adoption of electric cars is predicted to reduce GHG emission levels in a significant manner.

Although the share of renewable power in electricity generation has more than doubled over the past decade, electricity generated from coal, oil, gas, nuclear, and conventional hydro sources still accounts for almost 90 percent of power generation. Therefore, the current power mix is unlikely to lessen the carbon footprint associated with emissions from the transportation sector.

The transportation sector in the United States produced the highest volume of GHG emissions per capita in 2017, when the U.S. car parc comprised almost 270 million vehicles.

Power mix continues to affect the carbon footprint of EVs

	2017 share of coal power generation worldwide	2017 share of electric vehicle stock worldwide
China	44.8%	39.5%
United States	13.5%	24.5%
Japan	3.5%	6.6%
Germany	2.5%	3.5%
Netherlands	0.3%	3.8%
UK	0.2%	4.3%
France*	0.1%	3.8%
Norway**	-	5.7%

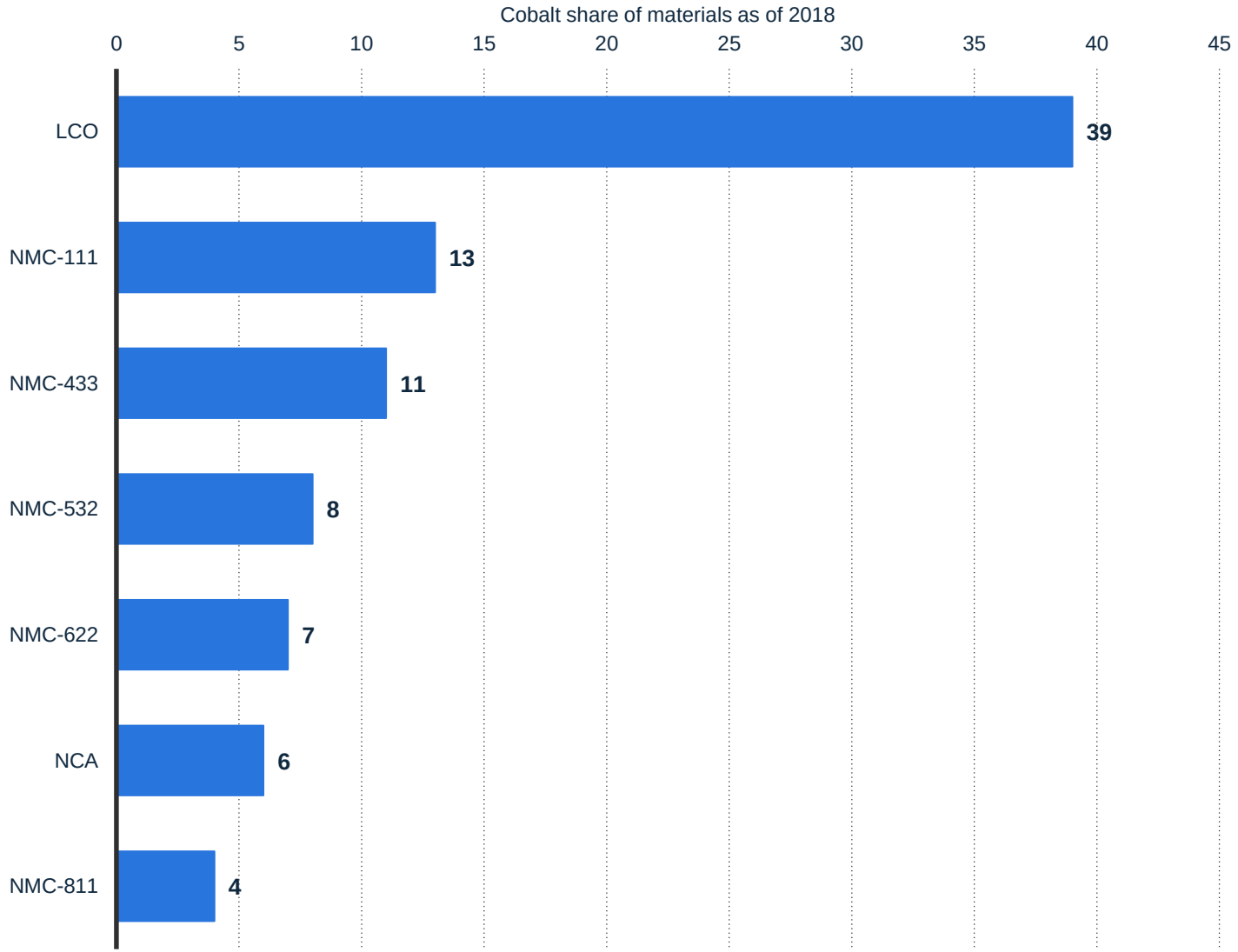


Note: Worldwide
Source(s): IEA; BP; Statista; Bloomberg New Energy Finance; World Economic Forum
Coal power: * The value for France (10.52 TWh) is for 2016; was taken from IEA's website, as this country was not listed.
** The figure for Norway (146 GWh) is for 2016; it's based on information on IEA's website, as this country was not listed.

The increased use of electricity from renewable sources softens EVs' carbon footprint, but electric car owners need to make an active choice to recharge where coal is not used as the primary energy source. However, this choice is not an easy one to make, considering the complex nature of the energy market with all its regional regulations. Ultimately, it is the share of coal power in a country's electricity mix that determines the carbon footprint of its EV fleet unless motorists select charging stations with low coal levels in the power mix.

China has the largest EV fleet, but also the highest share of coal in its energy mix. Norway's EV fleet has shown impressive growth and the country's coal use is nonexistent, but Norway's overall car market is small: Norway saw passenger car sales of under 150,000 units in 2018[5].

France seems to be well prepared, but its dependence on nuclear power has led some experts to question the sustainable viability of the French EV market.



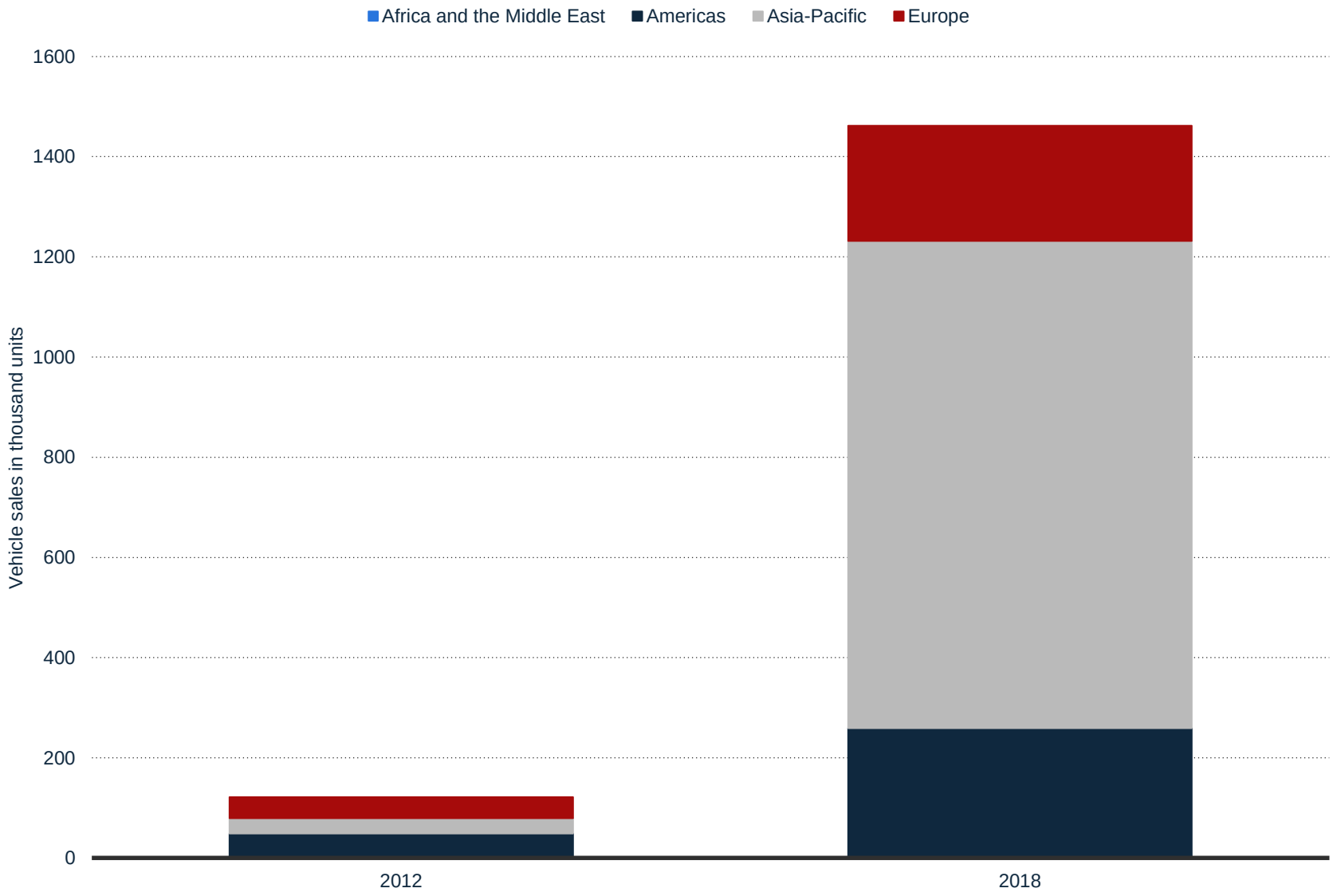
Note: Worldwide
Source(s): Bloomberg New Energy Finance; Bloomberg
NMC: nickel manganese cobalt; LCO: lithium cobalt oxide; NCA: nickel cobalt aluminum

Cobalt remains a critical ingredient in most battery types

A growing electric vehicle industry is expected to spur the demand for several materials, most notably cobalt, lithium, and nickel.

The composition of these commodities varies among the different types of lithium-ion batteries that are used in electric cars, most notably nickel manganese cobalt (NMC) batteries.

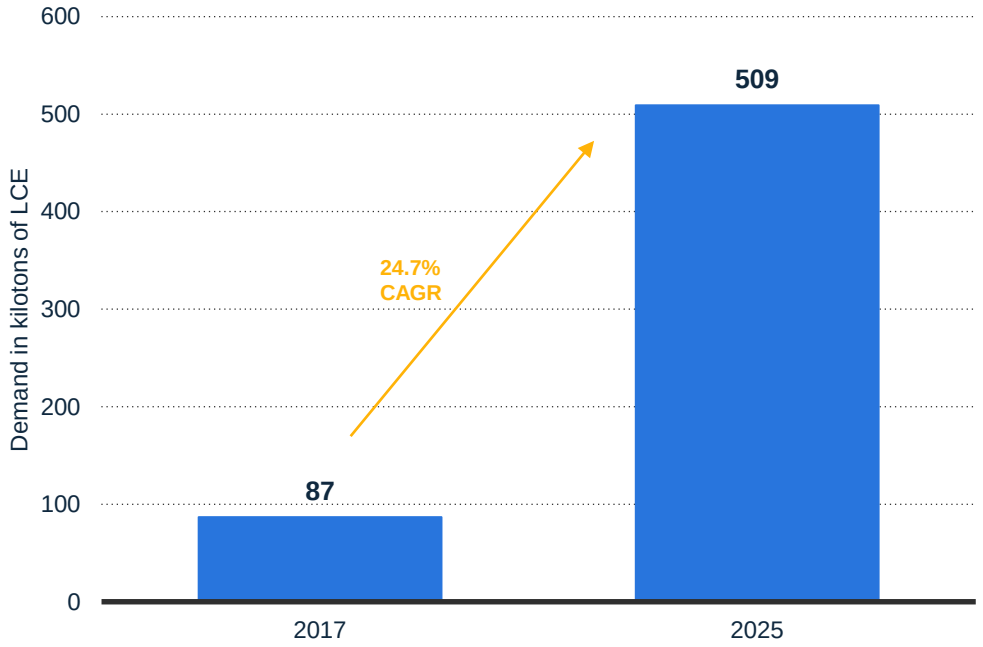
Currently, most electric vehicles are equipped with NMC-111 batteries. In 2018, cobalt accounted for around 13 percent of materials used in NMC-111 batteries, while lithium cobalt oxide (LCO) batteries reached the highest level of cobalt with about 40 percent.

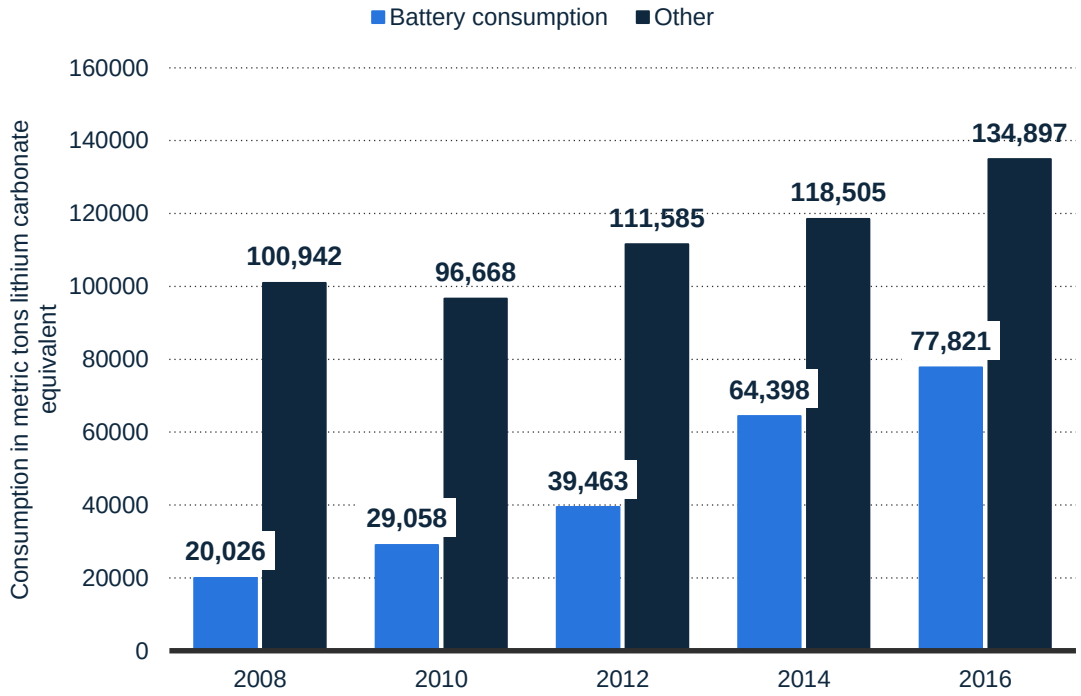


Regional breakdown of battery electric vehicle sales shows Asia-Pacific's dominance

The tremendous growth in electric vehicle sales that has already occurred globally is slated to trigger worldwide demand for the various commodities used in electric vehicle batteries, too.

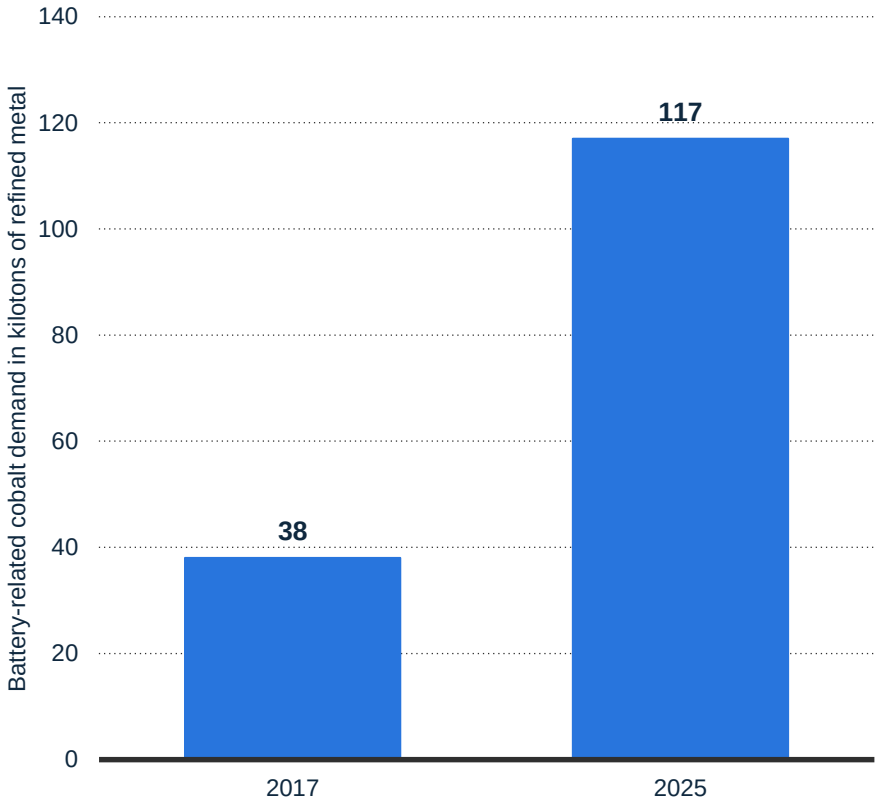
Lithium-ion batteries will likely drive lithium consumption

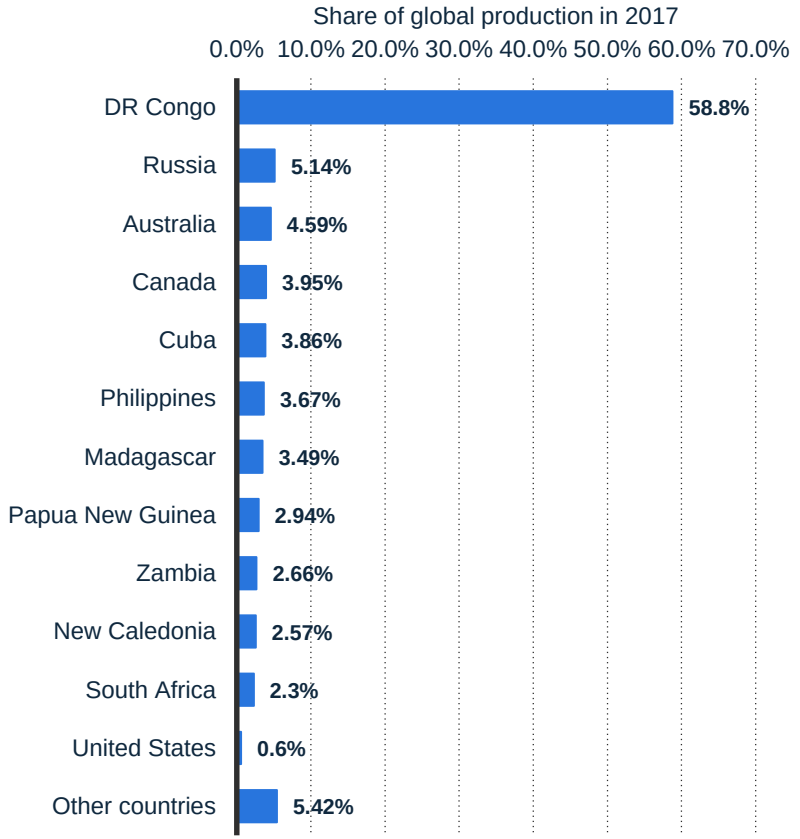




Note: Worldwide
Source(s): McKinsey; Roskill

Battery-related demand for cobalt drives Congolese cobalt production



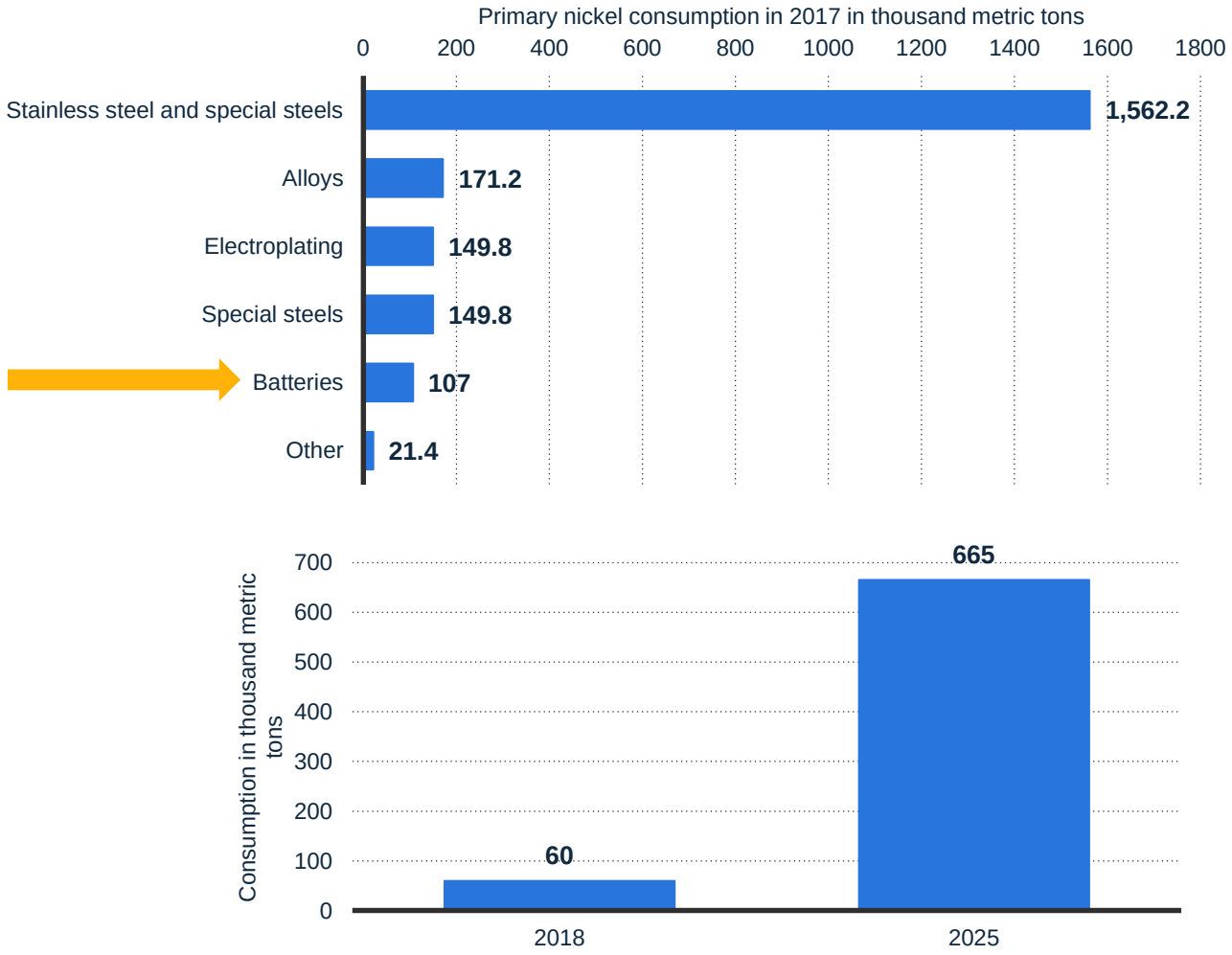


Note: Worldwide.
Source(s): US Geological Survey; McKinsey

The batteries segment within the global cobalt market is expected to see a compound annual growth rate of just over 15 percent.

Cobalt is often extracted in regions where safe working conditions are not always guaranteed, including the Democratic Republic of the Congo. An estimated 20 percent of Congolese cobalt comes from the country's artisanal mining sector, where workers lack basic protective equipment, exposing them to toxic, metal-containing dust[6].

Low-level battery-related nickel demand is forecast to grow



Note: Worldwide
Source(s): Norilsk Nickel; Various sources (Company data); UBS; Metal Bulletin

Nickel is expected to be the EV battery commodity yielding the highest compound annual growth rate between 2018 and 2025 with 41 percent.

However, the toxicity of this metal has sparked concerns about the negative impact of nickel mining on the environment and production workers[7].

While the metal manufacturing industry mainly uses low-grade nickel ores, the more stable nickel sulfate is required for the manufacture of batteries. This might be the reason why batteries only accounted for about five percent of primary nickel consumption worldwide in 2017.

Glossary

BEV - Battery electric vehicles run only on electricity, using power from a battery.

CO^2 - Carbon dioxide is a greenhouse gas.

EV - BEVs, FCEVs, PHEVs, and hybrid electric vehicles.

EVSE - Electric vehicle supply equipment, or chargers, provide EVs with electricity.

FCEV - Fuel cell electric vehicles run only on electricity, using power from a fuel cell.

GHG - Greenhouse gases comprise methane, nitrous oxide, water vapor and carbon dioxide. GHG molecules absorb solar heat and thus lead to an increase in the earth's temperature.

Hybrid vehicles - Hybrid vehicles run mainly on gasoline or diesel, but have an electric motor as well.

ICE - Internal combustion engines create energy from burning fossil fuels such as diesel and gasoline.

MPG - Miles per gallon measure the number of miles a motorist can drive in a vehicle using one gallon.

NMC batteries - Nickel manganese cobalt batteries, also abbreviated NCM

PEV - Plug-in electric vehicles comprise PHEVs and BEVs, can be plugged in to charge from an off-board electric power source.

PHEV - Plug-in hybrid electric vehicles run mainly on electricity, but have an ICE as well.

Rechargeable batteries - In batteries, electricity is produced through the movement of electrons between anode and cathode. Rechargeable batteries function according to the same principle, but also have the ability to be recharged.

xEV - BEVs and PHEVs

Footnotes

[1] Share Now (2019): “Your Car is Always There”, retrieved from https://www.your-now.com/our-solutions/share-now

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