EXECUTIVE SUMMARY

FUTURE ENERGY FOR MOBILITY

The Electric Vehicle Inflection Tracker: 2020 Edition

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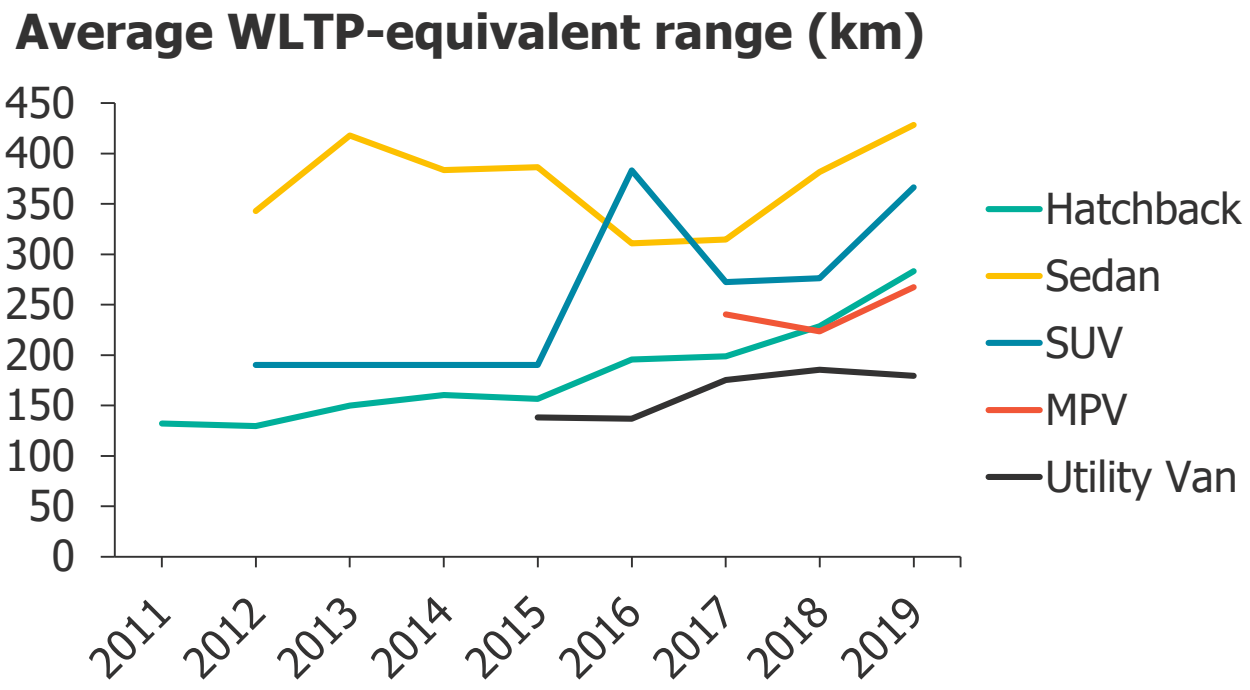
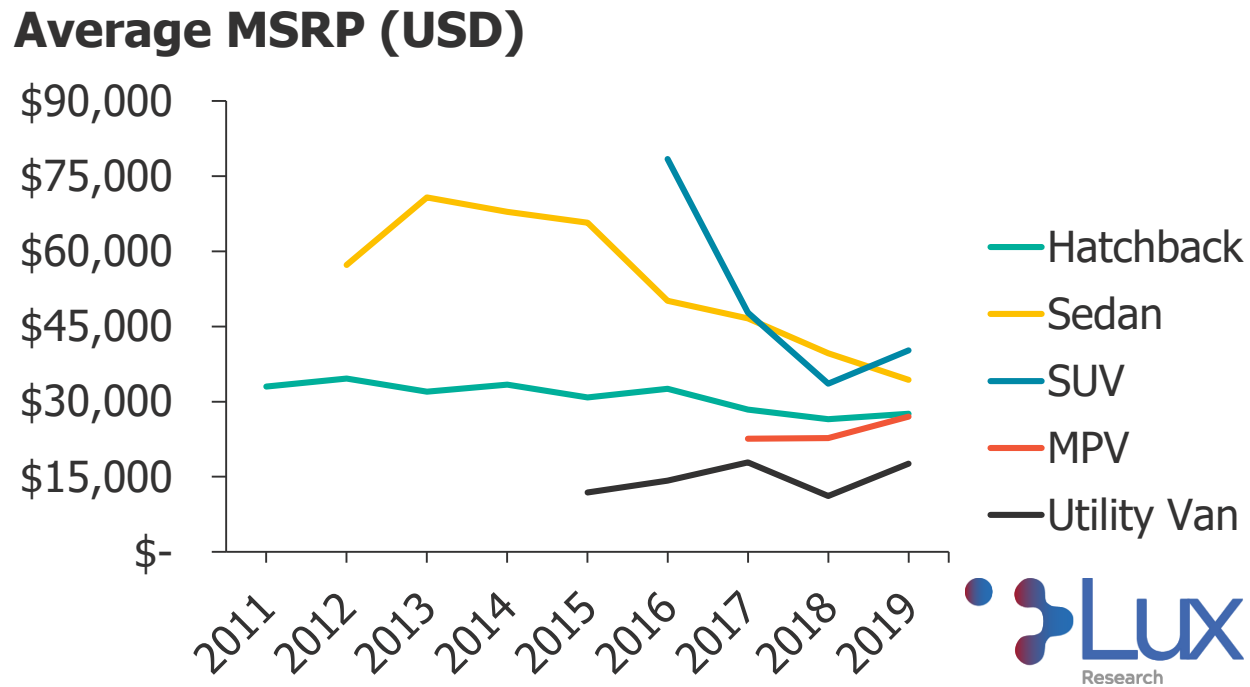
Executive Summary

Electric vehicles are a crucial tool for automakers to reduce fleet emissions. Although to date they represent only a few percent of overall vehicle sales, automakers have made significant progress in addressing key pain points for consumers considering buying a battery electric vehicle (BEV).

- The average BEV MSRP declined to $33,901 in 2019 compared to $42,189 in 2016.
- The average BEV's range has consistently increased at 13.7% CAGR since 2011 to reach 370 km (230 miles) in 2019.
- The average BEV increases long-distance travel time by 22% when accounting for time spent charging.

In the future, expect automakers to focus on improving efficiency as a way to improve charging speed and minimize the size of the battery.



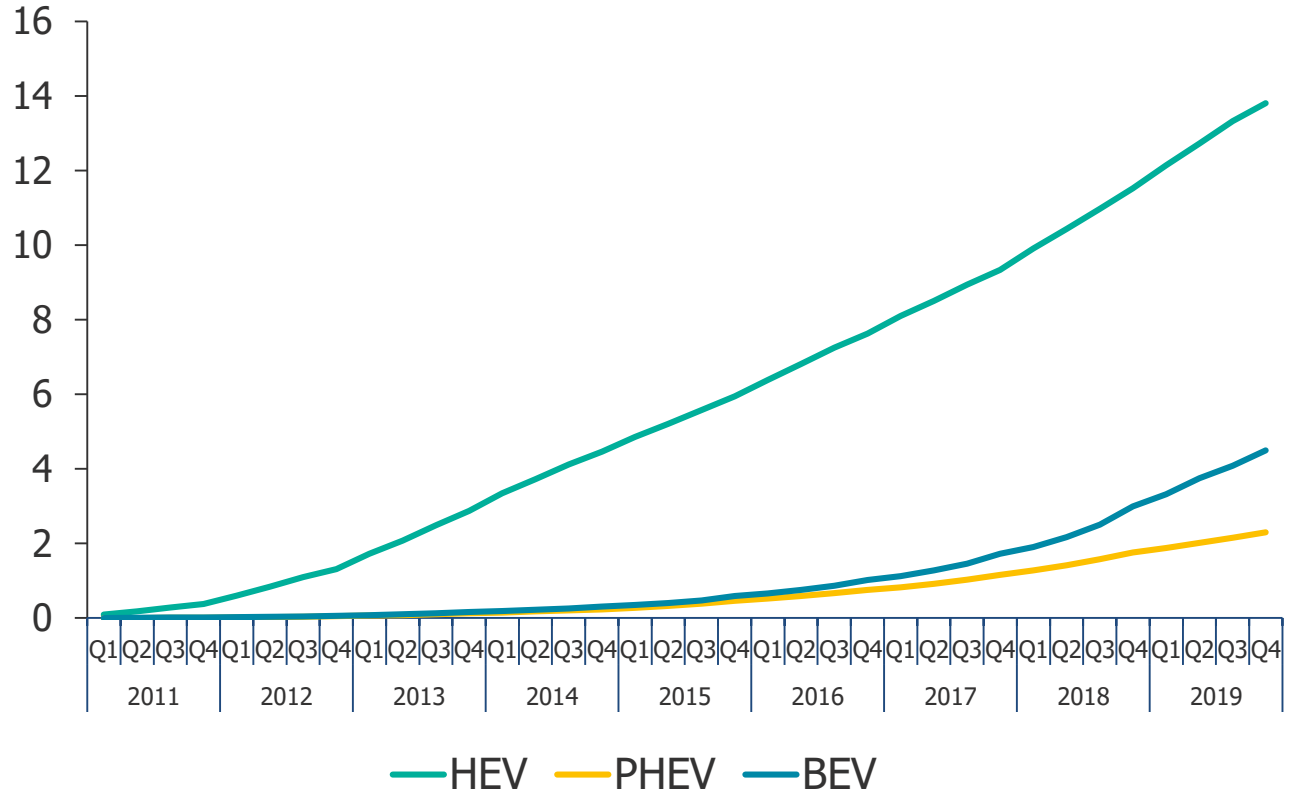


In the past decade, sales of all types of electrified powertrains have grown steadily

The automotive industry is under pressure to reduce emissions. Whether from governments that are placing limits on the amount of emissions from vehicles or consumers who are more conscious of the environmental impacts of their choices, automakers can't ignore a push to reduce emissions.

In response to this challenge, electrified powertrains are a promising avenue to reducing or eliminating emissions from vehicles. Electrified powertrains make up a range of options, including lower-cost hybrid vehicles (HEVs), which use a battery to harness energy normally lost during braking, battery electric vehicles (BEVs), which are solely powered by electricity, and plug-in hybrids (PHEVs), which can be used in both ways. Among these powertrains, BEVs are seeing the most significant growth and are the primary focus of the full report.

Cumulative electrified powertrain sales
Millions of units (since 2011)



TOYOTA MOTOR CORPORATION

2019 sales: 10.7 million

Future electrification strategy:

Toyota's plan for offering low-emission vehicles has been to build and sell hybrids until its fuel cell technology is ready. However, as BEV sales have accelerated and Toyota's FCV sales have remained low, it is forced to offer electric vehicles. Its commitments are significantly lower than those of its peers – releasing six BEVs by 2025.

It aims for half its vehicle sales to be "electrified" by 2025, but that likely will be mostly HEVs. Its Prius Prime is one of the most popular PHEVs to date, and the company will likely deploy those powertrains to other models in its lineup as it did with hybrid powertrain technology.

Platform approach:

The few BEVs Toyota is planning will be built on a ground-up BEV platform with Subaru dubbed e-TNGA (electric Toyota New Global Architecture), which, like its peers, will be modular to allow for various motor (80 kW to 150 kW, or 300 kW for dual-motor versions) and battery (50 kWh to 100 kWh) configurations. Like most manufacturers, Toyota is first focused on selling vehicles in China and Japan before expanding to other geographies.

Key Planned Models

2020 Toyota Mirai (FCEV)
Lexus UX 300e

2021

2022

2023

Key Investments and Partnerships

Panasonic — Joint venture partner for manufacturing hybrid and future BEV batteries

TOYOTA RESEARCH INSTITUTE — Partnered with MIT and Stanford to apply materials informatics to emerging battery materials

Key Targets

- Releasing six BEVs by 2026
- Aiming for 50% of its global sales to come from HEV, PHEV, or BEV powertrains

Battery Strategy

- Toyota has manufactured its hybrid batteries through a joint venture with Panasonic, but higher volumes of batteries required for BEVs have led the company to sign supply agreements with CATL
- Toyota's solid-state battery program remains one of the world's best, and a joint venture signed with Panasonic indicates that Toyota is looking to manufacture these batteries as well

FORD MOTOR COMPANY

2019 sales: 5.1 million

Future electrification strategy:

Although its electric vehicle portfolio has lagged to date, Ford has an aggressive electrification plan. It is now committing $11 billion to bring 40 hybrid and electric vehicles, including 16 BEVs, to market by 2022. Given that Ford's lineup features mostly large vehicles like trucks and SUVs, the company is expected to mostly hybridize those vehicles.

Platform approach:

Ford heavily modified its C-segment platform for its first dedicated BEV, the Mustang Mach E, which hit is calling global electrified 2 (GE2). However, the company is also leveraging platform expertise of its partners in future plans. Starting in 2023, Ford will begin using the MEB platform from VW as part of a wide-ranging partnership including autonomous driving and electric vehicle development. It also announced that Lincoln's first electric vehicle, an SUV likely to be released in 2022, will use Rivian's platform.

Key Planned Models

2020

2021 Ford Transit electric
Ford Mustang Mach-E (GE2)

2022 Ford electric pickup
Lincoln SUV (Rivian)

2023 European BEV (MEB)

Key Investments and Partnerships

RIVIAN

Invested $500 million in EV startup Rivian

SolidPower

Invested in solid-state battery startup Solid Power

Key Targets

- 40 electrified vehicles and 16 BEVs released by 2022
- Release at least one BEV in Europe using VW's MEB platform by 2023

Battery Strategy

- Ford has used LG Chem for BEV batteries, and for the upcoming Transit electric and Mustang Mach-E, LG Chem installed dedicated production lines in its Poland manufacturing facility
- Ford hasn't invested in cobalt or lithium supplies as other automakers have but does partner with IBM and its battery supply chain to use blockchain to ensure it uses responsibly sourced cobalt in its BEVs

Lux's Electric Vehicle Inflection Tracker focuses on changes in key metrics as a leading indicator of adoption

Although numerous studies suggest many consumers are open to considering a plug-in vehicle for their next purchase, today, these vehicles remain less than 5% of overall sales. Those hesitant often cite concerns like limited range, slow charging, and the higher price tag. **Lux's Electric Vehicle Inflection Tracker quantifies trends in key concerns cited by potential BEV buyers**. Specifically, we consider trends in the number of models available, average range and price, and the impact of fast charging on a BEV's ability to drive long distances.

Global BEV sales data was used from Lux's Automotive Battery Tracker. To remove high-priced outliers, we limited this analysis to models that sold more than 1,000 units per year. We also segment the data in two different ways:

- **Regional**: China remains the largest market for plug-in vehicles and has a unique BEV ecosystem where models tend to be cheaper than in other markets. In some plots, we differentiate between vehicles designed and sold exclusively in China (China-specific) and those sold globally (Global).
- **Averages**: When discussing price and range, we include averages among all vehicles available to consumers (nonweighted) as well as an average weighted by how many vehicles each model sold (weighted).

BEV INFLECTION POINTS

Price vs. range

Data Highlights:

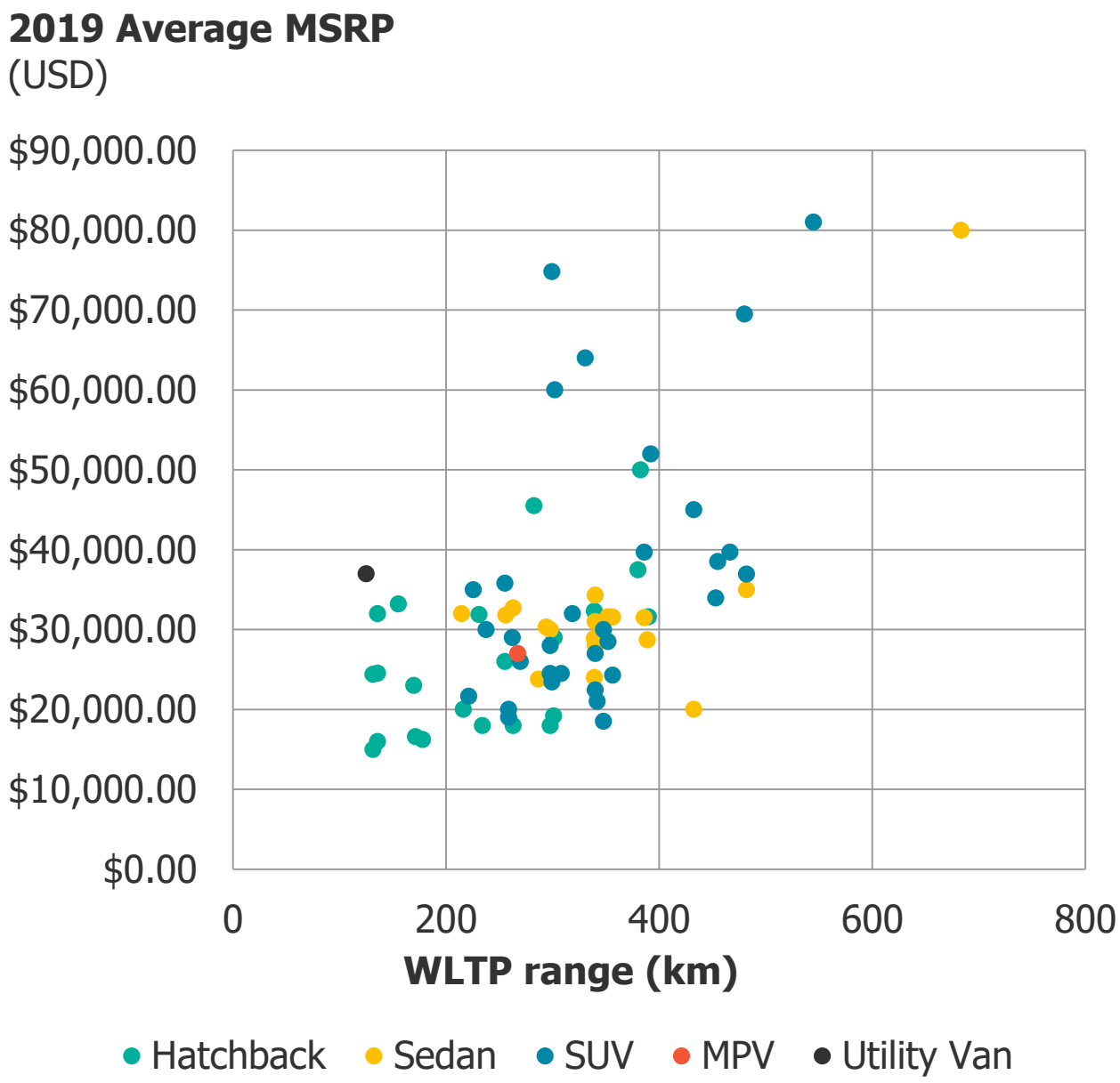
- The ten models which provide the lowest cost per range are all China-specific models, led by the GAC Aion S
- The Tesla Model S's high price tag is justified with a leading WLTP-converted range of 683 km

Additional Context:

Price and range are at the forefront of man consumers minds, in were major factors in the excitement around the Chevy Bolt and Tesla Model 3 launches. Today some automakers fare better than others in delivering long-range at a low price, something vehicles sold in China have done better than those sold globally.

Outlook:

The bottom right quadrant and upper right quadrant are expected to populate first as more automakers strive to compete with the Tesla Model 3, Nissan Leaf, and other low-cost vehicles. As automakers are expected to electrify higher-priced brands first to focus on profitability, the upper right quadrant of vehicles with both long range and higher price tags should see the most growth.



The full list of data, including specific model names, can be downloaded at the "PPT Slides & Data" tab at the top of the screen.

BEV INFLECTION POINTS

Efficiency

Data Highlights:

- The Hyundai Ioniq EV is the most efficient vehicle, requiring less than 0.1 kWh to travel 1 km, while the Audi E-tron is the least efficient passenger vehicle, requiring 0.32 kWh/km
- On average, every kWh of battery capacity adds 6.1 km of range

Additional Context:

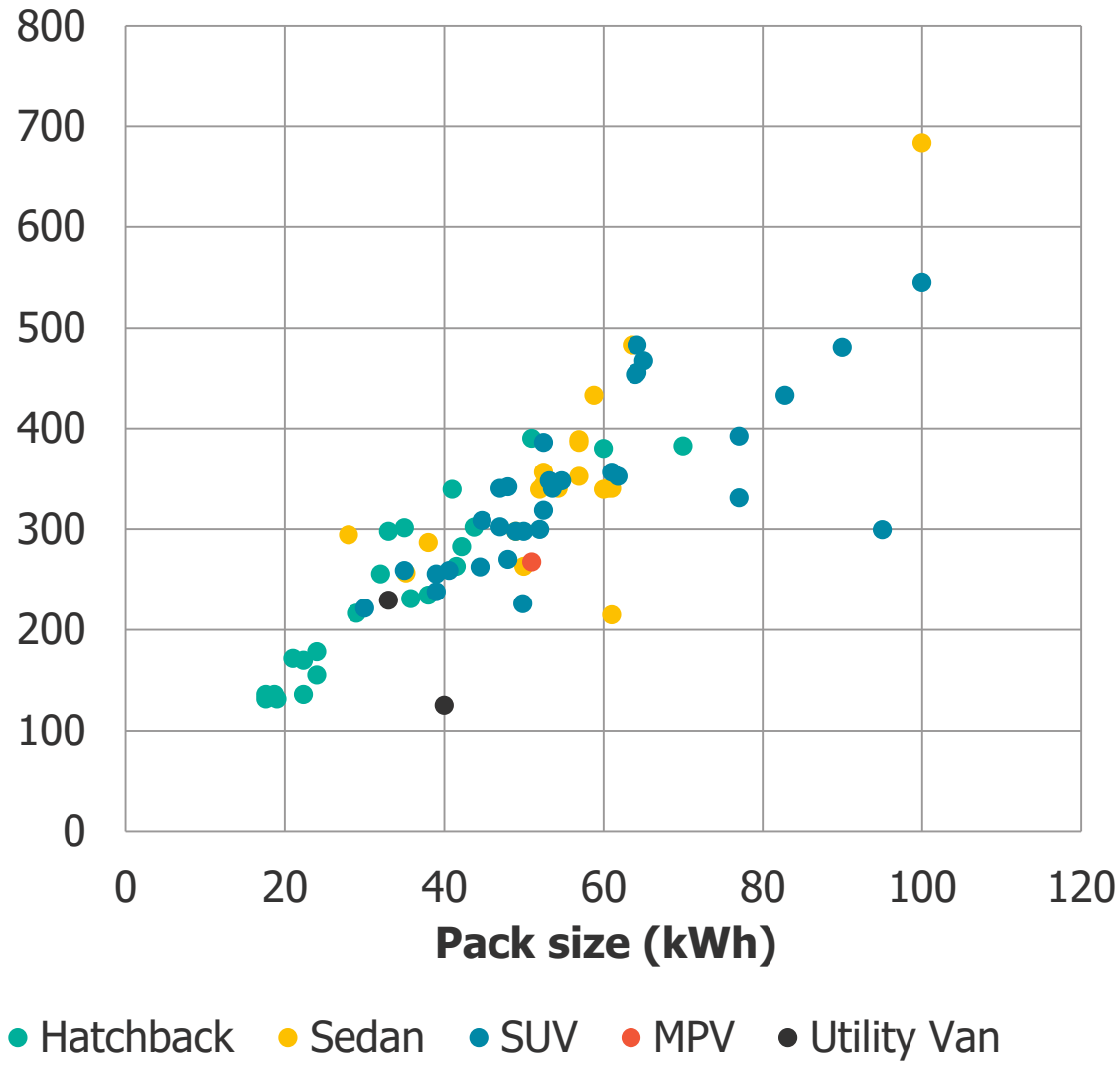
Efficiency is correlated with vehicle type, as eight of the 10 most efficient models are hatchbacks, and on average, hatchbacks are 16% more efficient than SUVs.

Outlook:

Automakers haven't placed a great emphasis on efficiency, but poor range results from Tesla competitors such as the Jaguar I-Pace, Porsche Taycan, and Audi E-tron will likely spur interest in this area. However, software updates may unlock additional range, which Audi and Jaguar have already done – increasing the usable capacity in the battery.

2019 Average WLTP range

km



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"Range anxiety" and "charge time trauma" remain significant barriers to broader EV adoption

Along with high costs, many consumers cite concerns over range and charging infrastructure as key reasons to not consider electric vehicles. These concerns usually fall into one of two categories:

- **Range anxiety**: The fear that an electric vehicle won't have enough range to complete all or most trips consumers need their vehicles to make.
- **Charge time trauma**: The concern that a vehicle will take too long to charge, potentially stranding electric vehicle users on the road for extended periods of time.

At the heart of both of these concerns is the ability to drive electric vehicles long distances. To measure this, we've modeled the time each electric vehicle model would take to travel 1,000 miles – a distance requiring multiple charging stops for most EVs and also an upper limit for how far most can travel in a day – to account for both a vehicle's range and its charging speed. To calculate this number, we make a few assumptions:

- All vehicles are assumed to travel an average of 60 mph (~97 km/h).
- BEV charging data is based on manufacturer claims, and if not available, estimated from maximum charging power and battery capacity; five minutes are added to each stop to account for time spent finding a charger and plugging it in.
- ICE vehicles are assumed to have roughly 400 miles (~644 km) per tank, and each stop lasts 15 minutes.

Efficiency will emerge as the next big focus in BEV design

To date, lowering the cost of batteries has been the primary mode of reducing BEV costs. While still a major focus, cost reductions from economics of scale are limited, and future battery price reductions are expected to slow. As automakers push for profitability, more efficient powertrains allow for more range or fewer batteries. Furthermore, improved efficiency also allows vehicles to effectively charge "faster," as each kWh added to the vehicle results in more miles of range added. This will create opportunities for innovations outside the battery cell:

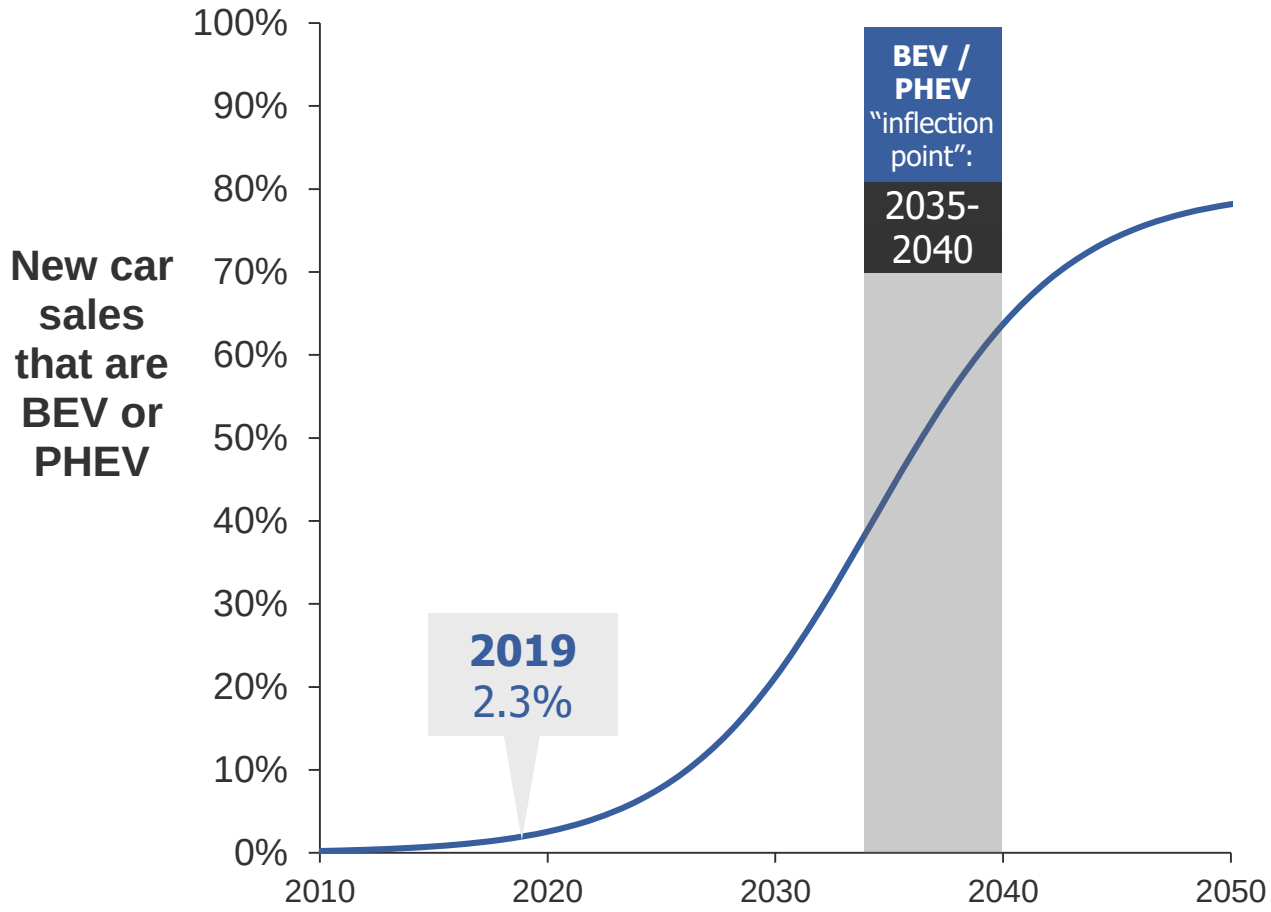
- **Electric motors:** Most electric motors are already highly efficient, but new designs that are efficient over a wider range of torque and RPM as well as promising lower costs are emerging. Startups like Magnax, Linear Labs, and C-Motive all target opportunities in mobility.
- **Battery management systems (BMS):** Many BEVs today restrict the window of usable charge to protect the battery, leaving in some cases more than 10% of the nominal battery capacity unusable. Some solutions are hardware-focused, such as Titan AES's ultrasound-based BMS, which improves the accuracy of state-of-charge measurements. Others are software-focused, such as Jaguar releasing an update to BMS software that enables a wider state-of-charge window to be used.

Despite nearly identical dimensions and battery pack size to Tesla's Model S, the Porsche Taycan provides significantly less range – 201 miles vs. 370 miles in EPA testing. This is due to a combination of only using 90% of the battery's capacity, less efficient motors, and wider tires.

Advancements in EV price and range point to the inevitable EV inflection point when PH/EV sales surpass those of ICEs

Lux makes no changes to its long-term EV forecast projecting that the electric vehicle inflection point – when plug-in vehicles (PHEV and BEV) make up more than half of vehicle sales – will occur between 2035 and 2040. While to date adoption was tracking ahead of our forecasts – in part due to strong governments subsidies and a successful aggressive ramp-up of Model 3 production – impacts from COVID-19 will likely set back adoption of plug-in vehicles along with the broader automotive market in the coming two to three years.

Over the next decade, the luxury and premium mass markets will see the biggest adoption of Evs, as that segment is tolerant of the higher costs. Competition in the lower-priced mass market is expected in the mid-2020s, when EVs are more competitive with ICE counterparts.



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