McKinsey Center for Future Mobility®

The future of mobility is at our doorstep

Compendium 2019/2020

Content

The future of mobility is at our doorstep

What mattered in the automotive and mobility markets in 2019, and what will dominate the space in 2020? We look closer at the autonomous, connected, electrified, and shared trends that matter.

The past year was a pivotal one, with many important achievements across the disruptive dimensions of mobility: autonomous driving, connectivity, electrification, and shared mobility (ACES). In 2019, electric-vehicle (EV) sales set another sales record globally, and EVs became much more prominent in the public awareness in major automotive markets, such as Europe. Many more cities have announced and already partially implemented further regulation of private-car-based mobility. Some players demonstrated truly driverless cars without backup drivers, setting new milestones in autonomous driving. Uber and Lyft—the two big disruptors in the ride-hailing space—went public in spring 2019. Also in 2019, regulators began granting approval to drone deliveries and to electric vertical takeoff and landing crafts, with these types of vehicles flying for the first time.

However, 2019 was also a year of reality checks, as congestion and public-transportation woes reached new heights for cities around the world, realization timelines for technology like autonomous vehicles (AVs) were postponed, and some new mobility business models failed to win over investors. Economically, global automakers had a tougher time in 2018 and 2019, with several headwinds: higher expenses required to meet stricter emission regulations, global trade tensions, and slowing sales in key end markets. These triggered profit warnings at several large OEMs and suppliers.

Given that key risks for the industry remain elevated and that competition from new mobility attackers is intensifying, the road ahead remains bumpy, as today's reality delivers a mixed picture for the future of mobility. On the one hand, there are big expectations with regard to future technologies and business models; on the other hand, there is an urgent need for a "double transformation." In other words, preparing companies for the mobility of tomorrow also means making today's business crisis resistant.

Please join us as we reflect upon this past year's milestones and look ahead to what we expect will be the continued momentum and additional wake-up calls that will keep on shaping the movement of people and goods going forward.

Investments across the mobility landscape

First, we see continued acceleration of investments in the relevant technologies—with e-hailing, semiconductors, and sensors for advanced driving-assistance systems and autonomous driving still being the front-runners (Exhibit 1).

Exhibit 1

Investment activities accelerated, with a few industry-shaping moves.

Total disclosed investment amount since 2010[1]

Technology cluster	**Investment,** $ billion	**Average annual investment,** $ billion **2010–13**	**2014–Feb 2019**
E-hailing	56.2	0.2	11.4
Semiconductors	38.1	0.8	7.4
AV[2] sensors and ADAS[3] components	29.9	0.6	5.6
Connectivity/ infotainment	20.8	0.6	3.9
Electric vehicles and charging	19.0	0.6	3.0
Batteries	14.3	0.8	2.1
AV software and mapping	13.5	0.3	2.3
Telematics and intelligent traffic	12.4	0.5	1.9
Back end/ cybersecurity	9.0	0.2	1.4
HMI[4] and voice recognition	7.4	1.2	0.6
Total	220.6	5.9	39.5

[1]Sample of 1,183 companies. Using selected keywords and sample start-ups, we were able to identify a set of similar companies according to text-similarity algorithms (similarity to companies' business description) used by the Competitive Landscape Analytics team.
[2]Autonomous vehicle.
[3]Advanced driver-assistance system.
[4]Human–machine interface.
Source: CapitalIQ; Pitchbook; McKinsey analysis

On a regional level, activity in the United States is strongest, but tech-intense locations, such as Israel, also play important roles in the mobility ecosystem. (Read more at "Israel: Hot spot for future mobility technologies.")

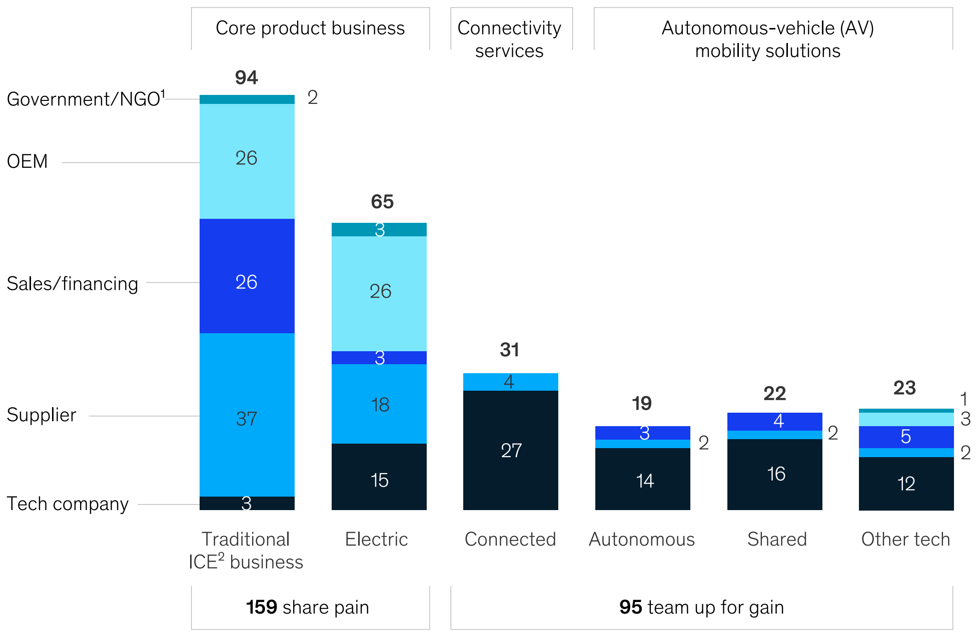
And the automotive industry actually is quickly turning into a true mobility ecosystem. OEMs have traditionally worked hand in hand with tier-one suppliers, but today, we are seeing the emergence of a broader ecosystem. This ecosystem is coalescing, as high-tech players enter the market, incumbents form new partnerships, and tier-two suppliers cut in line to offer products and services directly to OEMs, thus bypassing tier-one companies.

By our analysis, an OEM would have to invest nearly $70 billion to gain a defensible position across the critical ACES technologies. Hence, there is a renewed interest within the automotive industry for cooperation (Exhibit 2). For decades, OEMs have shared the financial burden in core areas like engine development and production. But given the challenges ahead, cooperation will become an even bigger success factor.

Exhibit 2

Two-thirds of partnerships initiated by OEMs since 2014 have focused on sharing investment burdens.

Total new OEM partnerships since 2014 by organization type, number



[1]Nongovernmental organization.
[2]Internal combustion engine.

Let us now have a look at the 2019 highlights of each of the ACES trends.

Autonomous driving

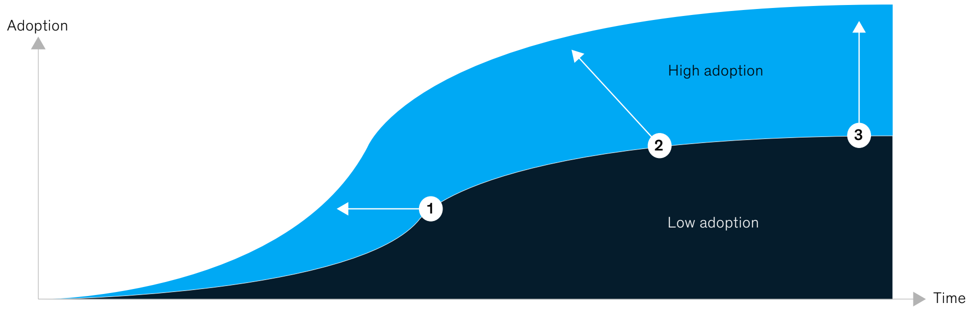
For investors, executives, and enthusiasts alike, autonomous technology and self-driving cars have long been some of the most interesting areas within the future-of-mobility space. This continues to be so. But 2019 certainly was a year in which optimistic forecasts had to be scaled back to a certain degree. Progress in AV technology was not as fast as previously anticipated; both value and premium OEMs—as well as tech players—revised their schedule for level 4 and level 5 applications, sometimes by years.

Yet the underlying logic for autonomous driving, especially in cities, remains intact. We believe electric, shared AVs—also called robo-taxis or -shuttles—could address mobility's pain points in cities (such as road congestion, crowded parking spaces, and pollution) while revolutionizing urban mobility, making it more affordable, efficient, user friendly, environment friendly, and available to everyone. If integrated seamlessly in the public-transportation system, it will be an important enabler in reducing today's share of private-car traffic (Exhibit 3).

Exhibit 3

To quantify uncertainty over autonomous mobility solutions, we created a market model based on the observation of trigger points.

Robo-taxi adoption projection over time



1. Start of commercial launch

- Will there be regulations on a national level?
- Will the key players collaborate to build robo-taxis?

Answering yes to both could lead to earlier adoption

2. Speed of adoption

- Do customers feel safe in robo-taxis and accept a potential increase in travel time?
- Are investors willing to finance robo-taxi fleets?

Answering yes could lead to earlier and greater adoption

3. Adoption in steady state

- How are robo-taxi prices compared with other means of transport?
- Will cities support or fight robo-taxis?

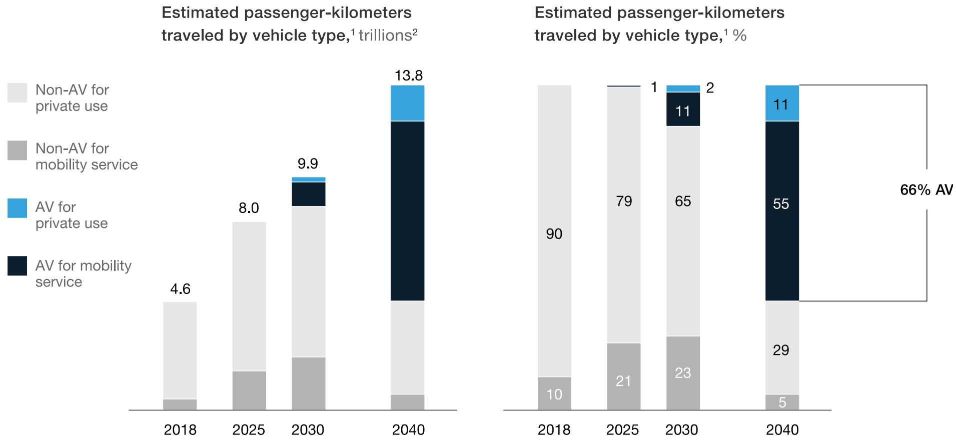
Answering yes could lead to greater adoption

As our colleagues explain in "Change vehicles: How robo-taxis and shuttles will reinvent mobility": "To reduce the levels of uncertainty surrounding shared AV mobility, the McKinsey Center for Future Mobility (MCFM) has developed a detailed and holistic model based on a thorough fact base, consumer surveys, expert estimates, and extensive discussions with relevant stakeholders."

Of the global markets for AVs, China catches the eye (Exhibit 4). It has the potential to become the world's largest market for AVs. As colleagues outlined in "How China will help fuel the revolution in autonomous vehicles," "in our base forecast, such vehicles could account for as much as 66 percent of the passenger-kilometers traveled in 2040, generating market revenue of $1.1 trillion from mobility services and $0.9 trillion from sales of autonomous vehicles by that year. In unit terms, that means autonomous vehicles will make up just over 40 percent of new vehicle sales in 2040, and 12 percent of the vehicle installed base."

Exhibit 4

Autonomous vehicles (AV) will travel about 66 percent of total passenger-kilometers in 2040.



[1]Baseline scenario.
[2]Figures may not sum, because of rounding.

While the new technologies will surely generate enormous value, no one can say where the economic profit will flow—or when.

For more, see "Development in the mobility technology ecosystem—how can 5G help?"

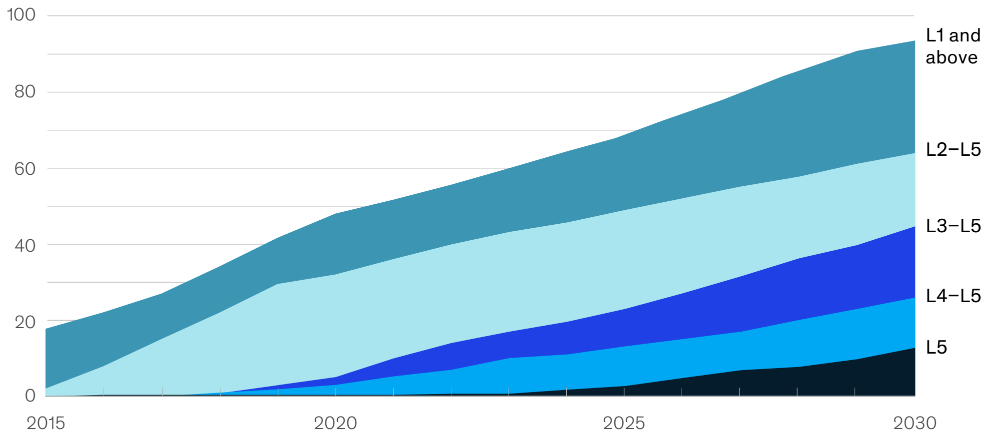
Connectivity

Connected cars are poised to become potent information platforms that not only provide better experiences for drivers but also open new avenues for businesses to create value. Conventional vehicles, once heralded as "freedom machines," will evolve into information-enveloped automobiles that offer drivers and passengers a range of novel experiences, increasingly enhanced by artificial intelligence and intuitive interfaces that far surpass today's capabilities. The key success factor for connectivity services is the clear value proposition the offering has, either to an external customer or to an internal stakeholder. It seems that this value is very often created only by combining data assets and capabilities from various partners.

As our colleagues lay out in "The trends transforming mobility's future," "we have identified five levels of connectivity, each involving incremental degrees of functionality that enrich the consumer experience, as well as a widening potential for new revenue streams, cost savings, and passenger safety and security. These levels reflect the potential for connectivity to stretch from today's increasingly common data links between individuals and the hardware of their vehicles to future offerings of preference-based personalization and live dialogue, culminating with cars functioning as virtual chauffeurs. Our research suggests that by 2030, 45 percent of new vehicles will reach the third level of connectivity [Exhibit 5], representing a value pool ranging from $450 billion to $750 billion. Our surveys also indicate that 40 percent of today's drivers would be willing to change vehicle brands for their next purchase in return for greater connectivity."

Exhibit 5

By 2030, 45 percent of global new-car sales could be at level 3 or above in connectivity.



From basic connectedness to complex experiences: The five levels of vehicle connectivity

L1

General hardware connectivity:
the driver is able to track basic vehicle usage and monitor technical status.

L2

Individual connectivity:
the driver uses her personal profile to access digital services via external digital ecosystems and platforms.

L3

Preference-based personalization:
all occupants enjoy personalized controls, their own infotainment content, and targeted contextual advertising.

L4

Multisensorial live interaction:
all occupants interact live with the vehicle and receive proactive recommendations on services and functions.

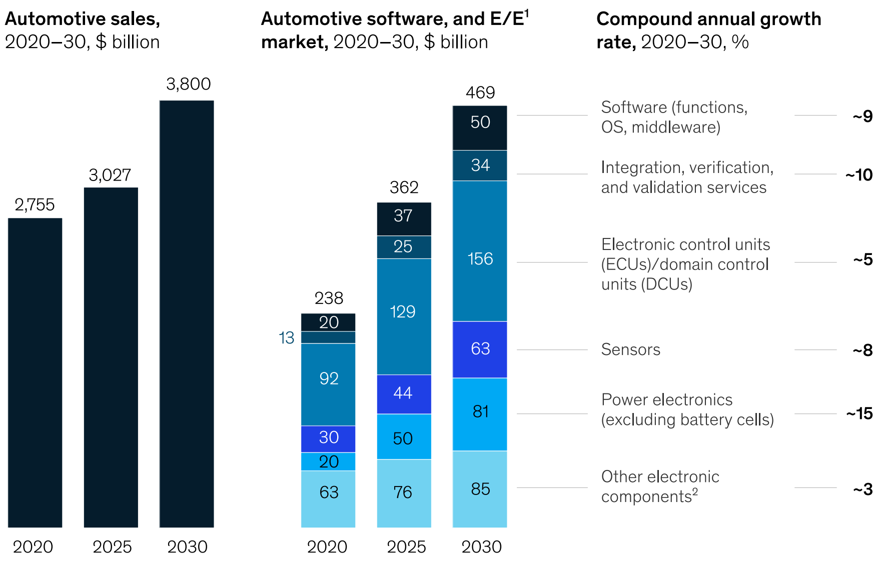
L5

Virtual chauffeur:
cognitive AI fulfills all occupants' explicit and unstated needs, predicting and performing complex, unprogrammed tasks.

Connectivity in cars is predominantly driven by the proliferation of a more centralized software and of electrical- and electronic-component architecture. As noted in "Mapping the automotive software-and-electronics landscape through 2030," this trend "will drive the market's expected expansion through 2030 (projected at a 7 percent compound annual growth rate). Significant variation is expected across the market's segments" (Exhibit 6).

Exhibit 6

The automotive electronic and software market will see a strong growth through 2030, driven by power electronics, software, ECUs, and DCUs.



Note: Figures may not sum, because of rounding.
[1]Electrical and electronic components.
[2]For example, harnesses, controls, switches, displays.
Source: IHS; McKinsey analysis

Electrification

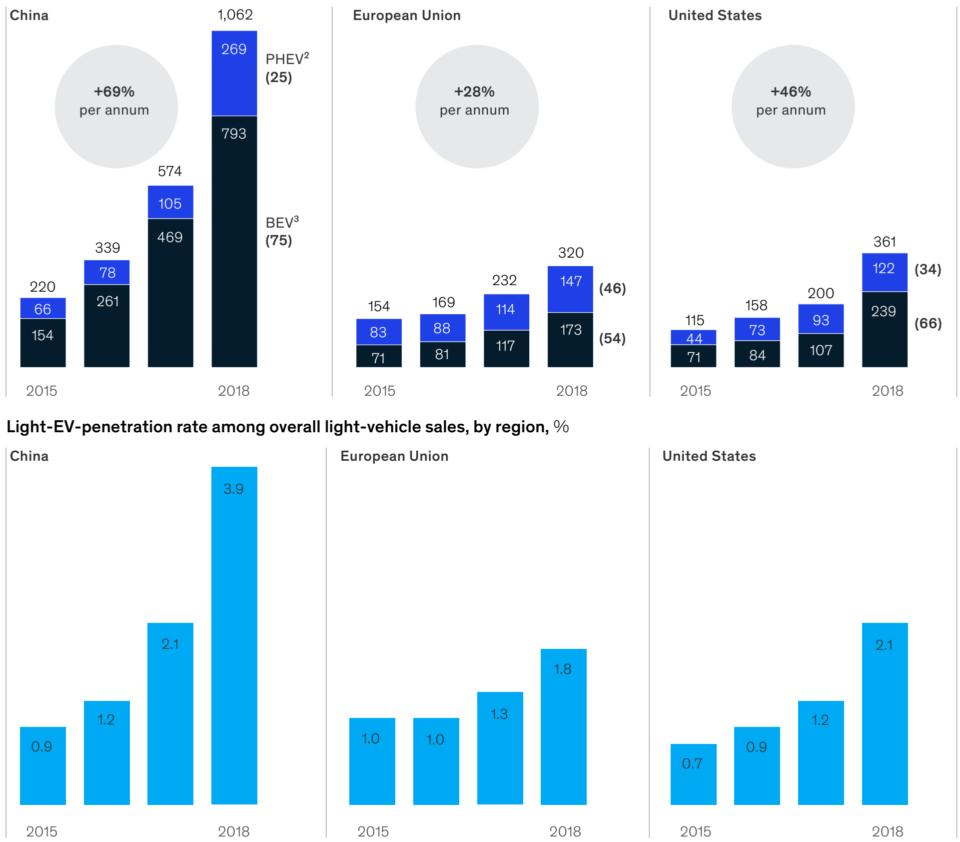
While the signals are somewhat mixed for autonomous technology, the "E" in ACES—electrification—certainly gained momentum in 2019. This development was triggered by two trends: tightening regulation—for example, in Europe—and rising customer demand.

As our colleagues explain in "Expanding electric-vehicle adoption despite early growing pains": "EV sales grew to more than two million units globally in 2018: an increase of 63 percent on a year-on-year basis, and a rate slightly higher than in prior years. Nevertheless, with a penetration rate of 2.2 percent, EVs still only represent a fraction of the overall light-vehicle market. The ratio of battery EVs (BEVs) to plug-in hybrid EVs (PHEVs) held relatively steady from 2017" (Exhibit 7).

Exhibit 7

China's electric-vehicle market is three times the size of that of Europe or the United States.

Light EV[1] sales, by region, thousand units (% share of EV market)



China:
- New models continually introduced
- Government phasing out EV-subsidy program by end of 2020
- Corporate Average Fuel Consumption and New Energy Vehicles dual-credit scheme applies as of 2019

European Union:
- Competitive premium-EV models launched
- New CO_2-emission targets for 2025 and 2030
- Transition from New European Driving Cycle to Worldwide Harmonized Light Vehicle Test Procedure

United States:
- Tesla Model 3 production scaled up
- Emission targets most likely relaxed until 2025
- New-model launches by key US brands

Note: Figures may not sum, because of rounding.

[1] Electric vehicle. [2] Plug-in hybrid electric vehicle. [3] Battery electric vehicle..

Source: EV-Volumes.com; McKinsey analysis

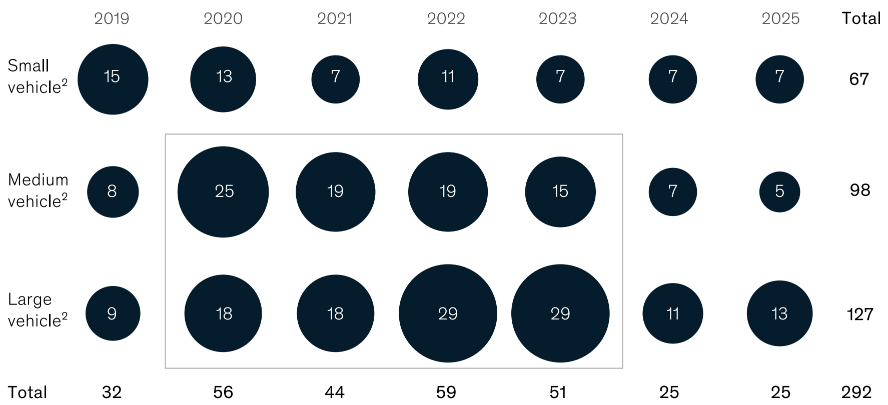
Projections for Europe indicate that automakers would need to sell up to 2.2 million EV units in 2021 alone to meet their fleet CO2 targets. That would be a steep ramp-up of EV sales in fewer than two years and equivalent to global EV sales in 2018. This is a big task not only for the automotive industry but also for adjacent industries. To power two million new vehicles, Europe would need the equivalent of about four gigafactories for the battery supply—and the additional raw materials. To meet charging demand, 300,000 to 400,000 public charging stations would be required.

As observed in How automakers can master new mobility, "OEMs are therefore moving quickly: to meet both regulator and customer demand, OEMs are significantly ramping up their battery electric vehicle (BEV) portfolios. Incumbent OEMs will bring more than 300 new BEV models to market by 2025" (Exhibit 8).

Exhibit 8

Incumbent OEMs will launch around 300 new battery-electric vehicles (BEV) by 2025, with a strong focus on medium and large vehicles.

BEV launches[1] by production start date, and vehicle size



New CO_2 targets by region, grams of CO_2 per km

[1]Includes US, European, Japanese, and South Korean OEMs.
[2]Small = A/B segment, medium = C segment, large = D/E segment.
[3]Phase-in from 2020 for 95% of fleet.
Source: IHS Automotive (July 2019)

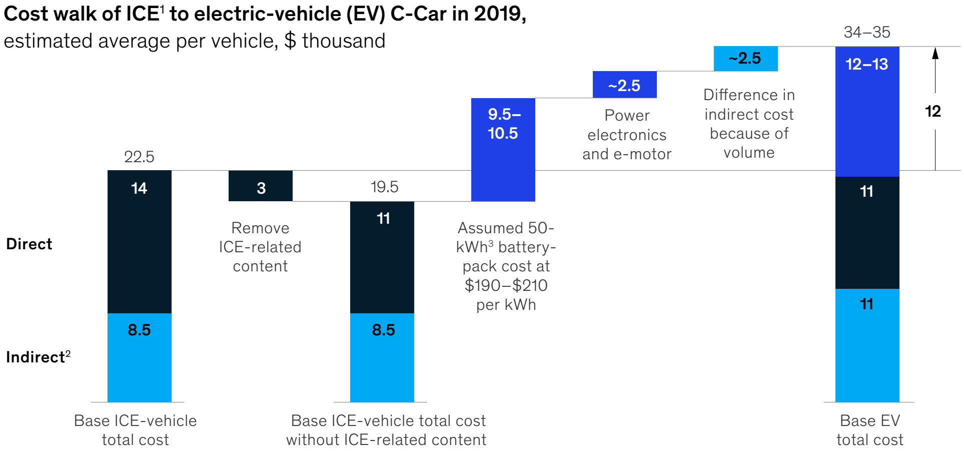
The challenge of making EVs profitable remains, but OEMs and their suppliers are working hard to address it successfully.

Advancements in battery technology, economies of scale in EV production, native EV design, and cooperation among OEMs can help bring down costs—which are currently still higher than for comparable internal-combustion-engine (ICE) vehicles (Exhibit 9).

Exhibit 9

There's a cost gap of about $12,000 between electric vehicles and internal-combustion-engine vehicles today

Cost walk of ICE[1] to electric-vehicle (EV) C-Car in 2019, estimated average per vehicle, $ thousand



[1]Internal combustion engine.
[2]Includes average incentive cost of $2,000.
[3]Kilowatt-hour; includes battery-management system.
Source: Industry experts; UBS; McKinsey analysis

For more, see "Making electric vehicles profitable."

The battery is by far the most valuable part of an electric car. With demand rising, players across the value chain need to scale up sustainable battery production. Across uses, from EVs to backup power generation—not to mention mobile phones and other consumer products—we estimate that current momentum will increase battery demand 14-fold between now and 2030. In a more optimistic target case (with even lower battery costs), the increase could even be 19-fold.

Read more in our joint article with the Global Battery Alliance and World Economic Forum, "Three ways batteries could power change in the world."

Shared mobility

As in the other dimensions of future mobility, we see divided areas within shared or smart mobility as well. No doubt, mobility—especially in cities—needs to become smarter to become sustainable (again). Cities need to combine multiple modes of transport—including private cars, public transport, robo-taxis, robo-shuttles, micromobility, cycling, and walking—into integrated transport systems in order to fight congestion and pollution and hence increase quality of life.

In this respect, 2019 certainly has been the year of many cities' announcements of their future mobility visions, including micromobility. With micromobility being a nascent market in Europe, many start-ups introduced shared e-scooters in European cities.

As our colleagues shared in "Micromobility's 15,000-mile checkup," "our base-case estimate of the shared micromobility market across China, the European Union, and the United States is … $300 billion to $500 billion in 2030 [Exhibit 10]. To put that into perspective, it equals about a quarter of our forecasted global shared autonomous-driving market potential of roughly $1,600 billion in 2030."

In the United States, the growth of e-hailing services certainly brought challenges, such as congestion. E-hailing is already having a major impact on cities and suburban areas. "Ridesharing is not simply a substitute for traditional modes of automobile transportation, such as personal vehicles, taxis, and rental cars," as our colleagues laid out in "How sharing the road is likely to transform American mobility." "On the contrary, fully one-half of all ridesharing trips would not have been taken but for ridesharing [Exhibit 11]. In the face of such challenges, some cities are taking aggressive action, including capping total hailing licenses and setting wage floors for drivers."

Exhibit 10

The shared micromobility market in China, Europe, and the United States could reach $300 billion to $500 billion by 2030.

Estimated size of micromobility market, by region, in 2030, $ billion

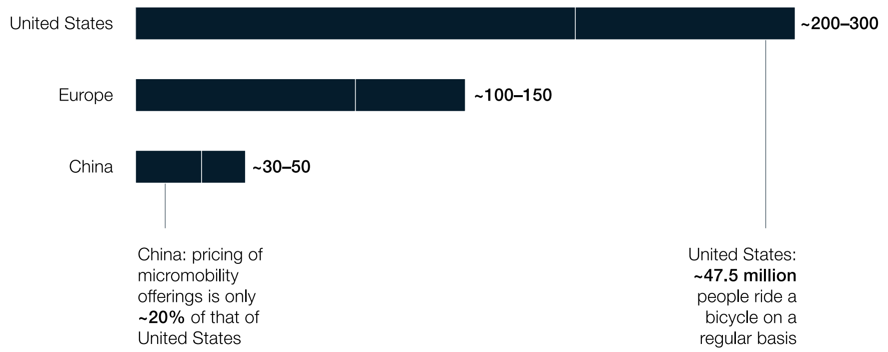
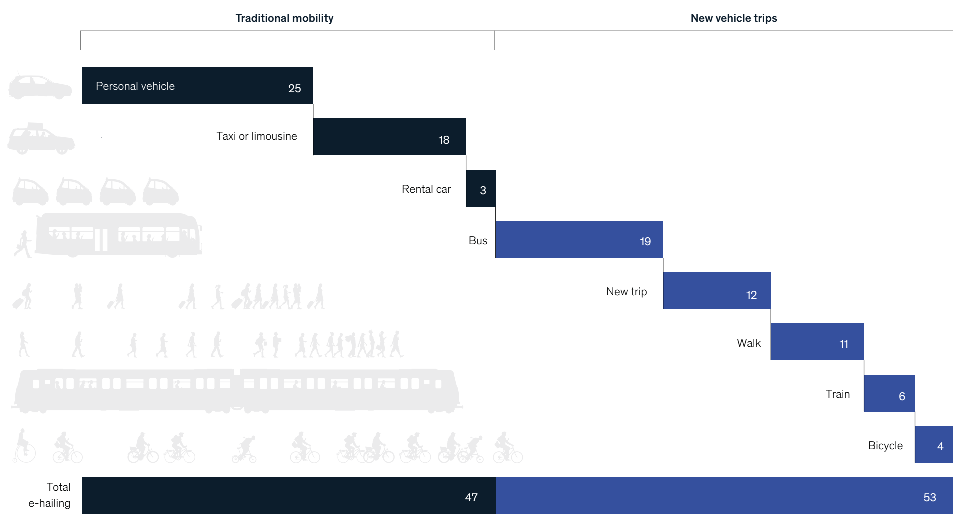


Exhibit 11

More than half of e-hailing trips are new passenger-vehicle miles, causing public concerns over growth in traffic and congestion.

E-hailing growth sources, % of trips that would have been taken by alternative mode of transport



Note: Figures may not sum to 100%, because of rounding.
Source: US Department of Transportation; McKinsey analysis

The 2020 outlook

One thing that is certain is the fast-changing world of future mobility. We do expect that 2020 will be at least as interesting as 2019 along several dimensions:

— Consumers. As CO2 regulations in Europe kick in next year and more EVs need to be pushed onto the road, 2020 will be an important year to measure the reinforcing power of electrification. Early adopters love their EVs, but will followers as well? Will OEMs and their suppliers manage to make their EV supply chains as efficient, robust, and sustainable as those of their conventional vehicles? And will the charging infrastructure keep pace with the growing EV demand? Not to forget: How will automakers and suppliers manage to smooth the transition of their workforces and investments from an ICE world to one with partially or fully electric power trains?

— Technology. Might 2020 be the year in which more attention is given to the transport of goods? The commercial-mobility segment could catalyze some noteworthy developments. The first of two examples here is autonomous driving in the context of shared mobility. Specifically, the replacement of the driver cost is a significant element of the total cost of ownership. Hence, we see significant activity from established players and start-ups in order to make this happen. The second example is alternative power trains. With close to 20 countries now having announced national road maps for hydrogen and major investments announced across industries—including in the heavy-duty, long-distance transport sector—the fuel-cell technology begins to become a more feasible alternative.

— Market and competition. 2020 will be characterized as the year of the intensifying "double mobility transformation," with players operating in an economic slowdown but, at the same time, needing to rethink their business models in a time of heightened city regulation, technology disruptions, and changing consumer needs. How will the financial market look at industry players? It's a broad range, from the discounted OEMs on one end to the celebrated tech players on the other. For more, see "Down but not out: How automakers can create value in an uncertain future."

— The growing role of regulation. For many players and for many technologies, cities will be the most important stakeholders. From "sticks" (such as parking fees, low- or no-emission zones, and city tolls) to "carrots" (such as piloting new robo-taxi or -shuttle service-mobility solutions), it will be cities where the future of mobility will be decided. And 2020 will likely see bold announcements by cities to change their mobility systems.

Timo Möller is a partner in McKinsey's Cologne office, **Asutosh Padhi** is a senior partner in the Chicago office, **Dickon Pinner** is a senior partner in the San Francisco office, and **Andreas Tschiesner** is a senior partner in the Munich office. The authors are members of the McKinsey Center for Future Mobility.

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Compendium

Start me up: Where mobility investments are going

Our latest mobility start-up and investment tally shows the industry invested $120 billion in the last 24 months as it prepares for the years to come.

March 2019

by Daniel Holland-Letz, Benedikt Kloss, Matthias Kässer, and Thibaut Müller

The automotive industry is shifting into gear as a broader definition of mobility takes hold. Driven by the four ACES trends—autonomous driving, connected cars, electrified vehicles, and smart mobility—automotive OEMs, suppliers, and new entrants such as tech players and venture capitalists are attempting to build strongholds in the emerging mobility ecosystem.

We estimate that securing a strong position across all four areas would cost a single player an estimated $70 billion through 2030. It's doubtful any individual OEM could shoulder this level of investment alone, which is why partnerships and targeted acquisitions offer an attractive strategy for staying ahead of competitors.

Investments continue to grow strongly

Investments in new mobility start-ups have increased significantly (Exhibit 1). Since 2010, investors have poured $220 billion into more than 1,100 companies across ten technology clusters. Investors invested the first $100 billion of these funds by mid-2016 and the rest thereafter. For this update on our Start-up and Investment Landscape Analysis (SILA) report, we have broadened our definitions, refined the analysis, and fine-tuned our approach (see sidebar, "Methodology," for more on what's changed since our first article).

Exhibit 1

Analysis on the mobility start-up and investment landscape shows activities across ten clusters.

One measure of how dramatically investments have grown involves a comparison of the periods 2010–13 and 2014–18, when average investments across all technologies jumped sevenfold (Exhibit 2). Our analysis reveals that more than half of the investment volume comes from large investments with transaction values greater than $1 billion—these are industry-shaping moves and include the mergers and acquisitions (M&A) of established companies.

Exhibit 2

Investment activities accelerated, with a few industry-shaping moves.

Total disclosed investment amount since 2010[1]

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[2]Autonomous vehicle.
[3]Advanced driver-assistance system.
[4]Human–machine interface.
Source: CapitalIQ; Pitchbook; McKinsey analysis

Another clear trend is the tech-company challenge to incumbent automotive players on mobility: these nonautomotive players, together with venture capitalists and private-equity firms, are responsible for over 90 percent of the investments in the mobility space.

Furthermore, we identified another strong acceleration of investments in e-hailing players, mainly driven by large investments in top players. This indicates that investors expect a high return on investment. These investments, however, need to be seen in conjunction with those in autonomous driving (with a number of players active in both areas). Autonomous driving can be seen as the endgame of e-hailing, potentially also being the road to (greater) profitability of these solutions.

We also noted several other investment highlights in 2018. For instance, the latest transactions involving Cruise, the autonomous-driving unit of General Motors, reveal a post-money valuation (a company's value after it adds capital contributions and outside financing to its balance sheet) of $14.6 billion. That alone is responsible for roughly a third of GM's overall valuation on the public market.

What's more, Cruise and Honda are collaborating on a purpose-built autonomous vehicle. Honda will devote $2 billion to the effort over 12 years and make an additional $750 million equity investment in Cruise. In May 2018, SoftBank Vision Fund made a $2.25 billion investment in Cruise, split into $900 million at closing and $1.35 billion when GM is ready to deploy its autonomous cars for commercial use. Furthermore, SoftBank invested an additional $0.94 billion in Nuro.ai.

But autonomous-driving firms were not the only ones to collect significant funds: Grab, a Southeast Asian ride-hailing service, received $2 billion in new capital from investors including Toyota, which contributed $1 billion, and SoftBank, which invested $500 million. Grab's current value is north of $10 billion.

What's new in the past 12 months—a few highlights

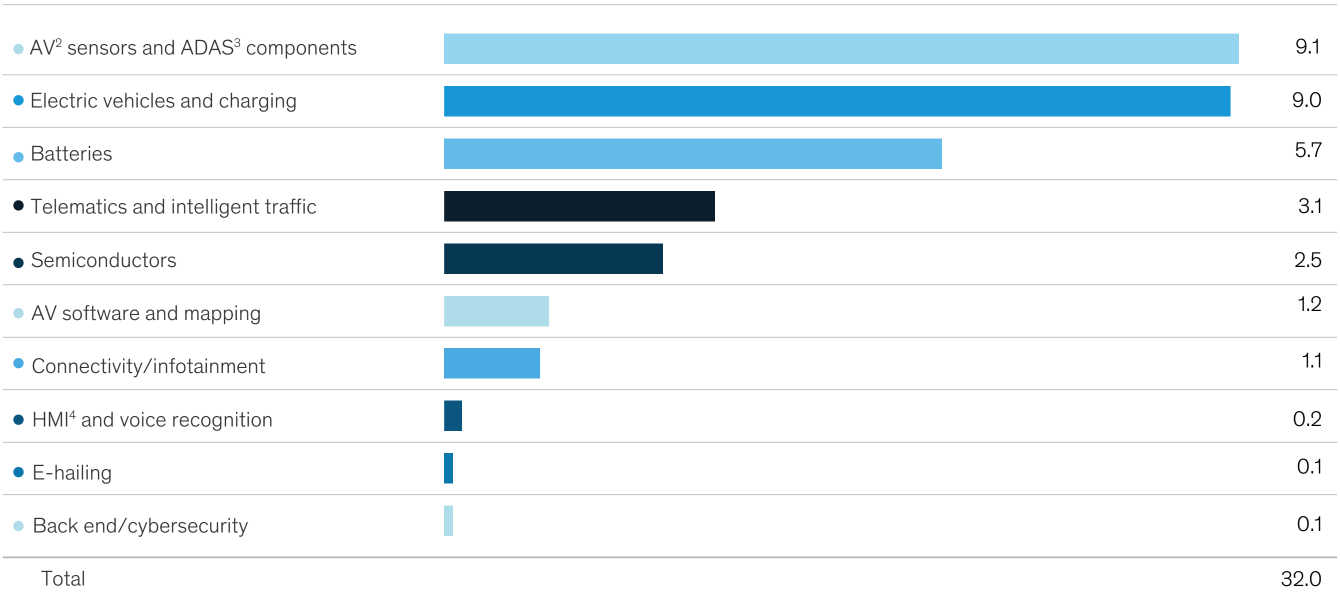
Beyond the overarching development, we have built on our existing analysis to deepen it in selected areas, for instance, considering patent activity, shared micromobility, the rising cost of technology, regional expansion, and other topics.

— Patent activity favors incumbents. In addition to investments, which offer one lens on mobility-market dynamics but do not capture internal company outlays, we also examined technology patents along the ACES clusters (Exhibit 3). We found that battery and charging technologies account for about half of the relevant patents issued but only 20 percent of company investments. That probably means many large companies do this work in-house via their own research departments. Comparatively, e-hailing services show the lowest number of patents issued, likely because differentiation in this cluster is driven more by network effects and less by technology. Traditional automotive players make up less than 10 percent of all investments but issue about 85 percent of relevant patents—an indication they invest more in internal research and development than in inorganic growth.

Exhibit 3

Analyzing patents offers another lens on market dynamics.

Total number of patents since 2010,[1] thousand



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Source: CapitalIQ; Pitchbook; McKinsey analysis

— Shared micromobility debuts. Micromobility companies[1] increased their investments by a factor of more than five from 2014 to 2018. Total investments now significantly exceed $1 billion, with an average investment of about $100 million per transaction in 2018. That's comparable to the combined investments in telematics, intelligent traffic systems, and the peer-to-peer space, although the average investment amount is two to three times as high. This investment intensity could support a view that sees it as a supplement to the future e-hailing market (among others), driven by the transition from station-based vehicle sharing to free-floating services.

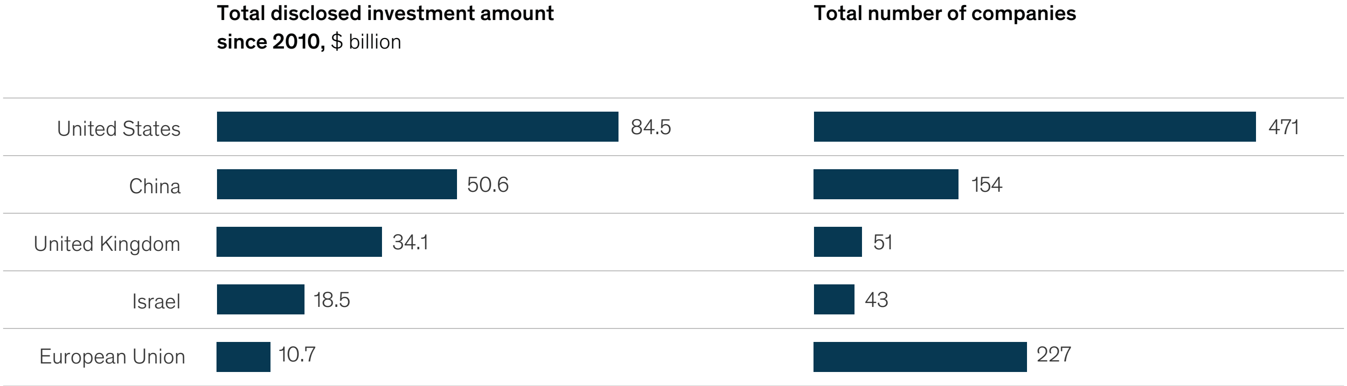
— Technology is becoming more expensive. The median investment amount for relatively smaller deals (less than $100 million investment volume) has increased two- to threefold since 2013, suggesting that the average cost of technology increased in recent years. This could indicate a maturing of the technology toward industrialization and deployment, as well as an overall increase in the cost of participating in the race for ACES technology.

[1] We define shared micromobility as including electric bikes (e-bikes), scooters (e-scooters), and mopeds (e-mopeds).

— **The regional split is lopsided.** Over a third of the overall investment in mobility went to companies in the United States, followed by China ($51 billion), the United Kingdom ($34 billion), and Israel ($18.5 billion, where $17.4 billion comes from investments into Mobileye). The next-highest European country is France, in tenth position. Even though the European Union (EU), excluding the United Kingdom, receives only 5 percent of global funding, it contains 19 percent of all identified companies (Exhibit 4). Thus, average investment sums in Europe remain far behind those in the United States and China. This breakdown is similar when looking at the source of money as opposed to the recipients: the top investors come from the United States, Japan, and China, while the largest investor in the European Union is Germany, at only $4 billion.

Exhibit 4

Investments show regional variations, with the greatest activity in China, the United Kingdom, and the United States.



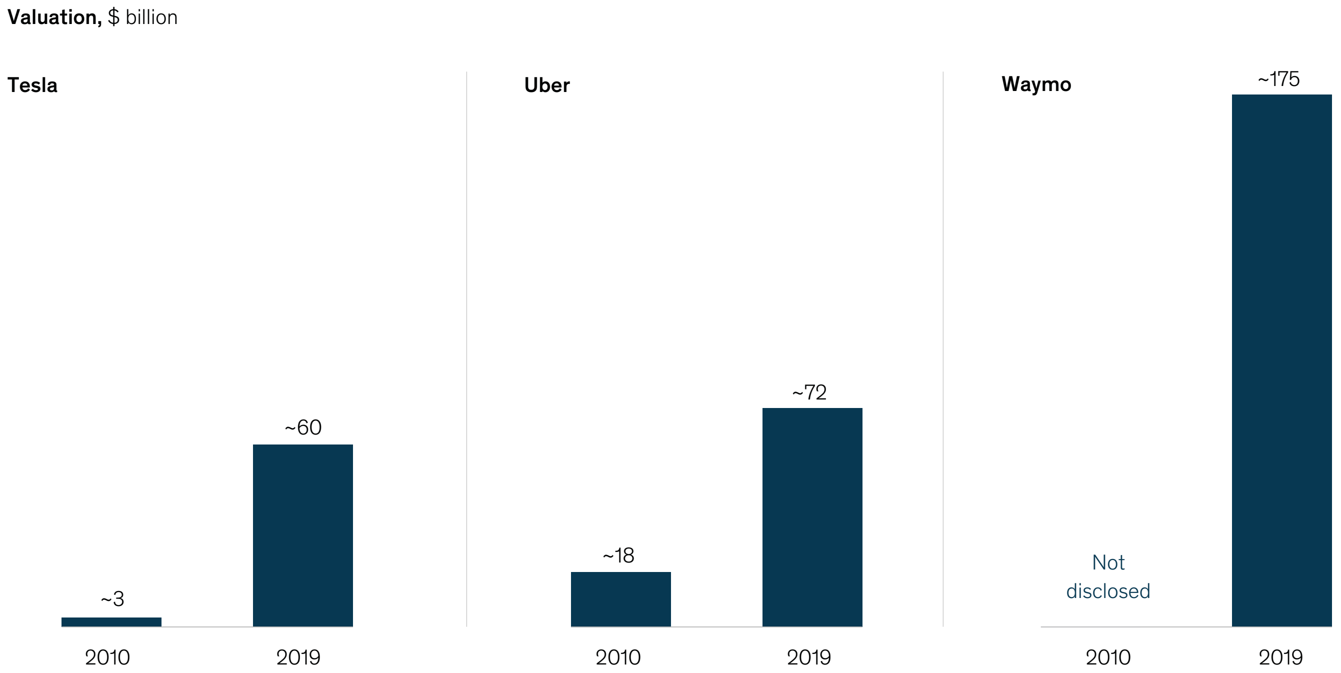
Source: CapitalIQ; Pitchbook; Cipher; McKinsey analysis

— **SoftBank is heavily invested.** Japanese tech player SoftBank has invested about $30 billion in automotive ACES trends to date, with a focus on autonomous driving and e-hailing. With its recent investment in Cruise and Nuro.ai, SoftBank now has a stake of more than $9 billion in autonomous driving, making it a strong player in the mobility space. An additional $30 billion has been invested in the semiconductor business, with significant exposure to future-of-mobility topics, in particular the hardware to bring about autonomous driving.

— **Tech-company valuations outpace incumbents.** Comparing today's valuations to those of 2010 shows the total market capitalization of traditional OEMs decreased by more than 10 percent. Meanwhile, tech players in the automotive space—such as Tesla, Uber, and Waymo—increased strongly and are now even higher than the valuations of traditional OEMs (Exhibit 5). Uber's recent valuation of more than $70 billion makes it more valuable than traditional premium OEMs such as BMW or Daimler. And although traditional OEM invest less in inorganic moves, they still hold a strong position in the ACES trends based on their patents and massive R&D expenses.

Exhibit 5

New mobility providers valuation has risen tremendously.



Follow the money! As the mobility transformation gathers momentum, investors are clearly targeting the four ACES trends—autonomous driving, connectivity, electrification, and smart mobility—thus providing a concrete measure of the scale and scope of change on the horizon. Our analysis also shows that tech players are significantly more active in external technology investments than established automotive players, who have traditionally made most of their technology investments in-house.

Daniel Holland-Letz is an analyst in McKinsey's Munich office, where **Matthias Kässer** is a partner; **Benedikt Kloss** is a consultant in the Frankfurt office; and **Thibaut Müller** is an associate partner in the Geneva office.

The authors wish to thank Timo Möller and Andreas Tschiesner for their contributions to this article.

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Methodology

This study reflects findings from our 2019 update of McKinsey's analysis of the mobility start-up and investment landscape; see earlier analysis in our 2017 article, "Analyzing start-up and investment trends in the mobility ecosystem." We have analyzed the investment landscape since 2010 along the four ACES trends: autonomous driving, connectivity, electrification, and smart mobility.

McKinsey's SILA tool reveals areas with the largest investment activity by using big data algorithms and semantic analytics. It leverages inputs from comprehensive private and venture-capital investment databases covering about two million companies. Furthermore, it analyzes developments over time and across geographies, and identifies implicit technological similarities among organizations. SILA displays output at the level of single investments or at an aggregated company view. Analysts can also tailor it to include analysis of specific technologies, use cases, subsets of companies, or types of companies.

How automakers can master new mobility

The European automotive industry finds itself in a changing market that is showing signs of slowing down. How can OEMs scale up emobility at the same time?

September 2019

by Matthias Kässer , Friedrich Kley, Timo Möller , Patrick Schaufuss, and Andreas Tschiesner

For several years now, the European automotive industry has found itself in the midst of a disruption. While the business model of producing and selling cars with combustion engines has been very stable for decades, automakers now face technological challenges such as the ACES trends (autonomous, connected, electric, and shared mobility), demand that's shifting toward Asia, changing business models (vehicle sharing instead of ownership), and increasing instability caused by geopolitical and trade tensions. How can automakers cope with these challenges and master the new mobility world? By examining the current economic cycle, emerging technologies such as e-mobility, and the changing competitive landscape that's moving from value chains to ecosystems, this publication aims to give a set of perspectives on how to navigate this future that's more uncertain than ever.

Speed bumps ahead

After billing record years regarding both revenues and profits, the automotive industry is now facing an economic headwind (Exhibit 1). Margins are eroding, and many players issued profit warnings for 2018 and 2019. Many of the challenges facing the traditional value chain are short term, but others will require a long-term focus.

In the short term, geopolitical and macroeconomic risks certainly play an important role. Tensions in the international trade system and factors such as Brexit signal a high degree of uncertainty for the industry. At the same time, long-time boom markets such as China are showing the first signs of saturation. In Europe, the looming carbon dioxide (CO_2) penalties plus the cost for meeting stricter Worldwide Harmonized Light Vehicle Test Procedure (WLTP) standards challenge automakers, accompanied by more traditional factors such as intensifying competition, and new market entrants.

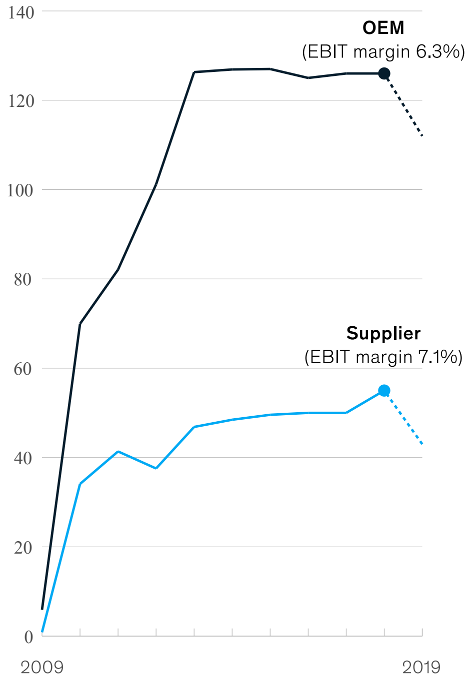
In the longer term, automakers need to invest in new technologies such as autonomous driving, connectivity, electrification, and shared mobility—while also mastering advanced manufacturing and materials.

On top of that, the needs and objectives of regulators (nine European countries have discussed restricting internal combustion engines by 2030) and certain customer groups (those who favor mobility services over car ownership) are harder to meet.

Exhibit 1

The automotive profit pool was at record levels over the last six years—but there is potential risk of a 'perfect storm' ahead.

Global automotive supplier and OEM[1] EBIT[2] operating profit, $ billion



Challenges to the traditional value chain

SHORT TERM

Geopolitical and macroeconomic risks: Trade wars, Brexit, market saturation, customs duties

CO_2 penalties/WLTP[3]: CO_2 fleet penalties, necessary electric-vehicle ramp-up cost of new WLTP standards

Classic automotive drivers: Segment shifts, aftermarket, competitive intensity, new market entrants

MID- TO LONG TERM

Investment in new technologies: ACES[4] trends, advanced manufacturing, advanced materials

Regulation: Internal combustion engine ban, increasingly tighter CO_2 regulations, city access restrictions

Changing customer needs: From car ownership to mobility services, digital branding

[1]Original equipment manufacturer. Includes top 21 OEMs and top 75 suppliers.
[2]Earnings before interest and taxes.
[3]World harmonized light-duty vehicles test procedure.
[4]Autonomous driving, connectivity, electrification, and shared mobility.
Source: US Federal Highway Administration; McKinsey analysis

Challenges create opportunities

The challenges are significant on many levels. Economy-wise, trade tensions could reduce world GDP by about 0.5 percent. Within the automotive industry, making electric vehicles (EVs)[1] profitable remains difficult: only higher-priced premium vehicles deliver positive contribution margins. At the same time, a single automaker would need to invest at least $70 billion over next 10 years in ACES trends to build a strong position in all trends (Exhibit 2).

Exhibit 2

While the challenges are significant, they in turn provide great opportunities for players to conquer new markets and further reduce costs.

Challenges to the existing business model

Geopolitical and macroeconomic risks

–0.5

percentage-point reduction in world GDP from trade wars (25% tariffs on all bilateral trade)

Near-term electric-vehicle business case at risk

<0%

contribution margin on battery-electric vehicles (BEV)

Investments in new technologies

>$70 billion

investment into ACES[1] required by OEM,[2] calling for "burden sharing"

Challenges to the existing business model that open up opportunities

CO_2 penalties

>€15 billion

penalty payments in Europe in 2021 with EV ramp-up in base-case scenario

Changing customer needs

40%

of customers willing to change brands for digital and connected services

Regulation

9 countries

in Europe discussing the ban of internal-combustion engines (ICE) by 2030

New opportunities

Emerging revenue pools

>$2.5 trillion

new market volume emerging in service and mobility businesses by 2030

Artificial intelligence (AI) opening new horizons for cost efficiency

4–19%

bottom-line optimization potential from AI across value-chain steps

Asia

>40%

of 2030 revenue pools in Asia

[1]Autonomous driving, connectivity, electrification, and shared mobility.
[2]Original equipment manufacturer.

A double-edged sword

Projections for Europe indicate that automakers would need to sell up to 2.2 million EV units in 2021 alone to meet their fleet CO_2 targets (Exhibit 3). This is a steep ramp-up of EV sales in less than two years and equivalent to global EV sales in 2018.

This is a big task not only for the automotive industry, but also for adjacent industries. To power two million new vehicles, Europe would need the equivalent of about four gigafactories for the battery supply—and the additional raw materials. To meet charging demands, 300,000 to 400,000 public charging stations would be required.

Exhibit 3

Incumbent OEMs will launch around 300 new battery-electric vehicles (BEV) by 2025, with a strong focus on medium and large vehicles.

BEV launches[1] by production start date, and vehicle size

	2019	2020	2021	2022	2023	2024	2025	Total
Small vehicle[2]	15	13	7	11	7	7	7	67
Medium vehicle[2]	8	25	19	19	15	7	5	98
Large vehicle[2]	9	18	18	29	29	11	13	127
Total	32	56	44	59	51	25	25	292

New CO_2 targets by region, grams of CO_2 per km

95	117	121
Europe[3]	China	California

[1]Includes US, European, Japanese, and South Korean OEMs.
[2]Small = A/B segment, medium = C segment, large = D/E segment.
[3]Phase-in from 2020 for 95% of fleet.
Source: IHS Automotive (July 2019)

Revving up e-mobility

OEMs are therefore moving quickly: to meet both regulator and customer demand, OEMs are significantly ramping up their battery electric vehicle (BEV) portfolios. Incumbent OEMs will bring more than 300 new BEV models to market by 2025 (Exhibit 4).

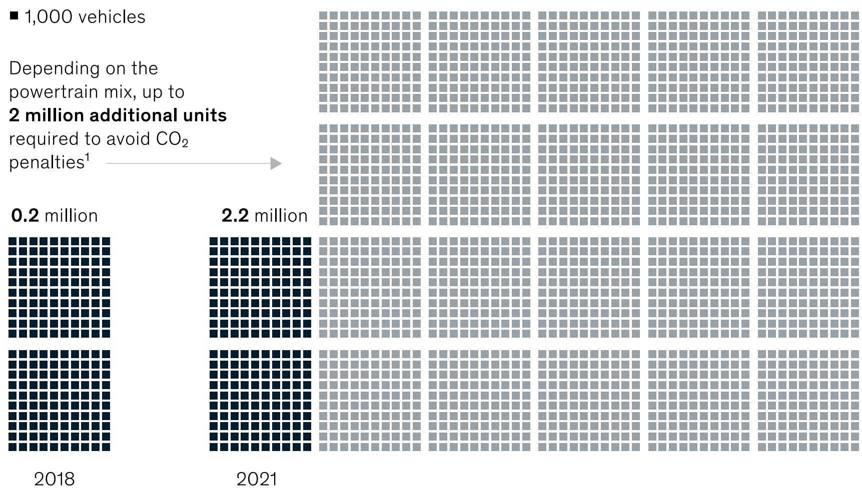
As the business case is more attractive, OEMs are focusing on large and medium-sized cars for the coming years. This is understandable from an economic point of view but will not necessarily help OEMs meet CO_2 targets at scale, as the price point is still too high for many consumers.

Advancements in battery technology, economies of scale in EV production, native EV design, and cooperation between OEMs can help bring down costs.

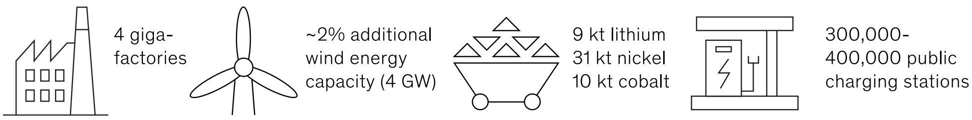
Exhibit 4

European automakers must sell an additional two million electric cars in 2021 to avoid CO_2 penalties.

Battery-electric vehicle (BEV)/plug-in hybrid electric vehicle (PHEV) sales in Europe



Prerequisites for successfully building up the e-ecosystem



[1]Assuming a constant overall sales volume of 15.2 million passenger cars and a stable gasoline/diesel share and ratio until 2021; BEV/PHEV share of 1:1 assumed.
Source: EEA; Bernstein; McKinsey analyis

Demand is rising

Consumers are already inclined to buy BEVs or plug-in hybrid EVs (PHEVs). China leads the pack, with 86 percent of Chinese consumers considering buying such cars. German consumers are at 64 percent. While American consumers still tend toward traditional vehicles, more than half—51 percent—now consider EVs when purchasing a new vehicle.

And the EV experience is extremely positive: more than nine out of ten current EV owners consider an EV for their next car as well.

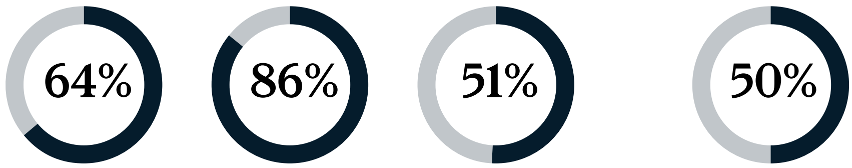
However, infrastructure needs to grow in line with growing EV demand. Fifty percent of potential BEV buyers are concerned about limited range or access to charging stations. Moreover, the EV supply chain is still shaky—EVs currently have very long delivery times (Exhibit 5).

Exhibit 5

Better infrastructure will convert many consumers to electric vehicles.

Considering purchasing

Concerns



BEV[1]/PHEV[2] consideration rate in **Germany**

BEV/PHEV consideration rate in **China**

BEV/PHEV consideration rate in **United States**

of potential BEV buyers are concerned about access to **charging stations** or **limited range**

Repurchasing

>9 out of 10

current BEV owners consider BEVs for their next car purchase

Supply

~770,000

unit backlog for Tesla models as of 2019

[1]Battery-electric vehicle.
[2]Plug-in hybrid electric vehicle.

New powertrain players

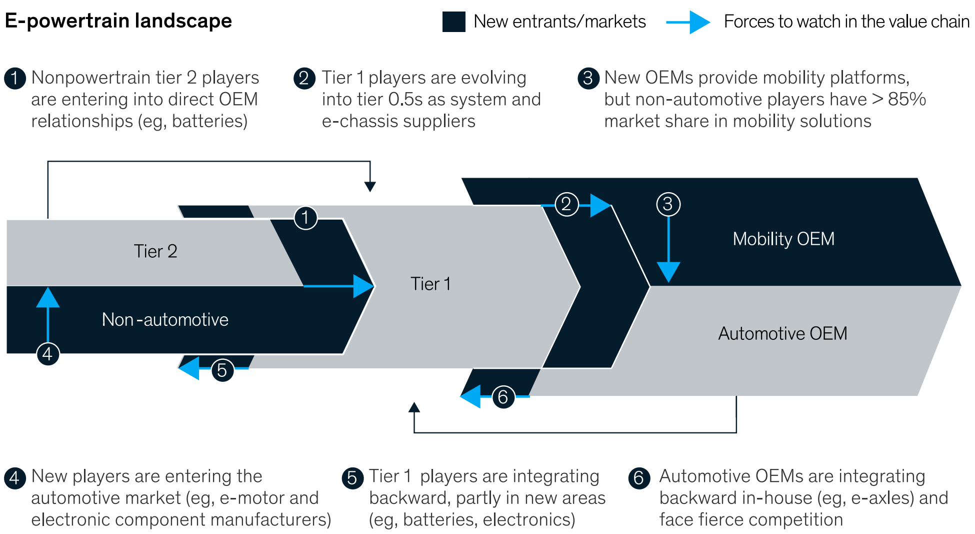
Taking a closer look at the powertrain supply chain, one can see it is currently in flux.

Non-automotive players are entering the market—and they make more than 90 percent of the investments in mobility start-ups. Fifteen automotive suppliers offer or develop an e-axle system solution, which is the basis upon which new brands can easily offer their own vehicles (Exhibit 6).

Exhibit 6

Disruptions in the e-powertrain value chain create new opportunities for many types of players.

E-powertrain landscape



Racing the tech giants

Tech giants are the other major players shaking up the automotive industry, increasing competition in a big way. Backed by large cash reserves or high stock market valuations (or both), these companies are trying to redefine how mobility will look in the future.

In light of this, automakers should not neglect their traditional strengths: they should continue focusing on design, sustaining production excellence, and maintaining a big service operations footprint. But they can learn from tech companies and adapt across three dimensions: creating new ecosystems and business models, forging partnerships, and establishing new levers for efficiency gains (Exhibit 7).[2]

Exhibit 7

The automotive industry must take action along three dimensions to keep up with tech giants.

Ecosystems and business models		Partnerships		Efficiency	
Shape, don't react	Allocate resources	Share pain	Team up for gain	Explore new technologies	Attract new talent
Drive innovation of new solutions even if they harm traditional business models	Shift resources to new technologies	Turn competitors into partners to share investment burdens and decrease risks	Cooperate with technology leaders to explore new opportunities	Unlock new frontiers of profitability by actively exploring the potential of artificial intelligence	Enhance talent pools to expand data- and technology-driven business models

Succeeding in tandem

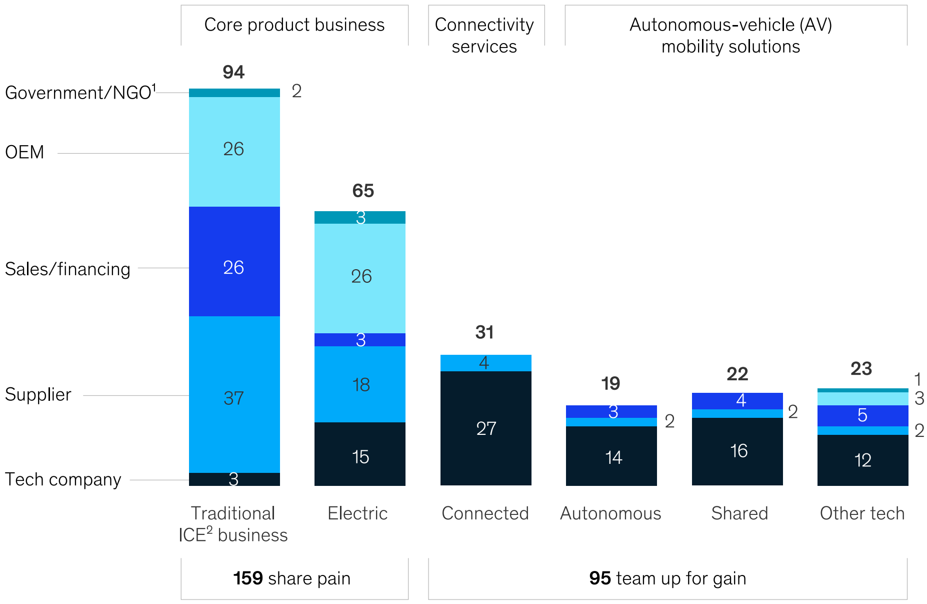
Cooperation within the automotive industry is not new—for decades, OEMs have shared the financial burden in core areas like engine development and production. But given the challenges ahead, cooperation will become an even bigger success factor.

Our analysis shows that the majority of new cooperations in the industry are still in these core, investment-heavy areas (Exhibit 8); 94 new cooperations have been forged in this space since 2014. But electrification cooperations are on the rise: 65 have now been forged, and interestingly, 15 of them are between OEMs and tech companies. This figure is even higher for connectivity-related cooperations: 27 out of a total of 31 are between OEMs and tech players, giving them a high share in the autonomous-driving and shared-mobility markets.

Exhibit 8

Two-thirds of partnerships initiated by OEMs since 2014 have focused on sharing investment burdens.

Total new OEM partnerships since 2014 by organization type, number



[1]Nongovernmental organization.
[2]Internal combustion engine.

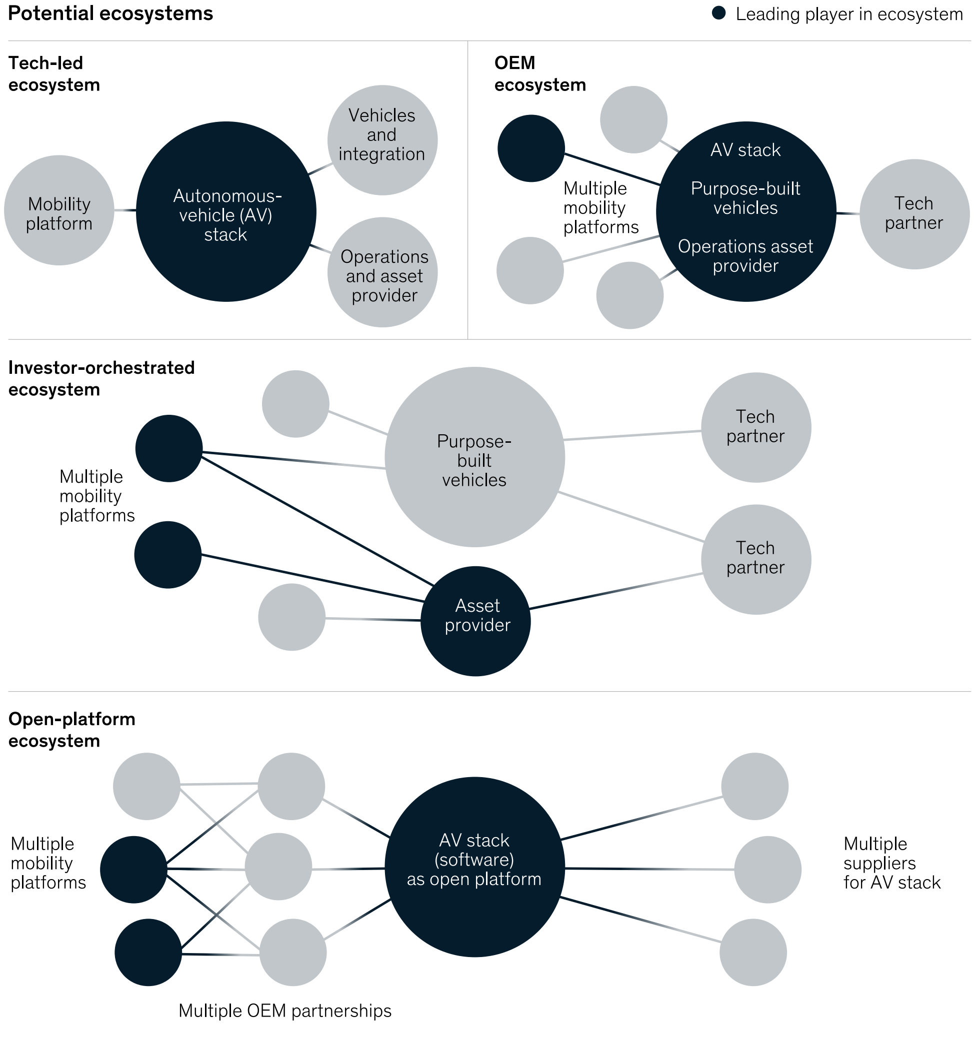
From value chains to ecosystems

These cooperations are only the first step into what we call an ecosystem for mobility . As the traditional value chains between suppliers and OEMs begin to dissolve, new entrants, tech companies, and governments and regulators will play bigger roles.

In the long run, it is expected that a handful of global ecosystems based on different players will emerge (Exhibit 9). These could take the forms of a tech-centric ecosystem focused on the AV stack, an OEM ecosystem, an investor-orchestrated ecosystem, and an open-platform ecosystem.

Exhibit 9

Several ecosystem archetypes are emerging to dominate the market.



Boosting EBIT with AI and analytics

Technology is not only central to developing these ecosystems, but also one lever to optimizing efficiency and profitability in the future. Artificial intelligence (AI) is a prime example of an essential technology for the automotive industry beyond traditional levers.

Since many companies work on the edge of traditional cost optimization—63 percent of executives say they have reached limits, for example, for lean manufacturing—AI and Industry 4.0 promise to deliver additional cost-optimization potential.

There are numerous use cases along the value chain (Exhibit 10).

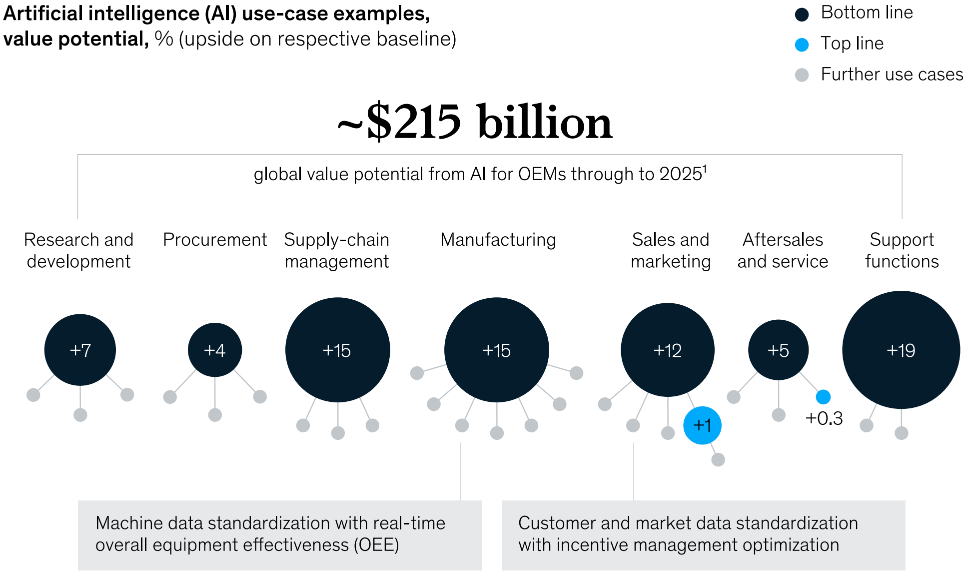
For instance, overall equipment effectiveness (OEE): today, most solutions fail to accurately measure OEE due to unavailable or heterogeneous data. With AI, data sources can be linked and harmonized—allowing automated, real-time reports that address further efficiency potential.

Another example: while OEMs usually spend 10 to 20 percent of their revenues on incentives, it might be one of today's most undermanaged expense categories. AI offers the potential to significantly reduce customer rebates and vehicle time in stock. By predicting demand, OEMs can optimize build-to-stock vehicle configurations, and vehicle distribution, as well as offer targeted rebates and promotions.

Exhibit 10

AI use cases offer potential along the full automotive value chain.

Artificial intelligence (AI) use-case examples, value potential, % (upside on respective baseline)



[1]Equivalent to 9 percentage points of earnings before interest and taxes.

The road ahead for the automotive industry is certainly not straight and smooth; in fact, it is uncharted, windy, and bumpy. But one thing is clear: mobility has always been and will remain an important constant in human societies.

Therefore, if traditional OEMs and suppliers manage to turn the short-term challenges and long-term disruptions to their business models into opportunities, they will be able to continue growing successfully—and make healthy profits to boot.

1. Includes battery electric vehicles (BEVs) and plug-in hybrid electric vehicle (PHEVs).
2. For more, see *RACE 2050—a vision for the European automotive industry*, January 2019.

About the author(s)

Matthias Kässer is a partner in McKinsey's Munich office, where **Patrick Schaufuss** is an associate partner and **Andreas Tschiesner** is a senior partner; **Friedrich Kley** is a consultant in the Hamburg office; and **Timo Möller** is a partner in the Cologne office.

Change vehicles: How robo-taxis and shuttles will reinvent mobility

Uncertainties surround the future of shared autonomous vehicles. Modeling scenarios for their development and adoption can help companies on the road ahead.

June 2019

by Kersten Heineke, Philipp Kampshoff, Martin Kellner, and Benedikt Kloss

Modern cities feature an odd mix of excitement, opportunity—and pain. Much of the latter results from getting around: sitting in traffic congestion, hunting for parking spaces, breathing exhaust emissions.

Understanding cities' problems with private cars

All cities, to a greater or lesser extent, have a problem with private cars. As an example, let's look at Los Angeles. Today, it suffers from congestion that leads to an increase in travel time of 44 minutes per day, or 170 hours per year, that are lost for every driver, making it the most congested city in the United States and Western Europe.[1] The city also aims to address car-related safety issues that it wants to solve with its "Vision Zero" target to reduce traffic deaths and serious injuries to zero by 2025.[2] Furthermore, public-transportation usage in Los Angeles is low compared with car-based mobility; additionally, Los Angeles, like most other cities, faces emission problems, heading the list of most polluted US cities regarding ozone.[3]

These challenges result largely from today's mobility situation. As in nearly all major cities in the world, private-car usage dominates LA's mobility mix, accounting for about 80 percent of all passenger miles traveled in Los Angeles County.[4] Public transportation handles only about 5 percent, while the stake of shared mobility is below 1 percent today. However, there's accelerating adoption of shared mobility in particular, driven by the rise of electric e-scooter sharing, among other factors.[5]

We believe electrified, shared autonomous vehicles (AVs)—also called robo-taxis or shuttles—could address these pain points while revolutionizing urban mobility, making it more affordable, efficient, user friendly, environment friendly, and available to everyone.

That's the dream, but the future is uncertain. No one knows today when the technology will be mature enough, when mass-market adoption might start, where it will start, whether customers will adopt it, or how fast and large this adoption will be.

However, robo-taxi and shuttle mobility have the potential to disrupt our future mobility behavior and to cannibalize many of the miles people travel each day. This could fulfill daily mobility demands but also may signal the end of mass private-car ownership—at least in high-income urban and suburban areas.

Many companies are already operating large testing fleets of shared AVs, and even more companies have announced that they will launch fleets sometime between 2019 and 2022. The companies involved range from OEMs and suppliers to tech players and start-ups.

There are, of course, many uncertainties regarding the development of shared AVs. To deal with these and to make strategic decisions, it's important to model future AV development and adoption using the most up-to-date facts and opinions, as well as a holistic set of input parameters that can be tracked and adopted over time.

Creating a shared-mobility supermodel

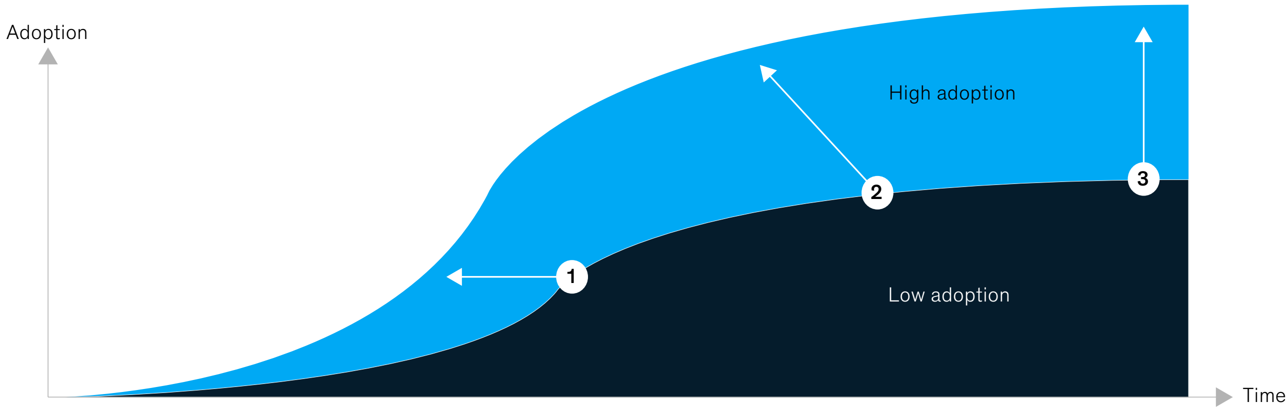
To reduce the levels of uncertainty surrounding shared AV mobility, the McKinsey Center for Future Mobility (MCFM) has developed a detailed and holistic model based on a thorough fact base, consumer surveys, expert estimates, and extensive discussions with relevant stakeholders. Our goal is to contextualize trends and disruptions in the overall development of the mobility market. We plan to update the model on a regular basis to incorporate the latest developments regarding technical maturity, customer adoption, regulation, and comparison to total cost of ownership of alternative modes of transport (Exhibit 1).

[1] TomTom Travel Index, Tom Tom, tomtom.com.
[2] "Vision Zero Los Angeles, 2015–2025," City of Los Angeles, visionzero.lacity.org.
[3] "Most polluted cities," American Lung Association, lung.org.
[4] "National household travel survey," Federal Highway Administration, 2017, nhts.ornl.gov; our analysis also draws on research from the American Public Transportation Association and the California Department of Transportation.
[5] "For a more detailed view of the micromobility market, see Kersten Heineke, Benedikt Kloss, Darius Scurtu, and Florian Weig, "Micromobility's 15,000-mile checkup," January 2019, McKinsey.com.

Exhibit 1

To quantify uncertainty over autonomous mobility solutions, we created a market model based on the observation of trigger points.

Robo-taxi adoption projection over time



1. Start of commercial launch

- Will there be regulations on a national level?
- Will the key players collaborate to build robo-taxis?

Answering yes to both could lead to earlier adoption

2. Speed of adoption

- Do customers feel safe in robo-taxis and accept a potential increase in travel time?
- Are investors willing to finance robo-taxi fleets?

Answering yes could lead to earlier and greater adoption

3. Adoption in steady state

- How are robo-taxi prices compared with other means of transport?
- Will cities support or fight robo-taxis?

Answering yes could lead to greater adoption

The model is dynamic and regionally sensitive. For example, to model future robo-taxi and shuttle mobility as accurately as possible, we took several perspectives into account. Robo-taxi and shuttle mobility will differ from city to city, for instance. Each city is unique regarding its modal split, public-transport penetration, efficiency, congestion levels, the wage levels of taxi drivers, and so on. Other factors that can differ include the cost of car ownership, the cost of parking, local taxes, city tolls, and so on. These urban markets are also unique in their robo-taxi adoption rates, rollout speeds, feasibility, and city support. Consequently, we used a bottom-up approach, introducing a city-clustering technique using city archetypes, modeling the robo-taxi and shuttle development of selected representative cities, then extrapolating the results to the global market.

Customer adoption rates for robo-taxis and shuttles will vary by mobility use case: customers will use robo-taxis and shuttles in different mobility use cases, most likely with different frequencies. To account for this, we defined more than 20 mobility use cases such as commuting, shopping, and airport transfers and took today's split and modal mix by city into account. We calibrated AV customer-adoption rates depending on the mobility use case and adjusted them by city as well. The different adoption rates depend on convenience factors, such as finding a parking space (or not) when going to the city center, and cost calculations, which depend on the next best alternative for the respective journey.

Robo-taxis will be disruptive. However, these disruptions could occur in different ways. To take these differences and remaining uncertainties into account, we modeled three scenarios per city: conservative, moderate (our base case), and aggressive.

Robo-taxis will generate new miles traveled

The model shows that introducing robo-taxis and shuttles will increase total miles traveled. Due to greater convenience, better availability, the provision of affordable mobility to people without driver's licenses, and competitive pricing, robo-taxis will generate trips and miles of travel that customers would otherwise not undertake. This increase will boost travel by about 10 percent in our base-case scenario.

Pricing will depend on today's spending for mobility. On the one hand, to be competitive and to attract as many customers as possible, robo-taxi and shuttle operators might set price levels as low as technology costs allow. Technology costs will go down over time, making shared AV mobility more affordable, which will be another driver for customer adoption. On the other hand, cities will probably not allow pricing to come close to or even undercut public-transport costs. Cities don't want consumers to avoid using public-transport offerings by switching to car-based mobility, because it would increase congestion and other urban problems. Likewise, pricing scenarios will differ from city to city, which we accounted for by investigating costs of transport at the city level and then evaluating different pricing scenarios depending on those costs.

The overall speed of adoption will depend on regional differences: the speed of customer adoption and market ramp-up will differ by region according to unique regulations, economics, and other factors. For example, higher driver costs in Europe and the United States mean that robo-taxi mobility will reach an earlier tipping point in those regions than in China, where driver costs are much lower. This will lead to earlier market ramp-up in Europe and the United States.

Applying the model to Los Angeles reveals new insights

Returning to our earlier example, Los Angeles has a head start on many cities in its acceptance of shared mobility. For instance, e-hailing services such as Uber and Lyft have taken off in the city. This acceptance will likely continue to grow over the next decade or so. The passenger miles traveled via shared mobility might increase significantly between today and 2030, rising from under a billion miles to approximately 20 billion to 30 billion (Exhibit 2).

Additionally, the introduction of potentially safer shared AV mobility options aligns with the city's goal of reducing the number of traffic deaths and serious accidents.

Applying our modeling approach in Los Angeles yields the following insights:

— In 2030, robo-taxis and shuttles could cut private-car usage by up to 20 percent compared with today in the base case, corresponding to roughly 10 billion to 20 billion passenger miles driven in Los Angeles in 2030.

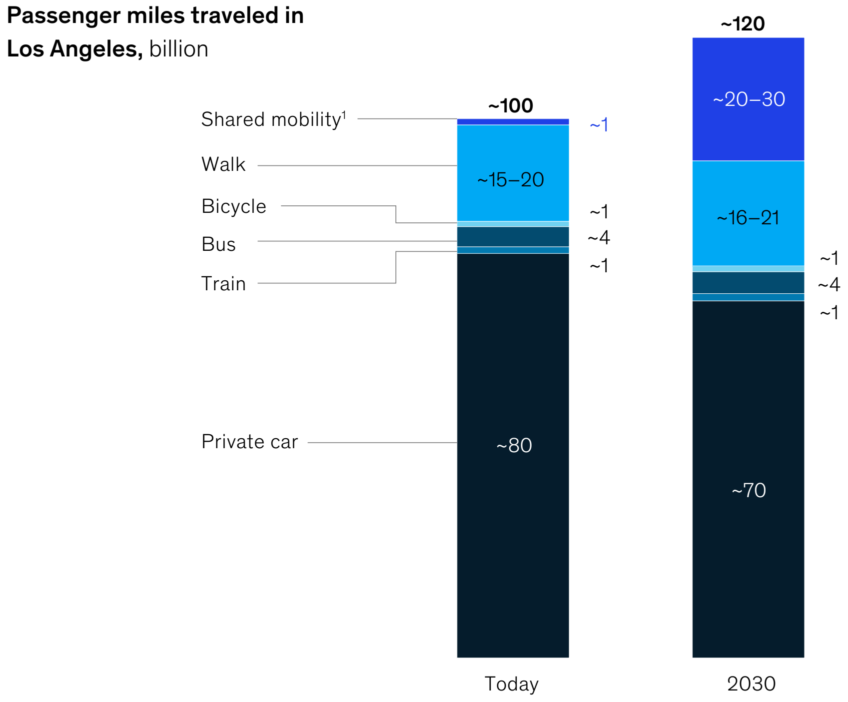
— The robo-taxi revenue potential in Los Angeles in 2030 might therefore range from $4 billion to $7 billion (pessimistic scenario) up to $15 billion to $20 billion (aggressive scenario).

— Commuting is the most relevant use case for AV mobility services (more than 20 percent of revenue) in Los Angeles, followed by going shopping (more than 15 percent) and attending to leisure activities (more than 10 percent).

— Conversely, shared AV mobility might only slightly cannibalize public transport since the latter will remain significantly cheaper, and cities have a huge interest in shifting passenger miles traveled by car to public-transport solutions. Robo-shuttles that are pooled with several passengers have the potential to reduce number of cars on the road in the long term, maybe even in collaboration with public-transport agencies.

Exhibit 2

In Los Angeles, passenger miles traveled via shared mobility could reach nearly 20 billion to 30 billion by 2030 under base-case modeling.



[1] Includes car sharing, ride-hailing, and all other forms of shared mobility (eg, person-to-person rental, shuttle services).

Source: American Public Transportation Association; California Department of Transportation; US National Household Transportation Survey; McKinsey analysis

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Beyond Los Angeles, we applied our modeling logic to several representative cities covering different regions of the world. What happens when we apply the model to Asia, Europe, the Middle East, and the United States to estimate the global robo-taxi and shuttle market potential in 2030? Does shared autonomous mobility have the potential to become a trillion-dollar market by 2030? We will reveal the answers to these questions and more in a forthcoming article.

Kersten Heineke is a partner in McKinsey's Frankfurt office, where **Benedikt Kloss** is a consultant; **Philipp Kampshoff** is a partner in the Houston office, and **Martin Kellner** is a consultant in the Munich office.

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How China will help fuel the revolution in autonomous vehicles

If the driverless-car phenomenon takes off in China, the payoff could be in the trillions of dollars.

January 2019

by Luca Pizzuto, Christopher Thomas, Arthur Wang, and Ting Wu

Self-driving cars could steer China's automotive industry into the passing lane. From driverless taxis to automated cargo trucks, autonomous vehicles (AVs) will change the nature of on-road driving and, in the process, revolutionize the automotive and mobility industries. Within this mix of opportunity and uncertainty, we believe AV players (from components vendors to mobility service providers) could earn trillions in revenues in China.

Fundamentally transforming mobility

McKinsey research suggests autonomous vehicles could, at some point, take over most of the automotive market in China. For instance, industry respondents to our survey indicate passenger vehicles used for mobility services such as "robo-taxis" will see a peak adoption rate of 62 percent, followed by private premium vehicles (51 percent) and private mass-market cars (38 percent). Mobility services will lead due to the autonomous vehicle's expected increased utilization (close to 24/7 operation) and lower labor costs (no drivers). The same rationale puts city buses at 69 percent adoption and commercial vehicles (CVs) at 67 percent.

Autonomous vehicles will likely shift a substantial share of the mobility market value away from products (that is, buying vehicles) and toward services (that is, paying for transportation per mile). This "mobility-as-a-service" (MaaS) transformation suggests dramatic changes ahead for vehicle sales volumes, business models, and the capabilities companies will need to thrive in this new environment. In China, we believe fully autonomous vehicles (SAE Level 4 and above) will see mass deployment in nine or ten years.

These shifts will change the rules of the game across the entire mobility space, as software and data become fundamental differentiators when building and operating cars. As such, the mobility sector will become ground zero for a convergence of industries that include automotive, transportation, software, hardware, and data services.

Today's automakers focus on selling new cars, transportation companies on providing services, and technology players on supplying hardware and software to automakers. In the future, new business models might emerge. Technology players could buy vehicles from automakers to provide services direct to consumers. Alternatively, automakers might vertically integrate in services and software development (as leading players are already doing today). Players in these sectors must reconcile their differences in product life cycles (for example, three to four years for automotive, weeks to months for software) and business models (for instance, products versus services) to compete and cooperate effectively with each other.

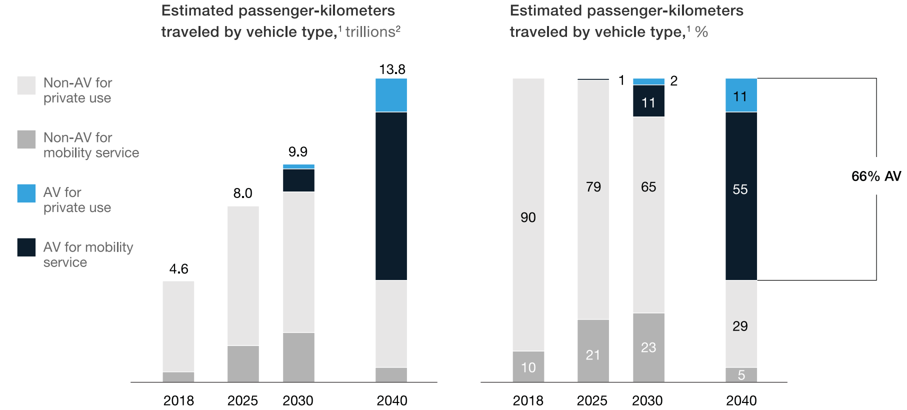
Clearly, many companies already have active autonomous vehicle strategies, including technology players such as Baidu, Tencent, and Waymo and automakers such as GM, SAIC Motor, and Tesla. However, given the industry's dynamic, fast-moving nature, players need to refresh their strategies constantly.

Understanding how China fits in

China has the potential to become the world's largest market for autonomous vehicles. In our base forecast, such vehicles could account for as much as 66 percent of the passenger-kilometers traveled in 2040 (Exhibit 1), generating market revenue of $1.1 trillion from mobility services and $0.9 trillion from sales of autonomous vehicles by that year. In unit terms, that means autonomous vehicles will make up just over 40 percent of new vehicle sales in 2040, and 12 percent of the vehicle installed base.

Exhibit 1

Autonomous vehicles (AV) will travel about 66 percent of total passenger-kilometers in 2040.



[1]Baseline scenario.
[2]Figures may not sum, because of rounding.

Autonomous vehicles could solve major infrastructure problems

In 2009, China passed the United States to become the world's largest and most important automotive market, going on to consume nearly 30 million light vehicles in 2018, almost 70 percent more than the United States. This continued explosive growth is overtaxing the country's automotive-related infrastructure, driving increased traffic congestion and pollution. Beijingers spend an average of 1.3 hours every day commuting—more than three times as much as the average US commuter. Autonomous vehicles will offer a potential solution to some of these infrastructure challenges. In the realm of shared mobility, they could reduce the number of vehicles on the road and free former drivers to work or relax en route. If powered by green electricity or hydrogen, they could also help reduce local vehicle emissions.

However, a complex environment could slow initial uptake of AVs

In the short term, given China's complex traffic environment, autonomous vehicles must adapt to road conditions and aggressive driving behaviors, which could slow adoption. However, a review of traffic severity worldwide reveals China's problem as one of degree, not kind. Western cities from downtown New York to Rome have similarly dense populations and levels of mixed traffic.

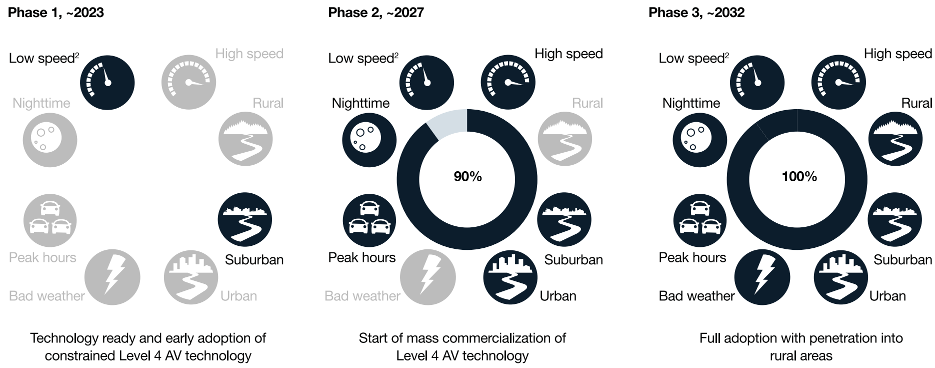
Consequently, the technology solution in China for autonomous driving will not differ much from those in other nations. Required computing platforms will likely conform because existing platforms feature enough "buffer" capacity to handle the more complex computing tasks required to analyze objects on Chinese roads. Sensor configurations would probably not change from region to region because current setups can cover all critical directions across very different driving use cases.

What is different in China involves the country's highly complicated signage, with traffic lights and road signs not yet fully standardized. Likewise, right-of-way issues resulting from the failure of Chinese drivers to follow road rules strictly add a major element of uncertainty to programing and "training" requirements for autonomous vehicles. Consequently, the need to optimize AV decision algorithms for Chinese roads could take more effort and training, which could add roughly two to three years to the adoption timeline compared with the United States. As such, the first applications of autonomous vehicles in constrained environments might begin in the next five years, but mass adoption will likely occur only after 2027, as it will require the technology to address the majority of conditions of urban and suburban driving (Exhibit 2).

Exhibit 2

Mass adoption of highly autonomous vehicles (AVs) in China will likely start in 2027.

Use cases and passenger-kilometers addressable by autonomous vehicles over time,[1] % of passenger-kilometers traveled



[1]Suburban area has less traffic and more simple driving conditions than urban area.
[2]Driving speed no more than 60 kilometers per hour.

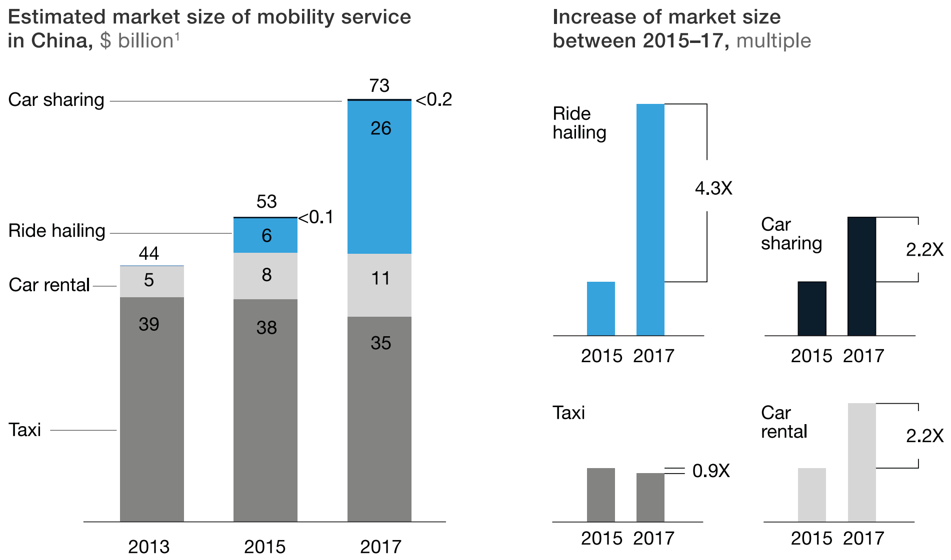
While the core algorithm for the operation of autonomous vehicles is largely the same on a global basis, operating in China will require additional data and testing. For example, developers need to collect and input local traffic data to resolve the issue of unique and ununified road signage. They must also optimize motion planning through road testing so the algorithm can learn to deal with issues caused by the relentless driving styles of some Chinese motorists.

Still, longer-term prospects appear promising

In the long term, China will likely emerge as the world's largest market for autonomous vehicles. In fact, the Chinese automotive market is already adopting MaaS at a rapid rate. For example, cars sold to provide mobility services today represent about 10 percent of China's total cars sales, and the country's mobility-services market has grown at double-digit rates over the past several years (Exhibit 3). This familiarization should translate into strong demand for mobility via autonomous vehicles in the long term.

Exhibit 3

Mobility services are growing strongly in China.



[1]Figures may not sum, because of rounding.

Source: iResearch; Ministry of Transportation in China; McKinsey analysis

Reaching an adoption inflection point

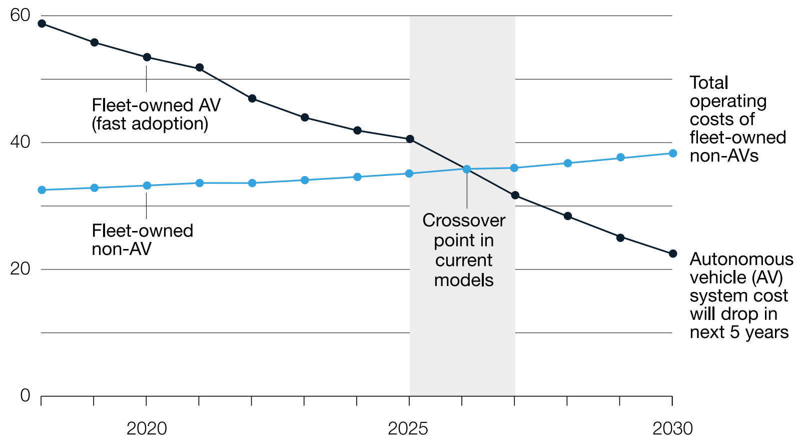
We developed a proprietary sizing model to forecast China's market for autonomous vehicles. The model takes a use-case approach, which analyzes the developments required for a specific category of autonomous vehicle, such as robo-taxis or automated trucks, to succeed in the marketplace. We surveyed more than 40 industry experts across the AV ecosystem and received feedback and advice from an external advisory board that included AV experts and executives from automakers, Tier-1 suppliers, technology companies, and mobility service providers. We learned the experts believe technology, rather than regulation, will likely hold back the adoption of autonomous vehicles. We chose two commercialization speeds: fast adoption and slow breakthroughs. Based on that analysis, we believe 2025–30 will represent an inflection point for adoption of autonomous vehicles, with the broad timespan dependent on the usage model and city-level driver economics.

Exhibit 4 shows the cost crossover analysis for a fully battery-electric vehicle used for mobility services as a robo-taxi. The major cost drivers include the vehicle's depreciation, the driver's cost, maintenance, insurance, and electricity (fuel). They do not include operational or management fees for running a mobility service fleet. The replacement of human drivers in autonomous vehicles will occur gradually due to safety and regulation considerations.

Exhibit 4

Autonomous 'robo-taxis' should reach an inflection point between 2025 and 2027.

Projected mobility service cost,[1] ¢ per km



[1]Apply the assumption of using a battery-electric vehicle; cost includes depreciation, driver cost, maintenance, insurance, and fuel/electricity cost but excludes fleet-management fee.

The cost of the total AV system (including sensors, computing platform, and software) should decrease rapidly after the technology matures beyond 2023, to approximately $8,000 in 2025. Once autonomous vehicles reach the crossover point, adoption will accelerate.

This inflection point is when, based on the functional robustness and cost curves of AV technologies, self-driven transport will reach economic parity with human-driven transport. In other words, the total cost per kilometer of an autonomous vehicle will roughly match that of a traditional car with driver. After this inflection point, demand for autonomous vehicles should rise steadily, depending on how the market develops. As this occurs, the potential for new players to seize control of the automotive value chain grows.

Industry profit pools to flow toward services and software

The advent of autonomous vehicles will expand the mobility profit pool in the Chinese autonomous vehicle industry by at least $60 billion compared with today's value. Car sales will remain a large share of the profit pool in the overall value chain, at $50 billion to $60 billion. However, mobility services profits will grow to become 25 to 30 percent of the total profit pool (including vehicles, components, mobility services, and fleet management) and could exceed those of car sales, especially if the MaaS market were less competitive (for example, if government cooperated with mobility players). On the other hand, AV technology and system integration will produce $15 billion to $20 billion in profits, representing 50 to 60 percent of the total auto-components profit pool.

Profit pools will depend on the competitive environment. In one scenario, robo-taxis will be operating via local public/private joint ventures. In this case, MaaS could make up $50 billion to $55 billion—over a quarter of the $195 billion profit pool in China. In another scenario, if robo-taxis were operating in a much more competitive free-market environment, the mobility services segment would shrink significantly to $15 billion to $20 billion. Whichever case prevails, the larger point is that autonomous vehicles could create substantial value for the industry and thus have a major impact on profit pools.

Shaping a Chinese AV revolution

The market for autonomous vehicles in China will offer huge opportunities to players willing to shoulder the risks involved, from local Chinese automakers to multinational companies to tech giants and mobility businesses. To capture these opportunities, players can either develop a differentiating service connection to the end customers or control key parts of the AV technology. Identifying which elements of the technology hold long-term strategic value and their evolution over time will enable players to locate the high-value "soul" of the autonomous-driving machine.

Tech stacks will complement value chains

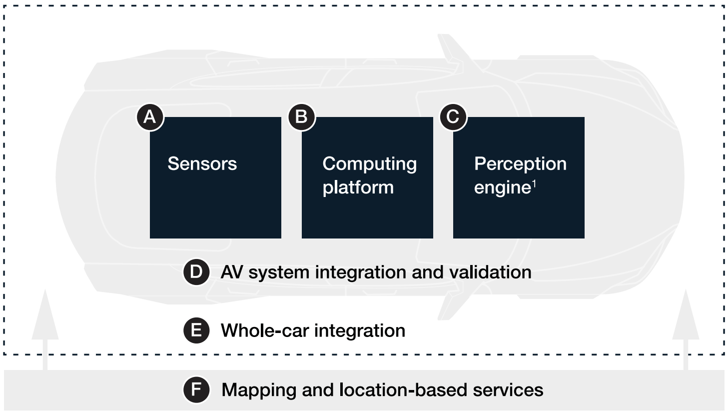
The emerging AV ecosystem differs from traditional automotive approaches because it focuses on the technology stack—a concept used in the high technology and computing industries (Exhibit 5).

The core elements of the technology stack include the sensors, the computing platform, software (including object detection and analysis as well as motion planning), system integration and validation, mapping, and location-based services (LBS). As such, it represents the core of an automobile's autonomous drive system. That makes it a critical part of the vehicle to "own" for automakers, suppliers, technology companies, and

Exhibit 5

An example helps illustrate a technology stack for an autonomous vehicle.

Autonomous vehicle (AV) technology stack layers defined



A — Sensors

Develop advanced AV sensor hardware with both sensing and signal processing abilities, eg, lidar

B — Computing platform

Develop AV computing processors (eg, CPUs, GPUs, or AI[2] accelerators)

Develop onboard computing platform with both hardware and operating system

C — Perception engine

Develop objective analysis (perception or sensor fusion) and decision making (motion planning) algorithms

Collect driving data to train the AV algorithm and optimize its performance

D — AV system integration and validation

Integrate off-the-shelf software, sensors, and computing platforms into an AV system

Test and validate the performance of AV system and interface with motion control

E — Whole-car integration

Design and assembly of vehicle integrating all off-the-shelf subsystems

Test and validate the performance of whole vehicles

F — Mapping and location-based services

Compose high-definition maps

Establish the connectivity of infrastructure and offer location-based services for AV fleet

[1]The algorithms and software involved in object analysis and motion planning.
[2]Central processing unit, graphics processing unit, and artificial intelligence.

others. It seems likely that the important elements of the stack will evolve over time, thus requiring companies in the segment to monitor and assess the potential disruptions linked to subsequent technology innovations as they occur.

Each tech stack layer has different critical success factors. For example, the sensor layer requires robust reliability and safety elements, as well as strong mass-production and production management capabilities to achieve necessary economies of scale. The algorithm and software layers require agile development skills and fast iteration capabilities to enable companies to work through training data to improve performance on a consistent basis. System integration and validation requires outstanding reliability and safety, and strong mass-production capabilities.

Building a Chinese tech stack

Of key interest to industry players is to what extent the Chinese stack will differ from that used in the rest of the world. The end state of this stack remains highly uncertain, as it depends on the competitiveness of different players and the regulatory environment. However, early indicators suggest that both global and locally developed solutions will emerge across the stack.

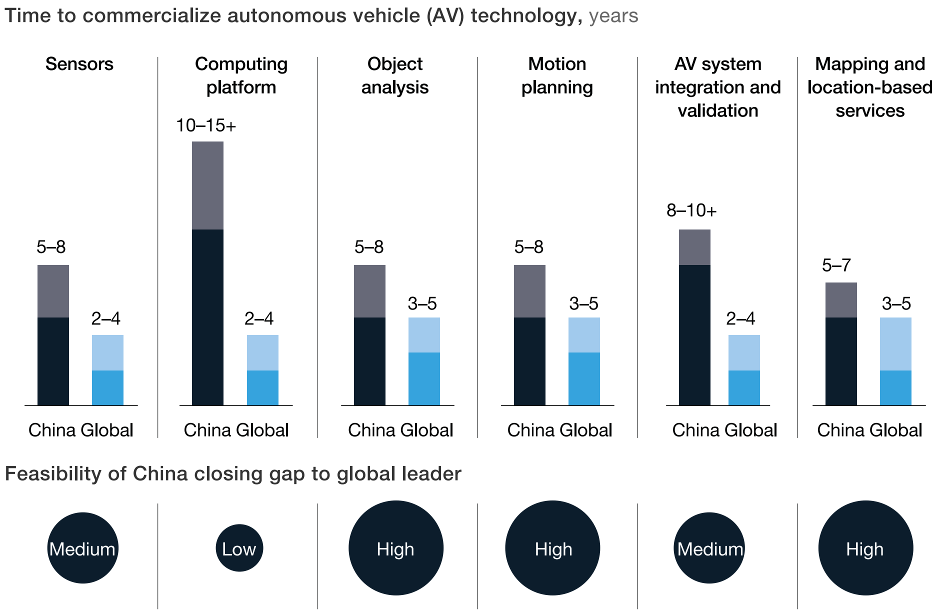
Economics will provide much of the answer here. Hardware components are most likely to benefit from the scale economics of global solutions. Sensors, cameras, lidar, and the computing platform require the same capabilities in China as in the rest of the world (and therefore benefit greatly from the scale impact of global solutions). Mapping, LBS, and data-cloud solutions will likely require heavy localization.

Some elements of a typical autonomous vehicle's technology stack—LBS and data cloud, for example—currently face so-called "negative restrictions" (for example, limitations on foreign-company involvement) by the government. Our research suggests local players alone will have access to most location-based services, leaving foreign companies and joint ventures at a disadvantage. The same appears to hold true for China's data cloud. That leaves the other five parts of the tech stack—the mobility services interface, the motion planning algorithm, connectivity functions, the central processing and graphics processing units, and sensors—currently open to foreign participation.

Surveys and interviews with experts in the automotive, mobility, and technology industries suggest Chinese players are at least two to three years behind international companies in the critical capabilities required for delivering the AV stack (Exhibit 6). In some cases, such as the computing platform and AV system integration, the Chinese automakers are more than ten years behind.

Exhibit 6

China's technology gap is largest for computing platforms and autonomous vehicle system integration and validation.



The Chinese government strongly supports local AV technology development, as shown by the establishment of multiple AV test zones, including Jiading in Shanghai and Xiong'an outside of Beijing. Initially positive, such support can help local players develop capabilities. Over time, however, the increasing drive toward localization could restrict competition in the sector (for example, hampering outsider abilities to operate locally or access local technology).

The venture-capital community and major internet players are investing heavily in China to close the global/local gap. Over the last five years, AV and component companies have received $7 billion in funding. Alibaba, Baidu, and Tencent have all invested in the sector by participating in funding rounds (for example, Baidu and Tencent with NIO, and Alibaba with Xpeng) and establishing partnerships (for instance, Alibaba with SAIC, Tencent with several OEMs, and Baidu with a wide range of players across the value chain as part of its Apollo ecosystem).

The large amounts of available capital noted above and the active involvement of the government will both actively help to shape the competitive landscape for autonomous vehicles in China. At the same time, to succeed, China's AV industry must integrate itself deeply with global ecosystems to avoid reinventing the wheel.

This type of integration will be imperative for Chinese players of all kinds because high-level AV technology requirements are fundamentally similar and thus transferable across markets and regions. Additionally, international players often have considerable advantages regarding some elements of the AV technology stack due to their global reach and expertise. As with any new technology, efforts to standardize as many elements of self-driving technology as possible could pay immense dividends down the road, especially for underresourced local players in China.

Identifying winners and also-rans

Winning the AV race will require industry incumbents to step out of their comfort zones and fully engage with a variety of players across the value chain and throughout the technology stack. Technology giants and other outsiders must also adopt new strategies to make sure their technology offerings become core parts of any standardized autonomous vehicle solutions. Additionally, players might need to move into new segments of the value chain (for example, mobility). As a result, winning will require cooperation between local and multinational companies and along the value chain.

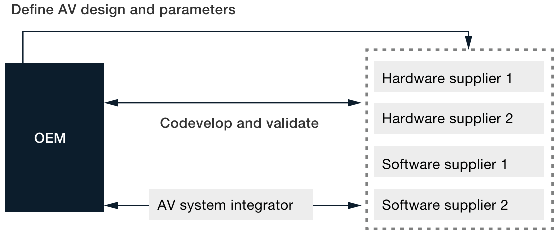
Several alliance models exist both across the AV technology stack (Exhibit 7) and between multinational and local players (Exhibit 8).

Exhibit 7

Three alliance models can be used to access the full autonomous-vehicle (AV) tech stack.

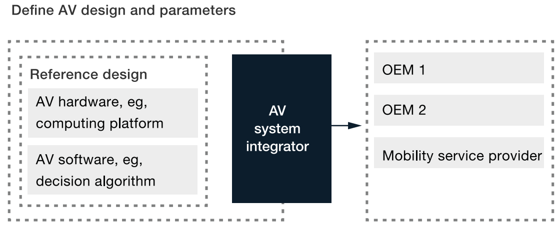
1 Integration by validation

- OEMs define AV design and key parameters
- OEMs codevelop AV technology with hardware and software suppliers, then integrate and validate
- Driver of technology definition: OEMs



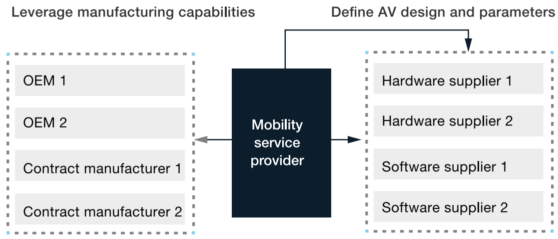
2 Integration by reference design

- AV hardware and software suppliers define AV design and key parameters, and provide OEM with reference design
- Supplier with core hardware/software competence conducts the system integration
- OEM could modify design within compatibility of AV system
- Driver of technology definition: AV tech companies



3 Use-case-driven alliance

- Mobility service provider defines AV design and key parameters, then codevelops and validates
- OEM/contract manufacturers produce AV for mobility service provider
- Driver of technology definition: mobility service provider



Source: Expert interviews; expert survey; McKinsey analysis

Exhibit 8

Several alliance models are possible for local and multinational players.

	Localizing global alliance	National champion stewardship	Locally enabled platform
Description	Led by a multinational front-runner in autonomous vehicles (AVs) with global and local partners to develop full AV tech and aim localize its product/ services for China market	Alliance of both Chinese and international players around a Chinese national champion endorsed or supported by government	A more egalitarian alliance among Chinese and global AV players enabled by a locally grown technology platform
Common objective	Access to AV tech stack and ensure technology readiness Deliver AV at affordable price for mass adoption		
Objective/ rationales	• Maintain auto technology leadership in Chinese market in AV era • Gain access to local market and approval by government	• Build up AV and auto competence for domestic companies • Provide case and experience for setting the AV regulations	• Aggressively reduce cost for local customers • Ensure wider access to AV technology among smaller and less technology-savvy players
Leadership background	Leading global OEM, auto supplier, or tech companies	Leading Chinese OEM or tech company with state-owned enterprise background	Privately owned local tech company or OEM

Source: Expert interviews; expert survey; McKinsey analysis

Preparing now for tomorrow's self-driving realities

For automakers, high-tech companies, and mobility services providers competing in China, the AV phenomenon may seem a decade or two away, but deferring positioning strategies can rob players of both influence and degrees of freedom.

Winning this game will require companies to evaluate their entry strategies carefully, balancing the high risk involved against the potential value of becoming a leader in the largest long-term market for autonomous vehicles in the world. In China as well as globally, autonomy and MaaS present a challenging landscape for investors due to the technological uncertainty and lack of proven business models. Companies making large-scale bets on conventional driving technologies (which will generate the bulk of market volume for at least the next half-decade) need to balance their investments in the old and the new at the same time.

We have a few suggestions for players developing their AV strategy:

- *Decide where to play.* Make a clear decision regarding what parts of the AV tech stack make the most sense for your company, both in terms of control points and differentiation. Establish a business model compatible with the identified source of differentiation.

- *Develop a road map to access the tech stack.* Identify the link between your source of differentiation and the technology road map you need to deliver. Estimate the company's capability gaps and the investments required to decide whether to develop the technology in-house or acquire the needed capabilities.

- *Choose the right alliance and ecosystem.* Determine your ecosystem and alliance strategy; no single player can deliver all the needed technology in the AV tech stack. At the same time, the AV value chain will differ from traditional ones. We believe going it alone is not an option. Instead, be ready to forge new partnerships and alliances as needed.

- *Build organizational agility.* Cultivate strategic and organizational agility so you can update your strategy and tactics to anticipate changes in market dynamics and react quickly to competitor or partner moves.

Beyond these four suggestions, multinational companies should consider creating a China-specific strategy with the flexibility to adapt their global models for China. That means developing the capacity to understand, respond to, influence, and shape what's going on in the country—and to develop tech-stack solutions in response. Multinational players today are uniquely aware of both the opportunity in China and the uncertainties regarding the competitive dynamics and localization requirements. That said, building a "global plus local" strategy and execution engine will not be a trivial exercise.

Likewise, local players should assess what specific parts of the AV tech stack it makes sense for them to own versus those they should access through partnerships with multinational players (at the cost of partially giving away value and control). Today, most local automakers depend primarily on tech-stack components provided by global companies, and thus have only limited investments in the core technologies and integration capabilities. Such a strategy can work for fast followers, but to play a disruptive role, companies will need to control their own tech stacks.

Getting started

While an autonomous vehicle can drive itself, firing up a company's AV strategy for China is more of a hands-on proposition. In addition to sorting through the traditional "where to play" and "how to play" questions, leaders need to make an unblinking assessment of the risks involved—both in being an industry leader and in waiting for others to lead the way. While such decisions are challenging under any circumstances, this one involves a trillion-dollar bet in China, home of the world's largest and most dynamic car market. With stakes this high, players will need much more than luck to gain a winning position.

About the author(s)

Luca Pizzuto is a consultant in McKinsey's Chicago office, **Christopher Thomas** is a; partner in the Beijing office, **Arthur Wang** is a partner in the Hong Kong office, and; **Ting Wu** is a partner in the Shenzhen office.

The trends transforming mobility's future

Mobility as we know it is about to change. A handful of trends will largely determine the benefits—and costs—for business and society.

March 2019

Since its inception, the automobile has been a flashpoint for technological, economic, and social innovation, doing as much as any human invention to change how people live—largely, but not always, for the better. Now it's time to buckle up again: the levels of disruption coming over the next dozen years are likely to exceed those of the previous 50 or more.

While much uncertainty remains about how, exactly, mobility's "second great inflection point" will unfold, many of the critical building blocks, and their potential, are becoming clear. Key to these developments are four trends most easily remembered by the acronym ACES: autonomous driving, connectivity, the electrification of vehicles, and shared mobility. Another development—the prospect of hydrogen-powered mobility—is worthy of special attention because of its potential importance for electrification.

In this compilation, McKinsey experts provide quick overviews of how each trend is evolving. The mix of analysis, insight, and data-informed prognostication should serve as a useful thought starter for CEOs and senior executives, in any industry, who seek to understand what the mobility transformation underway could mean for them today and tomorrow.

Mobility’s autonomous future

Autonomous vehicles hold the promise of massive social benefits—and industry disruption. Time to buckle up.

by Kersten Heineke and Philipp Kampshoff

It seems a lifetime ago that the first DARPA[1] Grand Challenge pitted 15 teams against one another in a driverless race across an uninhabited stretch of California’s Mojave Desert. The 2004 event, dubbed “Woodstock for nerds” by one participant, had no winner; the best performing car traveled fewer than eight of the course’s 142 miles. This was a modest start to what would become a technological revolution.

Fast-forward to December 2018 when Google’s Waymo announced the launch of a commercial autonomous-vehicle (AV) taxi service in the suburbs of Phoenix, Arizona. By October of that year, the company had already surpassed ten million miles driven in AV mode on public roads. Today, nearly every auto OEM and major supplier has an AV project in the works, and dozens of traditional competitors vie with tech upstarts for pole position in a market that promises to reshape the very nature of how people experience mobility.

To better understand the size and scope of the AV opportunity, the McKinsey Center for Future Mobility modeled more than 40 transportation use cases across a global mix of urban and highway settings, and under a range of technological, economic, and other conditions. The upshot? The global revenues associated with AVs in urban areas could reach $1.6 trillion a year in 2030—more than two times the combined 2017 revenues of Ford, General Motors, Toyota, and Volkswagen.

As important as these revenues would be for the providers of end-to-end mobility equipment and services, the effects on society would be more transformative still. If the United States, for example, fully adopted autonomous vehicles, the benefit to the public would exceed $800 billion a year in 2030 (exhibit).

- Nearly one-third of the benefit would arise from the public sector’s redevelopment of unnecessary parking spaces into more productive commercial or residential property. For context, the amount of land taken up by car parking in Los Angeles is more than 17 million square meters—equivalent to nearly 1,400 soccer fields.[2]

- About 15 percent would accrue annually to workers in the form of more productive commuting time. Further, we anticipate a yearly benefit of about one-half of 1 percent (somewhat less than $4 billion) in the form of reduced environmental

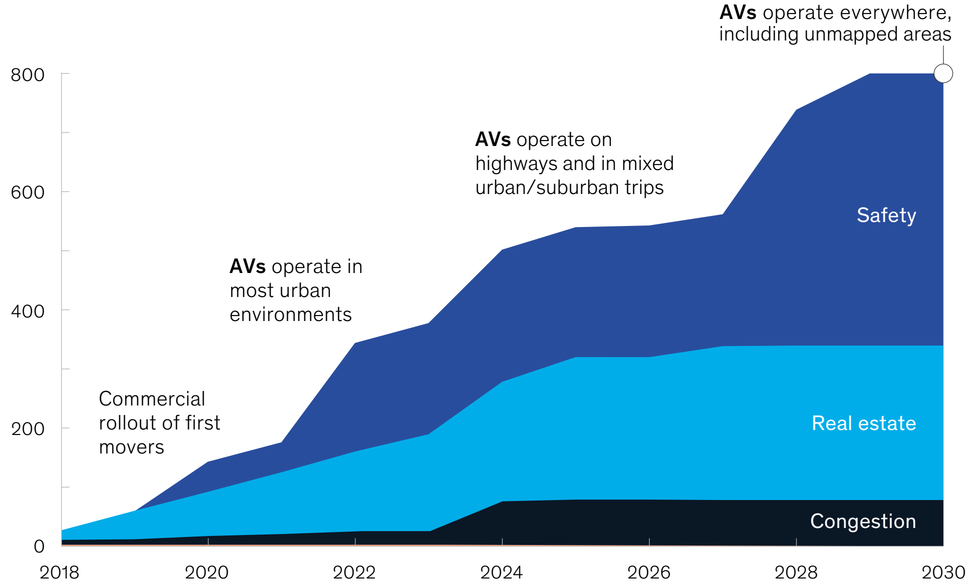
[1] The US Defense Advanced Research Projects Agency.

[2] See Adele Peters, “Just see how much of a city’s land is used for parking spaces,” *Fast Company*, July 20, 2017, fastcompany.com.

Exhibit

In the United States alone, if autonomous vehicles were fully adopted, the benefit to the public would exceed $800 billion a year in 2030.

Estimated public benefits[1] of autonomous vehicles (AVs), $ billion



[1] Environmental benefits are proportionately small (<$4 billion) and barely visible in the chart.

Source: US Federal Highway Administration; McKinsey analysis

damage, since, for example, more efficiently utilized vehicles idle less than others do.

- Finally, more than half of the benefits would stem from safer roadways and the avoidance of the millions of fatal and nonfatal accidents caused each year by human error. A comparable analysis of Germany found that by 2040, self-driving vehicles could save the country €1.2 billion a year through lower costs for hospital stays, rehabilitation, and medication alone.

Of course, not all the second-order effects of an AV-driven future are as unambiguously positive as saved lives. The insurance industry, for example, could face disruption if revenues from premiums shrink and new issues of liability arise; alcohol consumption could well increase as cars become more of a living space (and the crime of drunk driving becomes a memory); energy consumption would rise as self-driving cars, despite their efficiency, tap new pools of latent demand; and, most worryingly for cities, revenues from vehicle taxes and licensing fees would decrease dramatically.

Kersten Heineke is a partner in McKinsey's Frankfurt office, and **Philipp Kampshoff** is a partner in the Houston office. They lead the McKinsey Center for Future Mobility in Europe and North America, respectively.

Connectivity: Turbocharging the new mobility ecosystem

Connected cars are poised to become potent information platforms that not only provide better experiences for drivers but also open new avenues for businesses to create value.

by Michele Bertoncello, Gianluca Camplone, and Asad Husain

One promise of the mobility revolution now underway is that as cars become connected—the nodes of vast information networks—a new dimension of value unfurls for drivers, auto manufacturers, and innovative service providers. Conventional vehicles, once heralded as “freedom machines,” will evolve into information-enveloped automobiles that offer drivers and passengers a range of novel experiences increasingly enhanced by artificial intelligence and intuitive interfaces that far surpass today’s capabilities.

Many manufacturers and suppliers already access a wealth of vehicle data to improve or refine their cars and services, and possibilities abound for other players to share information as new ecosystems form. Consider how connectivity-enabled services could let restaurants advertise to hungry lunchtime travelers along

From basic connectedness to complex experiences: The five levels of vehicle connectivity

L1 **General hardware connectivity:** the driver is able to track basic vehicle usage and monitor technical status.

L2 **Individual connectivity:** the driver uses her personal profile to access digital services via external digital ecosystems and platforms.

L3 **Preference-based personalization:** all occupants enjoy personalized controls, their own infotainment content, and targeted contextual advertising.

L4 **Multisensorial live interaction:** all occupants interact live with the vehicle and receive proactive recommendations on services and functions.

L5 **Virtual chauffeur:** cognitive AI fulfills all occupants’ explicit and unstated needs, predicting and performing complex, unprogrammed tasks.

a given travel route. By using new forms of vehicle interactions (say, vocal commands or miniature holographic waiters) restaurants could offer menu options and preordering to save time when diners arrive.

We have identified five levels of connectivity, each involving incremental degrees of functionality that enrich the consumer experience, as well as a widening potential for new revenue streams, cost savings, and passenger safety and security. These levels reflect the potential for connectivity to stretch from today's increasingly common data links between individuals and the hardware of their vehicles to future offerings of preference-based personalization and live dialogue, culminating with cars functioning as virtual chauffeurs. Our research suggests that by 2030, 45 percent of new vehicles will reach the third level of connectivity (Exhibit 1), representing a value pool ranging from $450 billion to $750 billion.[1] Our surveys also indicate that 40 percent of today's drivers would be willing to change vehicle brands for their next purchase in return for greater connectivity.

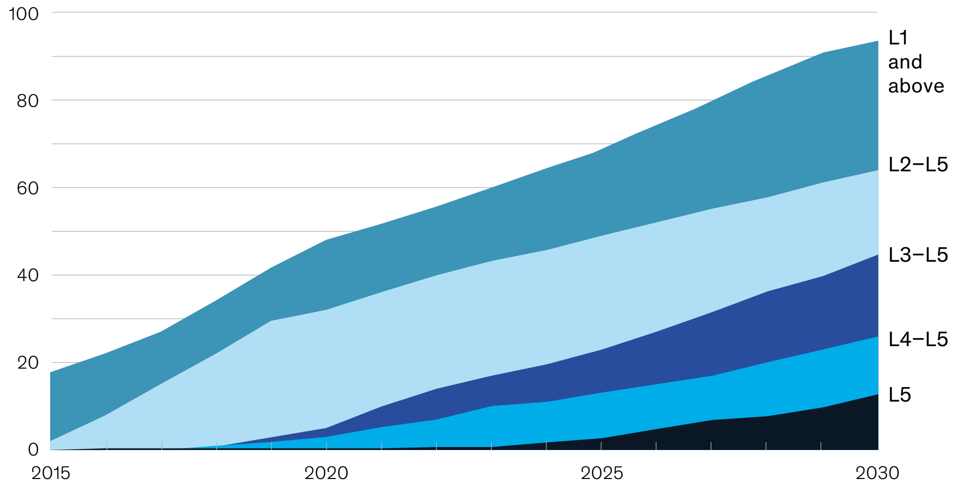
How this may play out for the insurance industry—a key link in the mobility value chain—is instructive (Exhibit 2). At level-1 connectivity, as insurers learn more about risk, drivers might receive a personal discount based on how and where

[1] We estimate that 45 percent of this value pool would come from new revenues (through direct monetization, tailored advertising, and data sales), 40 percent from cost reductions (for R&D and materials, customer acquisition, and customer satisfaction), and 15 percent from enabling improved safety and security (real-time driving intervention and hazard warnings).

Exhibit 1

By 2030, 45 percent of global new-car sales could be at level 3 or above in connectivity.

Global penetration of connected cars,
% of new light-vehicle sales by connectivity level

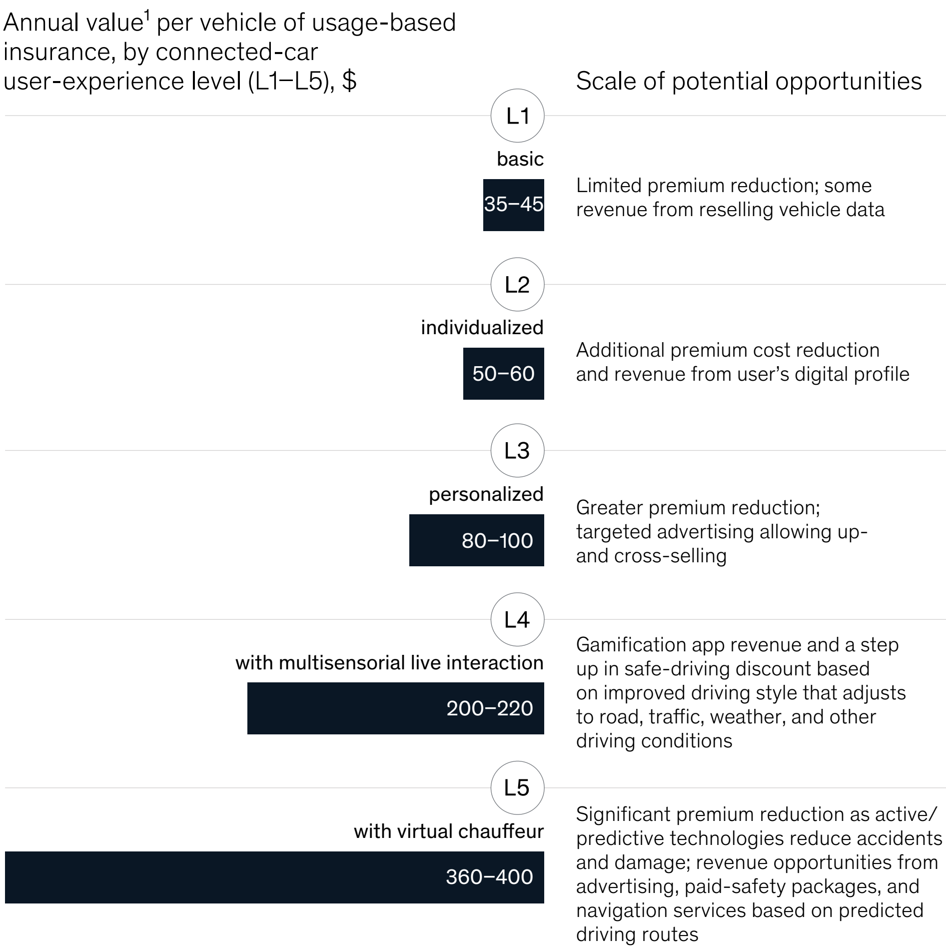


vehicles are driven. Level 2 would aggregate additional profile-based data on drivers and the driving environment, providing insurers with an even better risk profile. At higher levels of connectivity (levels 3 and 4), systems could analyze risky driving practices and signal them to vehicle operators via voice messages. Those precautions could be reinforced with interactive games and tutorials on safer driving strategies.

Level-5 sensor systems would incorporate sensors that could detect driver fatigue and suggest rest time—or even allow the car to take over some key driver functions, such as braking or steering to avoid collisions. Much of the value would arise from the diminished risk of insuring a driver, and savings would likely

Exhibit 2

Usage-based insurance illustrates the potential for connectivity to create increasing levels of value.



[1] Value is an estimate of total additional revenue for car OEMs, insurance players, and service providers, as well as costs saved per vehicle for insurers; doesn't include societal benefits. Estimates based on economics for typical developed markets.

Source: American Automobile Association; company annual reports; Covisint; Insurance Institute for Highway Safety; National Highway Traffic Safety Administration; SEC filings; McKinsey analysis be shared with consumers. An insurer's in-car platform might get additional revenue from, say, coffee shops advertising to fatigued drivers. Beyond that, these enhancements would create a more compelling proposition that car manufacturers and dealers could offer potential buyers. At the same time, they would create societal benefits by reducing the social costs associated with automobile accidents (such as the hospitalization of injured passengers and road-infrastructure repairs).

In the future, of course, both car owners and riders in passenger vehicles will need to be convinced of the value of new offerings—particularly those commanding a price. They will also need assurances that the data they are increasingly willing to share are secure. Meanwhile, companies will have to organize themselves around new, customer-centric business models and be open to partnerships, particularly with digital giants and innovative start-ups. What's certain is that the role of the car as we know it is up for revision: shifting from a mere mode of transport to a multimedia environment where connectivity is at the heart of a new customer experience.

Michele Bertoncello is a partner in McKinsey's Milan office, **Gianluca Camplone** is a senior partner in the Chicago office, and **Asad Husain** is an associate partner in the Toronto office.

Bending the cost curve for electric vehicles

Both production and consumer demand are rising briskly; design and production improvements could nudge electric vehicles toward profitability and diminish the need for subsidies.

by Patrick Hertzke, Martin Linder, and Shivika Sahdev

Low-emission electric vehicles (EVs) are crucial to locking in the benefits of enhanced mobility, and consumers are switching from internal-combustion engines to cleaner battery power at an accelerating pace. Global sales of EVs surpassed the one million mark (1.3 million) in 2017, and we forecast that sales could rise to as many as 3 million vehicles in 2020. As production ramps up, automakers are churning out some 120 new models annually, and more than 20 percent of all potential buyers now say they would consider an EV for their next purchase. Younger and urban buyers are even more enthusiastic.

As batteries become more cost effective, mileage capabilities increase, and charging stations multiply, sales of pure-play battery electric vehicles (BEVs) are now surpassing those of earlier plug-in hybrid-electric vehicles (PHEVs). The electrification gains are becoming more sustainable as well, evidenced by McKinsey's Electric

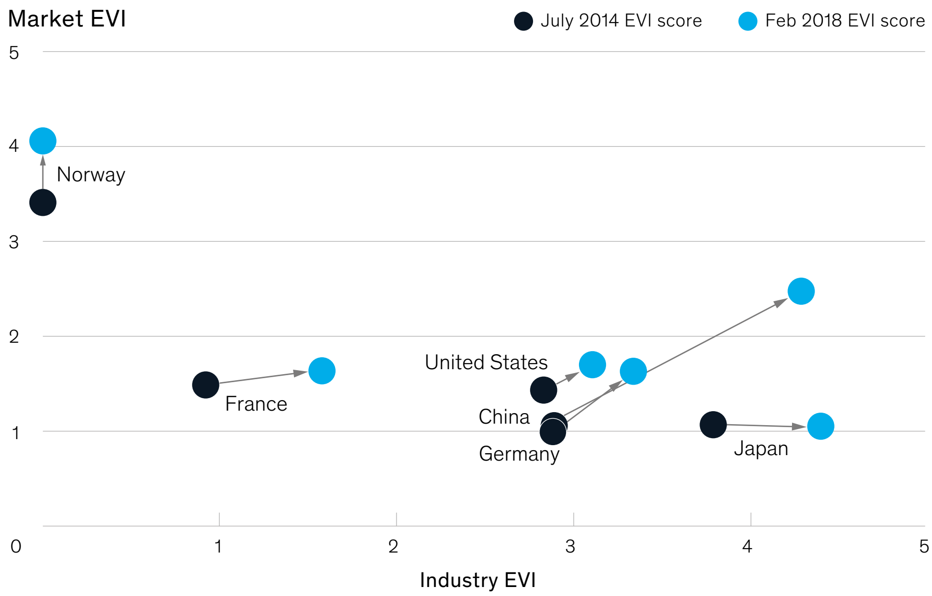
Vehicle Index (Exhibit 1), which measures both consumer demand and production capabilities across nations. EV sales have doubled annually in several markets with the help of plentiful subsidies and regulations that encourage adoption. Norway is an example of how fast the transition can happen: EVs soared to 32 percent of car sales, from 11 percent, in just four years, 2014 to 2018. China, with its car-clogged urban areas and a broad selection of vehicles at lower price points, has taken the global lead in sales—which increased by 72 percent in 2017—and looks set to remain on the up. Those gains are aided by continuing government subsidies and preferential rules, such as exemption from license plate lotteries for EVs.

Keeping electrification on this growth path will require an aggressive pace of manufacturing gains and innovations, particularly as governments seek to wind down subsidies. Government tax incentives, which can reach $7,000 or more for some vehicles, are still needed to close the average manufacturing cost gap, which we estimate at $8,000 for the average EV.

Exhibit 1

Countries are making headway in the development of e-mobility, in terms of both consumer demand and production capabilities.

Trends in Electric Vehicle Index (EVI) scores,[1] selected countries



[1] On a scale of 0 to 5; market EVI measures electric-vehicle (EV) share in overall light-vehicle market, government subsidies, and charging infrastructure; industry EVI includes assessment of OEM countries' production share of EVs and major components such as batteries and e-motors.

Our work shows that there's more than one way to close the cost gap with vehicles powered by internal-combustion engines (ICEs) while still improving performance.[1] Some companies, following the Tesla model, are moving boldly with native EV platforms, which are expensive—requiring an up-front investment of $1 billion or more—but offer advantages, notably a much bigger area for batteries (Exhibit 2). This in turn lets companies offer purchasers a wider range of mileage options. Native platforms also give automakers the flexibility to offer a variety of drivetrains (front-, rear-, and all-wheel drive), and additional options, such as more trunk space. Other manufacturers, by contrast, are adapting their current ICE platforms with targeted electrification, thus avoiding higher up-front investments as they strive to keep costs down in today's admittedly modest sales environment. These models often have smaller batteries (with shorter ranges) and fewer expensive options, such as digital entertainment systems.

All players, meanwhile, benefit from continuing advances in manufacturing technology and component design (for example, integrated powertrain components that reduce the number and weight of power cables). And across the board, manufacturers are coming closer to hitting the cost benchmarks established by ICE vehicles, so economies of scale in production and components are continuing.

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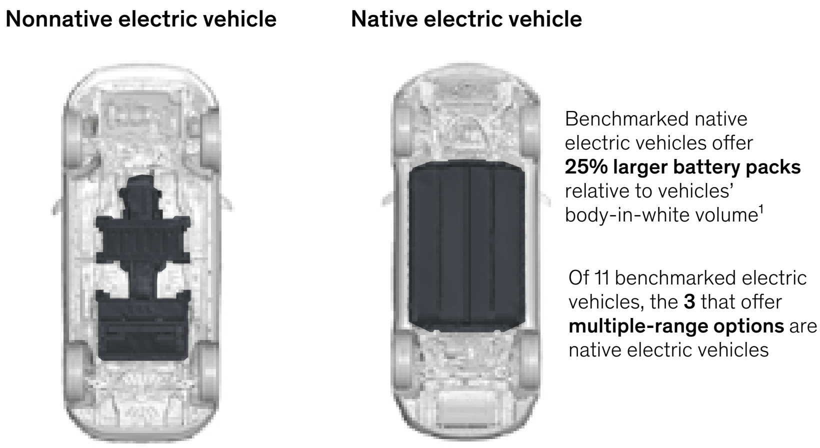
[1] See Antoine Chatelain, Mauro Erriquez, Pierre-Yves Moulière, and Philip Schäfer, "What a teardown of the latest electric vehicles reveals about the future of mass-market EVs," March 2018, McKinsey.com.

Exhibit 2

Batteries of native electric vehicles require less compromise and allow for greater flexibility.

Battery-pack architecture



[1] That is, measured at the stage when the car body's sheet-metal components have been welded together.
Source: A2Mac1; McKinsey Center for Future Mobility

Looking ahead to 2025–30, we expect the margin gap between EVs and conventional vehicles to shrink considerably. For example, if today's technology trends continue, battery costs will decline by 50 percent over the period—a big deal, since batteries represent one-quarter of today's EV cost premium (for a look at another area of energy innovation in mobility, see the next article in this package, "Hydrogen cars or battery electric vehicles—why not both?"). Already we've seen a steady flattening of learning curves for R&D on manufacturing and key components. Providing another economic lift will be government regulations that increase purchases in an effort to nudge along the transition to EVs. With higher sales volumes, companies can spread their higher fixed costs more effectively. As the cost gap narrows, more companies will gain the confidence to step up investments in native EV platforms. That will both provide for higher-performing vehicles, which are more attractive to consumers, and encourage cross-model platform sharing, which currently gives ICE production a cost edge.

This isn't to say there won't be rough patches along the road ahead. Continuing bursts of technical innovation and sometimes painful business-model adaptation will be needed to bridge the cost and manufacturing divide with today's cars—which, of course, have benefitted from decades of trial and error. Still, considering that a decade ago EV sales barely made a ripple in the pond of global auto revenues, market dynamics seem to be moving in the right direction, rapidly, for EV manufacturing.

Patrick Hertzke is a partner in McKinsey's Detroit office, **Martin Linder** is a partner in the Munich office, and **Shivika Sahdev** is an associate partner in the New York office.

Hydrogen cars or battery electric vehicles—why not both?

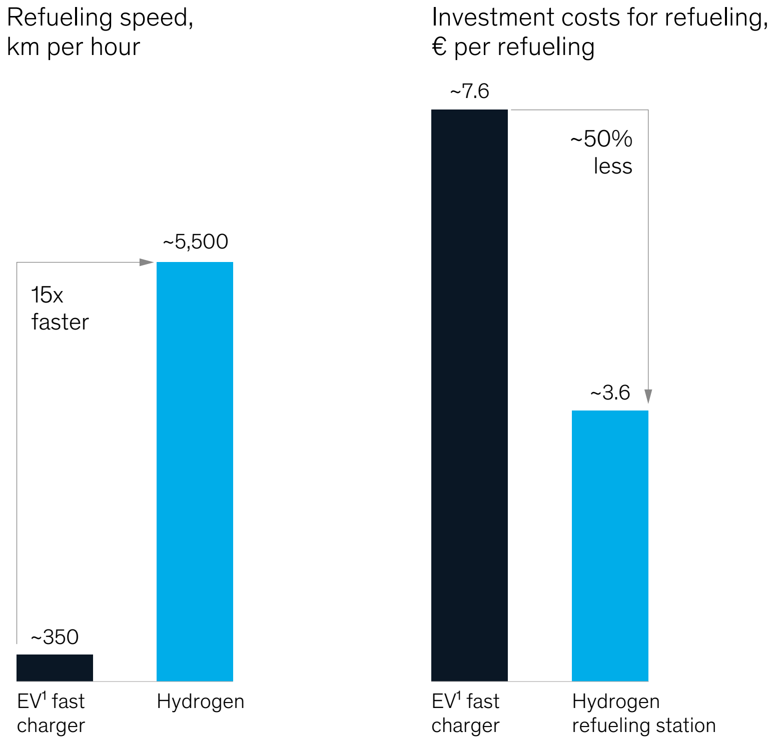
The future of carbon-free mobility may not be a winner-takes-all duel between electric batteries and hydrogen fuel cells.

by Bernd Heid, Martin Linder, and Markus Wilthaner

Battery-powered electric vehicles (EVs) are not the only alternative to cars with internal-combustion engines. Vehicles powered by hydrogen fuel cells have already begun trickling into select markets across Asia, Europe, and North America. While significant technical and infrastructure challenges remain, hydrogen offers several advantages over batteries. For starters, hydrogen vehicles fuel up relatively quickly—about 15 times faster than battery-powered EVs that use so-called fast-charging technology. Hydrogen refueling is also half as capital intensive as EV fast charging and requires about ten times less space (exhibit). In addition,

Exhibit

Among lower-emission options, hydrogen vehicles fuel up faster, and hydrogen refueling is half as capital intensive as refueling electric vehicles.



[1] Electric vehicle.
Source: Nationale Plattform Elektromobilität (NPE); Fastned; Forschungszentrum Jülich; McKinsey analysis

EV fast-charger stations next to highways can easily require several power lines carrying multiple megawatts of electricity to cover peak load, but more flexible sources of renewable energy can power hydrogen fuel cells. And while battery-powered vehicles have significant consequences for natural resources—particularly cobalt, nickel, and lithium—hydrogen is the most common element in the universe.

Producing hydrogen, however, is costly, and at present fuel-cell vehicles are less commercially viable than EVs in most use cases. But heavier vehicles require heavier batteries; and the heavier the payload and the longer the range, the greater the opportunity for hydrogen power. A hydrogen-powered 40-ton semitruck, for example, when produced at scale, draws even with a battery-powered truck in system costs at slightly more than 100 kilometers of operation and allows for approximately three tons more payload as well. All this suggests that hydrogen vehicles and EVs could become complements in an increasingly decarbonized future.

Bernd Heid is a senior partner in McKinsey's Cologne office, **Martin Linder** is a partner in the Munich office, and **Markus Wilthaner** is an associate partner in the Vienna office.

Ridesharing and the great urban shift

High-income urbanites already embrace ridesharing. By focusing on ways to become even more indispensable to existing customers, ridesharing companies can take growth to the next level.

by Troy Baltic, Russell Hensley, and Jeff Salazar

For all the hype—and maybe because of it—it's tempting to dismiss ridesharing as a niche or an idea whose time has not yet come. It is seen as a niche because ridesharing's market share is still comparatively small; in the United States, the largest providers together account for only about 1 percent of total vehicle miles traveled (VMT). And it is seen as an idea whose time has not yet come because so long as there are human drivers, the economics of ridesharing will be tough for providers and users alike. That will change, almost certainly, when autonomous vehicles (AVs) are out in force. For now, however, the driver's cut of each fare is typically much larger than the ridesharing company's, leading ridesharing companies to invest hundreds of millions of dollars each year developing AVs. An "AV dividend" that could be shared with customers, though, remains a thing of the future. For consumers who drive more than about 3,500 miles a year—as some 90 to 95 percent of US car owners do—using your own vehicle is still the cheaper option.

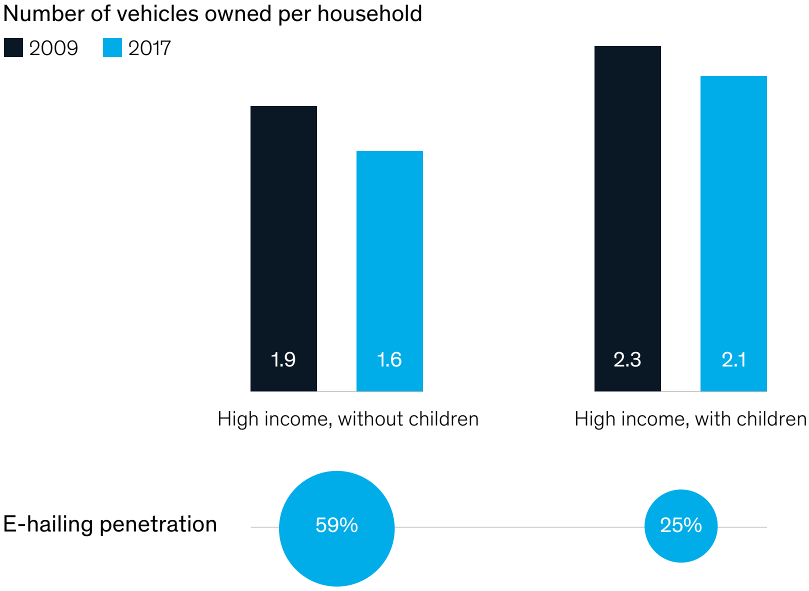
Even so, ridesharing is primed to accelerate. Globally, $55 billion has been invested in the industry in the past seven years. In the United States, this is a $30 billion market and growing. The country now has approximately ten metropolitan areas that generate $500 million or more in yearly ridesharing revenues, and compound annual growth rates are north of 150 percent. Perhaps most significant, data suggest that ridesharing's most important demographic—urban adopters—are experiencing a fundamental conceptual shift about car ownership. Among high-income urban consumers, ridesharing is increasing as vehicle ownership declines, a phenomenon that may have broader implications for car ownership in the future (exhibit).

Moreover, though ridesharing cost-per-mile has been settling in at about $2.50 in the United States since 2015 and fares are unlikely to rise in the near future, overall revenues still have plenty of room to run. Ridesharing companies can increase both the total number of trips users take and the average number of miles per trip by providing solutions for additional use cases—such as shopping trips, deliveries, trips with children, group nights on the town, and shared commutes, to name just a few—for core urban customers and new customers too.

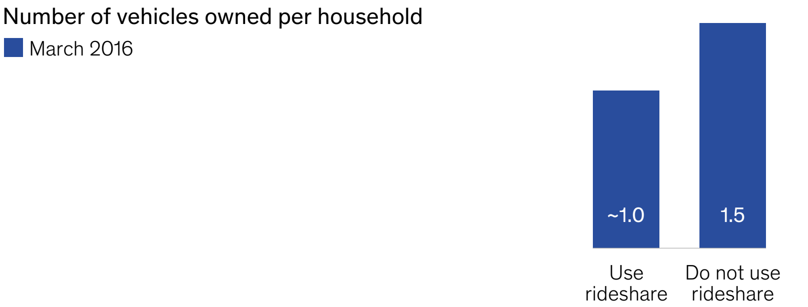
Exhibit

Core urban adoption of ridesharing today may have implications for car ownership tomorrow.

For US high-income urban households, ridesharing penetration is high even as vehicle ownership is falling ...



... and among all US households, those who use ridesharing own fewer vehicles.



[1] High-income households with children and those without children each represent 8% of US population.

Source: 2017 National Household Travel Survey, US Department of Transportation Federal Highway Administration; "Shared mobility and the transformation of public transit," March 2016, American Public Transportation Association; McKinsey analysis

Cost-effective design improvements offer a way forward. Adaptable and reconfigurable vehicle interiors make rides more comfortable and more accessible, and shopping trips and deliveries easier. They also provide for additional driver-focused improvements to make travel safer—a factor that women, in particular, identify as highly important. Design changes are especially compelling for commuters, seniors, and families. Tapping those opportunities can help put ridesharing on a trajectory toward 7 to 10 percent of VMT by 2030. In fact, achieving just a 2 to 3 percent share of VMT would increase ridesharing revenues by almost $40 billion.

Troy Baltic is an associate partner in McKinsey's Chicago office, **Russell Hensley** is a partner in the Detroit office, and **Jeff Salazar** is a partner in LUNAR, a McKinsey affiliate based in San Francisco.

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"Mobility's autonomous future"
Martin Kellner, Benedikt Kloss, Luca Pizzuto

"Connectivity: Turbocharging the new mobility ecosystem"
Saral Chauhan

"Bending the cost curve for electric vehicles"
Martin Kellner, Benedikt Kloss, Luca Pizzuto

"Hydrogen cars or battery electric vehicles—why not both?"
Hauke Engel, Jakob Fleischmann, Robin Katzenstein, Anna Orthofer, Henrike Schwickert

"Ridesharing and the great urban shift"
Shih-Yung Huang, Nathan Pfaff, Walter Thorn, Ben Veres

For more research, articles, and perspectives on mobility-related industries, or to learn more about the McKinsey Center for Future Mobility, visit McKinsey.com/mcfm.

Mapping the automotive software- and electronics landscape through 2030

The market for automotive software and for electrical and electronic components is expected to grow strongly in the next decade. What must companies know to succeed?

July 2019

Ondrej Burkacky , Johannes Deichmann, and Jan Paul Stein

Autonomous driving, connected vehicles, the electrification of the powertrain, and shared mobility (also called the ACES trends) are mutually reinforcing developments in the automotive sector. Combined, they are disrupting the automotive value chain and affecting all its stakeholders. Moreover, they are also significant drivers of the expected 7 percent compound annual growth rate in the market for automotive software and for electrical and electronic components (E/E), which is projected to grow to $469 billion, from $238 billion, between 2020 and 2030. At this rate, the software and E/E market is expected to outpace growth vastly in the overall automotive market, which is estimated to grow at a compound rate of 3 percent in the same time frame. Software and electronics have therefore become the focus of most automotive companies and their executives.

In this context, we offer a perspective based on our extensive research and analyses (see sidebar, “How we derived our insights”) on three crucial questions:

- What are the specific forces behind the automotive sector’s software and E/E growth dynamics and changing landscape through 2030?
- How will these forces affect the automotive industry’s long-established value chains?
- How can players inside and outside the industry optimally prepare for upcoming market developments?

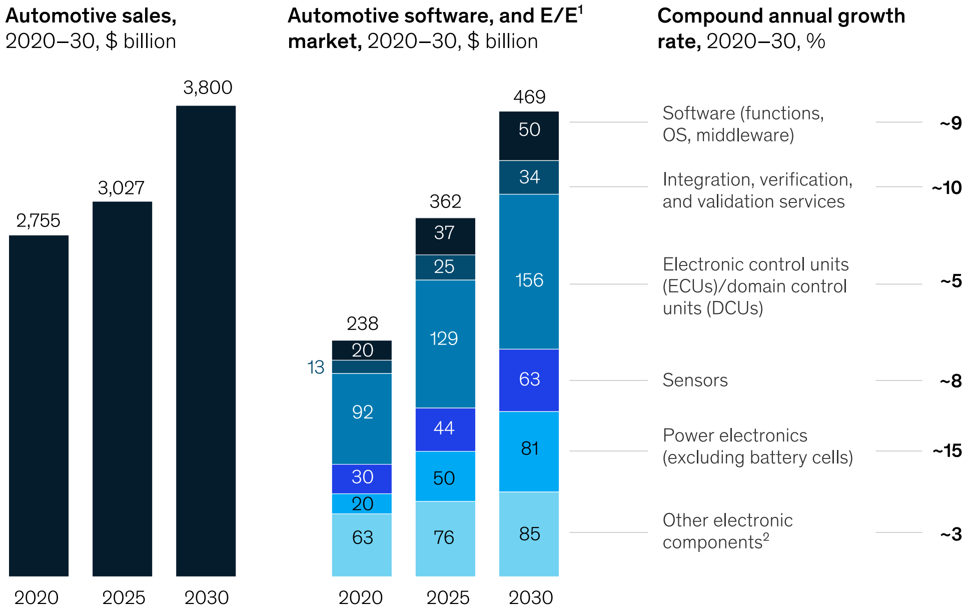
Our new report, *Automotive software and electronics 2030*, looks closely at these issues. The remainder of this excerpt outlines some high-level findings.

The automotive software and E/E component market will grow rapidly, with significant segment-level variation driven by the disparate impact of the ACES trends.

The overall trend toward a more centralized software and E/E architecture will drive the market’s expected expansion through 2030 (projected at a 7 percent compound annual growth rate). Significant variation is expected across the market’s segments (exhibit).

Exhibit

The automotive electronic and software market will see a strong growth through 2030, driven by power electronics, software, ECUs, and DCUs.



Note: Figures may not sum, because of rounding.
[1]Electrical and electronic components.
[2]For example, harnesses, controls, switches, displays.
Source: IHS; McKinsey analysis

Power electronics is expected to occupy the high end of the market's growth, at an annual rate of 15 percent. Autonomous driving will fuel growth in the software and sensors segments, expected to reach 9 percent and 8 percent, respectively. The segment that includes electronic control units (ECUs) and domain control units (DCUs) will continue to hold the largest share of the market, but growth here is likely to be relatively low, at 5 percent. While ECUs and DCUs will be used increasingly in autonomous-driving applications, price decreases from efficiency gains will counterbalance growth in the segment. Electric-vehicle platforms will be a new market for high-voltage harnesses, but the demand for low-voltage ones is expected to shrink, so the harness segment will grow at the slowest rate.

A separation of hardware and software would fundamentally change the dynamics of the automotive sector's landscape of players and value.

The days when OEMs comprehensively defined specifications and suppliers delivered them may be nearing an end. Neither OEMs nor traditional suppliers can fully define the technology requirements of new systems. Codevelopment between OEMs and suppliers is expected to become not just prevalent but also necessary. In addition, tech-native companies are expected to enter the space more boldly—something that will become easier as hardware and software sourcing become more separate. This separation would break up established value pools, reducing barriers to entry. For OEMs, the separation would also make sourcing more competitive and scaling less complex, and it would provide a standardized platform for application software while maintaining competition on the hardware side.

Both archetype-specific and cross-player strategies can position companies for success in the future landscape.

The strategic moves for OEMs include plans to keep the ever-growing cost of hardware and software development under control and to establish more agile cross-functional development organizations. Cross-functionality would benefit tier-one suppliers too, and so would actively partnering with OEMs to define their E/E architectures. Tier-two suppliers will want to specialize further and scale within an attractive niche to thrive even as many components become commodities. All players will benefit from building their software-delivery and E/E-architecture capabilities, embracing the latest technological innovations (including those related to the user interface, the user experience, and analytics), and abandoning absolutist notions of competition while analyzing the benefits of partnership within an emerging ecosystem .

About the author(s)

Ondrej Burkacky is a partner in McKinsey's Munich office, where **Jan Paul Stein** is a consultant. **Johannes Deichmann** is an associate partner in the Stuttgart office.

The authors wish to thank the Global Semiconductors Alliance and its members for their continued support and valuable contributions to the report.

Expanding electric vehicle adoption despite early growing pains

The latest analysis of our Electric Vehicle Index shows the global electric-light-vehicle industry continues to make solid progress. To accelerate growth further, several hurdles need to be overcome.

August 2019

by Patrick Hertzke, Nicolai Müller, Patrick Schaufuss, Stephanie Schenk, and Ting Wu

The global electric-vehicle (EV) industry continues to expand rapidly. However, regional performance varies, with some EV markets approaching near-mainstream status, while others remain stuck in neutral. Overall, global EV-sales volumes are becoming large enough to create substantial profit pools for well-positioned suppliers and other upstream players—but they are also having a negative impact on traditional OEM profit margins. The entire power-train value chain continues to recalibrate as OEMs follow different sourcing strategies across e-power-train components and as many incumbents, plus new suppliers, enter the market. In the current highly competitive environment, the ultimate winners have yet to be determined. With the breakeven for EVs still a few years away, OEMs are feeling the heat. To accelerate and ensure sustainable, profitable growth, the industry still needs to overcome several challenges. (For more on the research underlying this article, see sidebar, "What is the Electric Vehicle Index?")

Continued electric-vehicle growth through 2018

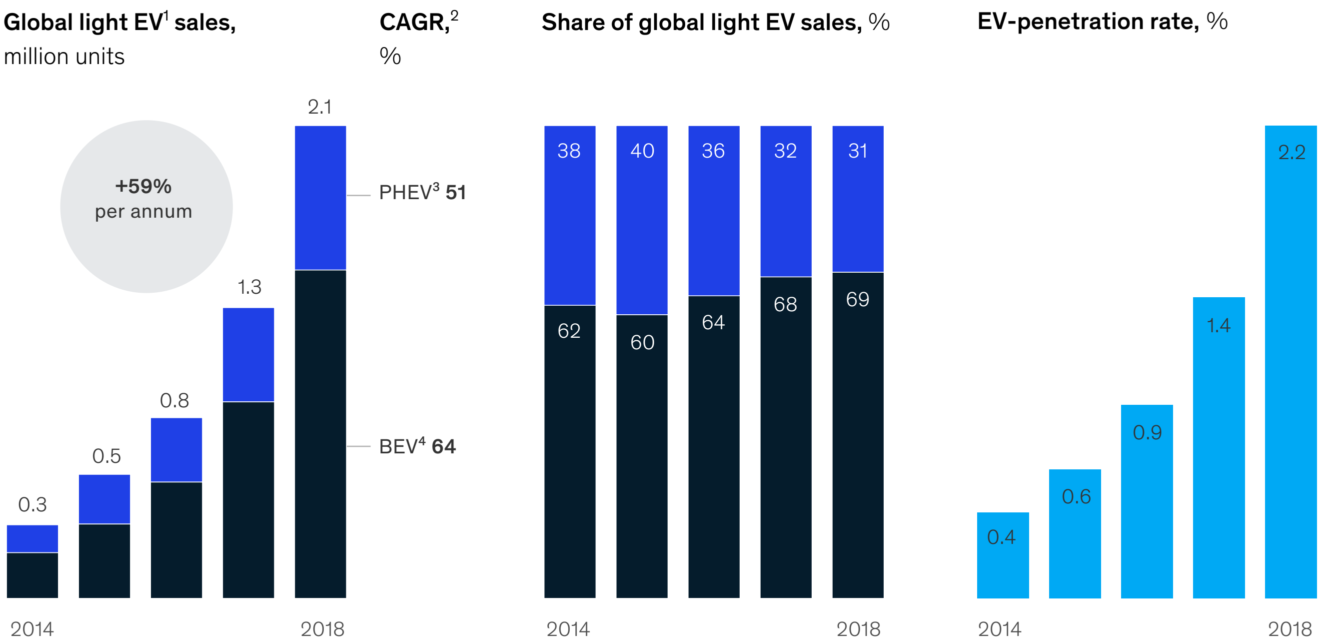
EV sales grew to more than two million units globally in 2018: an increase of 63 percent on a year-on-year basis, and a rate slightly higher than in prior years. Nevertheless, with a penetration rate of 2.2 percent, EVs still only represent a fraction of the overall light-vehicle market. The ratio of battery EVs (BEVs) to plug-in hybrid EVs (PHEVs) held relatively steady from 2017 (Exhibit 1).

Electric-vehicle-market snapshots

Regional performance varies considerably, with some EV markets approaching near-mainstream status, while others are simply marking time. A breakdown of EV-industry progress through 2018 by select countries or regions follows.

Exhibit 1

The global market for electric vehicles has grown at about 60 percent per year, reaching 2.1 million in 2018.



[1] Electric vehicle. [2] Compound annual growth rate. [3] Plug-in hybrid electric vehicle. [4] Battery electric vehicle.

Source: EV-Volumes.com; McKinsey analysis

What is the Electric Vehicle Index?

McKinsey's proprietary Electric Vehicle Index (EVI) assesses the e-mobility performance of 15 key countries around the world. It focuses on light-vehicle adoption as well as plug-in electric cars (battery electric vehicles (EVs) and plug-in hybrid EVs). Since the creation of the EVI several years ago, it has served as a critical tool to help organizations exposed to the automotive, mobility, and energy sectors understand how EV dynamics have evolved at a granular level and where they are trending for the future.

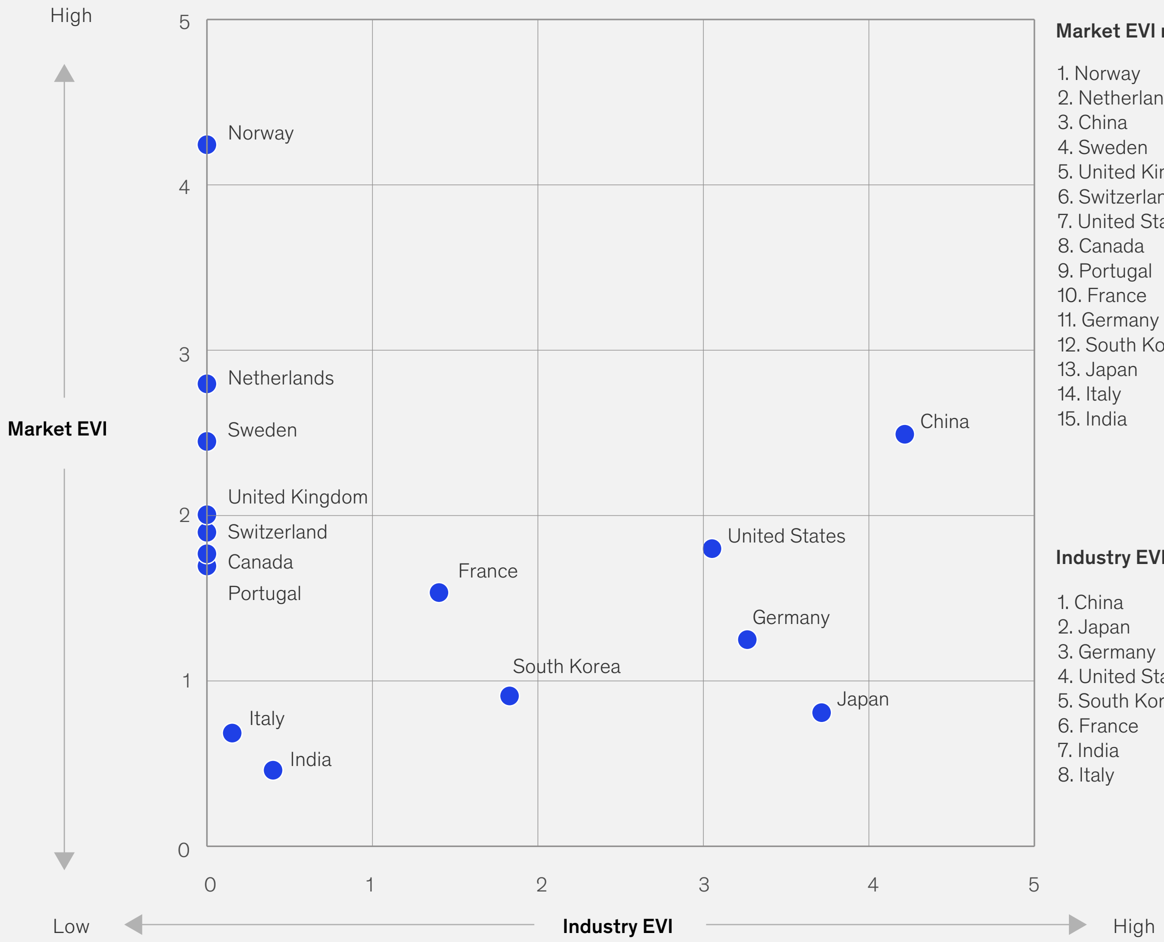
The index explores two important dimensions in the advance of electric mobility: markets and demand, on the one hand, and industries and supply, on the other. On the market side, it analyzes the share of EVs in the overall market. It also looks at incentives, such as subsidies; the existing infrastructure; and the range of EVs available. The industry side determines how successfully the automotive sector in each country has supported electric mobility. It involves analyzing a range of factors, such as the current and future share of EVs in the global production of vehicles, and incorporates key components, such as e-motors and batteries.

The EVI assesses every country on its key performance indicators and accumulates a score from zero to five. It then translates these into an overall weighted score, which is the basis for the final EVI matrix and country ranking (exhibit).

Exhibit

Norway leads electric-vehicle adoption on the market side, while China excels on the industry side.

Overall Electric Vehicle Index (EVI) results, score (range from low of 0 to high of 5)



Market EVI ranking

1. Norway
2. Netherlands
3. China
4. Sweden
5. United Kingdom
6. Switzerland
7. United States
8. Canada
9. Portugal
10. France
11. Germany
12. South Korea
13. Japan
14. Italy
15. India

Industry EVI ranking

1. China
2. Japan
3. Germany
4. United States
5. South Korea
6. France
7. India
8. Italy

Source: McKinsey analysis

China leads

China's EV market grew 85 percent over the prior year, significantly above the industry average. The market experienced healthy growth—despite a subsidy cut by the government, which significantly impeded sales of micro EVs that once represented around half of the Chinese EV market.

For BEVs in China in 2018, the minimum performance on electric range was increased to 150 kilometers (km), from 100 km, and the minimum performance on energy density rose to 105 watt-hours per kilogram (Wh/kg), from 90 Wh/kg. The government once more raised the bar for 2019, to 250 km and 125 Wh/kg, respectively. While last year, BEVs with a very high range and energy density benefited from an increase in subsidies, the government has now cut the incentives at all levels.

Standing at 1.1 million units, or 51 percent of global EV sales in 2018, China's EV market is now about three times the size of the European and US markets each (Exhibit 2). With the government aiming to phase out subsidies entirely by next year, OEMs are in doubt that the market will be robust enough to sustain its growth beyond 2020. Furthermore, the trend toward an overall market decline (light-vehicle sales fell around 15 percent through May 2019 compared with last year) might also affect the EV segment going forward.

Europe's mixed signals

The European EV market saw moderate growth (an increase of 90,000 units), with a mixed picture at the country level. Norway remains significantly ahead of other markets and appears on its way to mass-market adoption. Large markets (in absolute light-vehicle-unit sales terms) such as France, Germany, and the United Kingdom still have to gain momentum, with EV-market shares of around 2 percent, while comparably small Nordic countries, like Norway (40 percent market share), Iceland (17 percent), and Sweden (7 percent), currently perform the best. However, tightening CO_2-emission regulation will most likely lead to significantly larger market shares for EVs across Europe through 2020–21 and beyond.

North America gets an electric-vehicle boost

The US market almost doubled to 360,000 EV units, mainly because of the strong sales performance of Tesla's Model 3. Tesla sold 140,000 Model 3 cars in 2018, making it the best-selling EV in the United States (40 percent market share) and globally (7 percent). For the first time in the country, an EV model sold equally as well as comparable internal-combustion-engine (ICE) cars. While high sales numbers for the Model 3 in 2018 were partially supported by EV tax credits and high demand from the list of reservation holders, they still show that EVs can be attractive alternatives to gasoline-powered cars and that a strong market potential exists for a growing number of premium and mass-premium buyers. Nevertheless, sustainable market growth will also depend on regulatory developments, given ongoing discussions among federal and national parties regarding the rollback of 2025 fuel-economy standards as well as state authority under the Clean Air Act.

Japan follows a portfolio approach

Japan lost momentum from 2017, when sales increased by 142 percent driven by the introduction of a next-generation PHEV model. In 2018, the market declined by 9 percent compared with the year before, with EV penetration standing at only 1 percent. While Japanese OEMs were among the first movers with respect to the introduction of EVs, the country now lacks a strong push for more aggressive adoption. There has been some activity around BEVs recently, with Japanese OEMs moving from full hybrids and hydrogen fuel cells to pure battery-electric technology, as the former alternative-propulsion technologies struggle to win widespread global support.

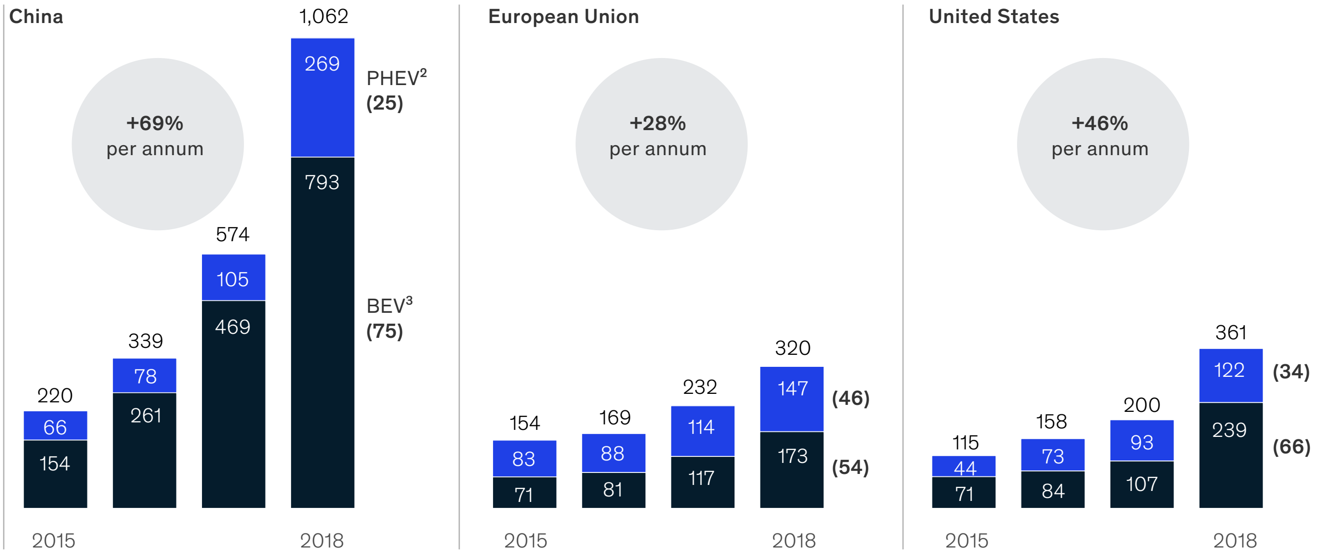
India's four-wheel market remains stalled, but two- and three-wheelers accelerate

The Indian EV market remains largely driven by mass- and low-cost-mobility segments, such as two- and three-wheelers. Recent government policies and those under debate could steeply accelerate electrification in these segments (for instance, differentiated tax policy promoting EVs and localized incentives to promote start-ups).

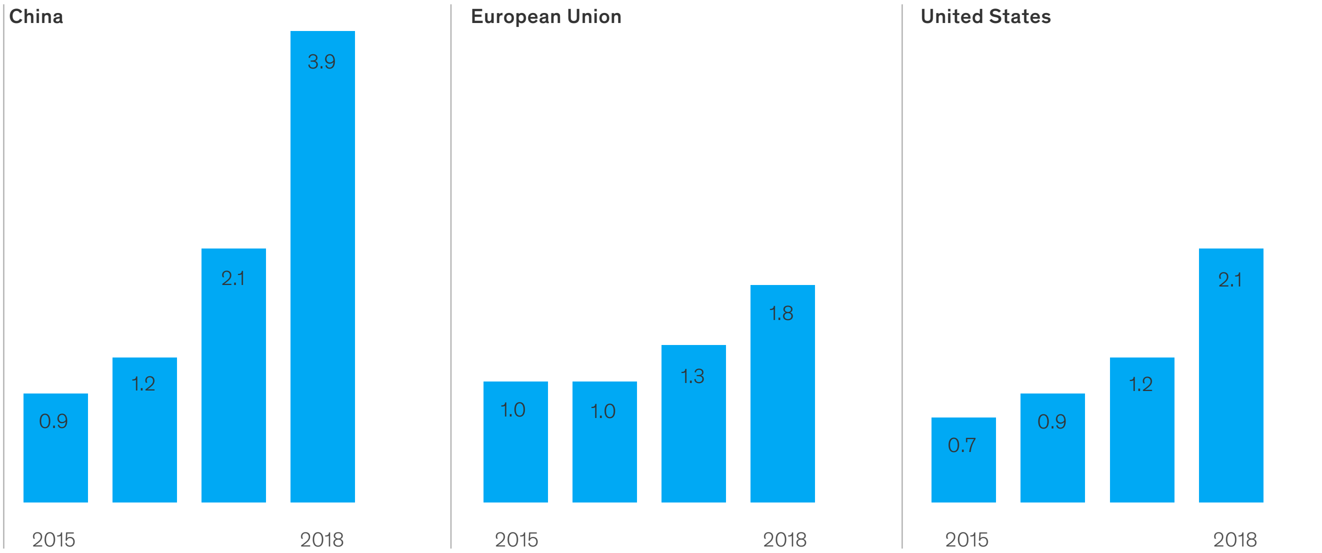
Exhibit 2

China's electric-vehicle market is three times the size of that of Europe or the United States.

Light EV[1] sales, by region, thousand units (% share of EV market)



Light-EV-penetration rate among overall light-vehicle sales, by region, %



China
- New models continually introduced
- Government phasing out EV-subsidy program by end of 2020
- Corporate Average Fuel Consumption and New Energy Vehicles dual-credit scheme applies as of 2019

European Union
- Competitive premium-EV models launched
- New CO_2-emission targets for 2025 and 2030
- Transition from New European Driving Cycle to Worldwide Harmonized Light Vehicle Test Procedure

United States
- Tesla Model 3 production scaled up
- Emission targets most likely relaxed until 2025
- New-model launches by key US brands

Note: Figures may not sum, because of rounding.

[1] Electric vehicle. [2] Plug-in hybrid electric vehicle. [3] Battery electric vehicle..

Source: EV-Volumes.com; McKinsey analysis

In addition to such regulatory tailwinds, product innovation in the form of new two- and three-wheel EV models rolling out each year (using longer-range lithium-ion batteries) and new business models, such as battery swapping, are having an impact. On the other hand, four-wheel EV sales have been almost unnoticeable so far, with fewer than 2,000 units sold in 2018 out of a total light-vehicle sales volume of four million units. Insufficient four-wheel consumer-focused government incentive schemes, limited models, price-sensitive consumers, and a lack of charging-infrastructure investment (public or private) are persistent challenges. Benchmarking policies focused on what other markets are doing could improve this situation, as could increases in EV imports while domestic players retool for EV production. This year, the government announced plans to order ride-hailing companies to convert 40 percent of their fleets to electric by 2026.

The global outlook for electric vehicles

Tesla is now the world's largest EV producer, followed by two Chinese automakers, BYD and BAIC Motor. However, industry observers project that in 2019 and 2020, the intensity of competition will heat up significantly, with competitive models launched by several international premium brands. Overall, international OEMs are expected to launch 66 EV models in 2019 and 101 models in 2020, including several models in larger D and E segments—as well as SUVs and crossovers (Exhibit 3). These launches are part of a bigger strategy, as automakers need to comply with increasingly stringent CO_2-emission regulations in Europe as well as Corporate Average Fuel Consumption (CAFC), New-Energy Vehicle (NEV), and other regulations in China.

The industry needs the emission relief EVs provide—especially in Europe, where average industry fleet emissions did not decrease for two consecutive years in 2016 and 2017. In addition, the European Union agreed last year—as the first market globally—to commit to even more stringent CO_2-emission targets through 2030, aiming to reduce CO_2 emissions by 37.5 percent from 2021 to 2030.

In China, the industry in aggregate overachieved its 2018 CAFC target of 6.3 liters per 100 km, while several international joint-venture companies and imported brands missed their individual targets (offset by positive credits carried over from past years). The enforcement of the EV-credit-quota system in 2019 and 2020, as well as the increasing stringency of CAFC targets, should support rapid EV growth. International OEMs should catch up on CAFC progress because of an increase in EV sales through new-model launches, although they may benefit less from government purchases.

Challenges to overcome to scale electric vehicles

While EV manufacturers continue to make progress in developing EVs with greater range, more power, and superior styling, the industry still needs to overcome several challenges to accelerate growth and scale EVs in a sustainable way.

Making bold choices to accelerate electric-vehicle profitability

Automotive-OEM-profitability compression because of EVs and other advanced technology is now a top concern for management: EV investments ramp higher each year, and increasing losses are tied to negative margins for most EV models sold in 2018. However, if OEMs pull the right levers, there are options to make EVs profitable. In the short term to midterm, these include redesigning EVs with new approaches to content trade-offs, expanding partnerships with mobility players, and making bolder moves to partner with competing OEMs on platform development and manufacturing. For a deep dive on the topic, see our article "Making electric vehicles profitable" on McKinsey.com.

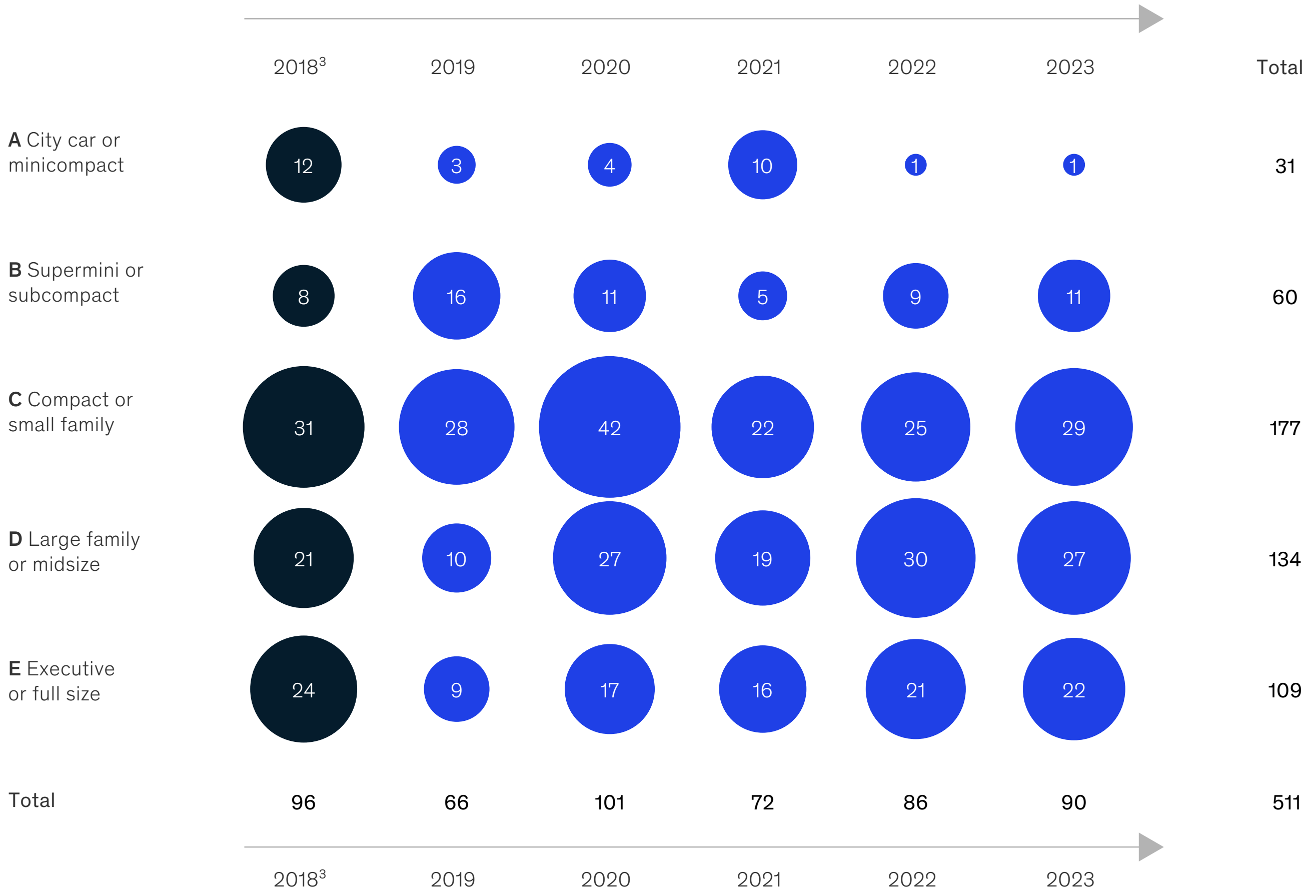
Synchronizing the electric-vehicle value chain

Across these different markets, we continue to find that OEM strategies to develop and promote EVs are not always in sync or well supported by all players in the e-mobility ecosystem. Recent shortages in battery-cell production leading to long waiting periods for some EVs in Europe is just one

Exhibit 3

Established OEMs are expected to launch around 400 new electric-vehicle models through 2023.

Existing and newly launched BEV[1] and PHEV[2] models by vehicle segment, number of model launches



[1] Battery electric vehicle. [2] Plug-in hybrid electric vehicle. [3] Cars actually produced in 2018. All subsequent year numbers are estimates by segment.

Source: IHS Markit; McKinsey analysis

example. An integrated approach across industries and government leaders would ease the burden. For example, greater clarity with respect to national- and city-level emissions and air-quality regulations through 2030 would help to do three things: provide greater ability to plan necessary investments in new mining production for raw materials, such as nickel and cobalt; ramp up localized battery-cell production with room to grow; and improve OEM volume planning. Similarly, the coordination of renewables ramp-up to meet greater electricity demand, potentially paired with second-life EV batteries to avoid peak-load strains on the grid, could be another "unlock." For further information, see our publications *Race 2050—a vision for the European automotive industry* and "Second-life EV batteries: The newest value pool in energy storage" on McKinsey.com.

Further expanding the model range

Despite the numerous model launches announced by international automakers for 2019–20, the available options still skew predominantly toward higher-priced premium vehicles. Mass-market EV choices that are competitively priced with existing volume-brand ICE vehicles are currently slated to hit the showrooms later. Accelerating availability of small, affordable vehicles will be especially important in early-stage price-sensitive EV markets, such as Brazil and India. More affordable options will also be critical for tapping into demand in mobility services—for example, independent ride-hailing drivers.

In markets such as China, small BEVs are frequently nearing—or at—purchase-price parity with ICE vehicles, especially with subsidies, and they are cheaper on a total-cost-of-ownership basis. Markets like the United States, which is heavily skewed toward large-vehicle demand, will need to take a different approach with models that can go head to head with today's crossovers and SUVs. Higher-range expectations for these vehicles may force OEMs to pursue greater scale at a global platform level and to partner up to drive costs down in batteries, e-motors, and other power electronics.

Industry and government can also collaborate to make strides in the decarbonization of transport and equipment and the improvement in air quality in cities through greater investments in, and promotion of, e-buses, EV commercial vehicles or e-trucks, and off-highway electrification (for example, in construction equipment and material handling). If the expected total-cost-of-ownership benefits in energy and maintenance costs are borne out in the test fleets rolling out across the globe from 2019 to 2022, we expect the pace of adoption to increase sharply in these vehicle types, as the economic benefits for businesses will be hard to ignore. For further information, see our articles "Harnessing momentum for electrification in heavy machinery and equipment" and "Fast transit: Why urban e-buses lead electric-vehicle growth" on McKinsey.com.

The global EV industry has accomplished major achievements in a relatively short time, driven by regulatory pressure, strong technical innovation in batteries, and increasing investment in EV platforms. But as EV markets continue their rapid but sometimes unpredictable growth toward mass-market proportions, automakers have begun to experience growing pains in their supply chains and in their bottom-line results. Fortunately, long-term cost trends continue to head downward, and in the near term, there are still many levers that the industry can pull. However, solutions for OEMs will require bolder moves, new design and business-model thinking, and better collaboration with suppliers, governments, fleets, and even competitors. For an industry that typically plans in two or three five-year product cycles, we may now be roughly one product cycle away from a more sustainable automotive market, with respect to both carbon footprint and OEM economics.

Patrick Hertzke is a partner in McKinsey's Detroit office; **Nicolai Müller** is a senior partner in the Cologne office, where **Patrick Schaufuss** is an associate partner and **Stephanie Schenk** is a research specialist; and **Ting Wu** is a partner in the Shenzhen office.

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Making electric vehicles profitable

March 2019
by Yeon Baik, Russell Hensley, Patrick Hertzke, and Stefan Knupfer

Introduction

The future looks bright for electric-vehicle (EV) growth. Consumers are more willing than ever to consider buying EVs, and sales are rising fast. Most major markets have consistently registered 50 to 60 percent growth in recent years, albeit from small bases. More new models from a growing cadre of automotive OEMs make finding a suitable EV easier: in 2018 alone OEMs launched about 100 new models and sold two million units in total globally. Likewise, performance improvements continue with respect to range, performance, and reliability. Regulations in major car markets—namely China, the European Union, and the United States—compel OEMs to produce more EVs and encourage consumers to buy them.

However, there is a problem: today, most OEMs do not make a profit from the sale of EVs. In fact, these vehicles often cost $12,000 more to produce than comparable vehicles powered by internal-combustion engines (ICEs) in the small- to midsize-car segment and the small-utility-vehicle segment (Exhibit 1). What is more, carmakers often struggle to recoup those costs through pricing alone. The result: apart from a few premium models, OEMs stand to lose money on almost every EV sold, which is clearly unsustainable.

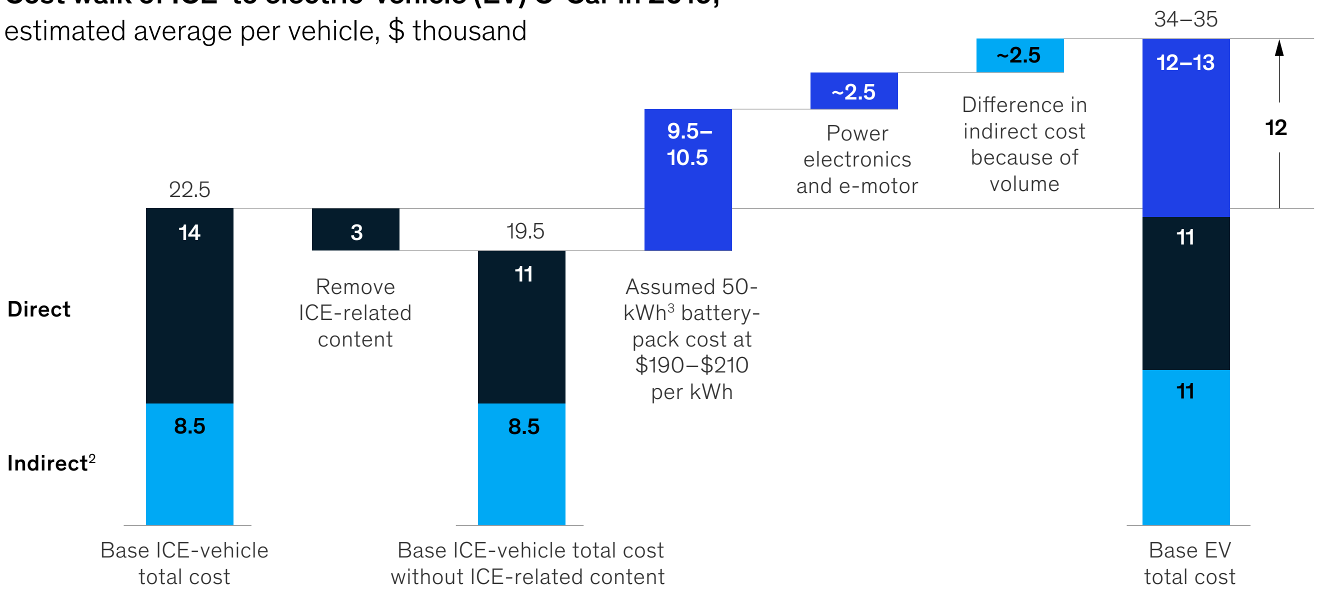
Many carmakers appear to be resigned to this fate, at least for now. Battery costs represent the largest single factor in this price differential. As industry battery prices decline, perhaps five to seven years from now, the economics of EVs should shift from red to green. Current thinking holds that the industry will continue to produce EVs—largely because it has little alternative in the face of stringent fuel-economy and emissions policies—and that the industry will, in the meantime, absorb the losses.

Our analyses show that better options exist, even today, to accelerate the industry toward profitability from both product and business-model perspectives. Some of these options include aggressively reducing cost through "decontenting," optimizing range for urban mobility, partnering with other automakers to reduce R&D and capital expenditures, targeting specific customer segments, and exploring battery leasing.

Exhibit 1

There's a cost gap of about $12,000 between electric vehicles and internal-combustion-engine vehicles today

Cost walk of ICE[1] to electric-vehicle (EV) C-Car in 2019,
estimated average per vehicle, $ thousand



[1]Internal combustion engine.
[2]Includes average incentive cost of $2,000.
[3]Kilowatt-hour; includes battery-management system.
Source: Industry experts; UBS; McKinsey analysis

An industry in a jam

Understanding the challenges and opportunities for OEMs requires examination of the changing landscape of consumer attitudes, product availability, EV economics, and regulatory tailwinds.

Consumer preferences on electric vehicles

Consumers' EV preferences are shifting. The share of global consumers that would consider purchasing an EV is on the rise. In the United States, between 10 and 30 percent of consumers indicated their preference to consider an EV as their next purchase on national surveys.[1] In Europe, the reported share of consumers considering EV purchase was higher, at 40 to 60 percent,[2] and in China, it was over 70 percent, given the presence of strong government incentives to adopt these vehicles.[3] This trend is even more pronounced among customers younger than 50 years old living in urban areas. Sales in 2018 only provide a partial view, given that EVs accounted for less than 5 percent of sales in most markets. However, the pace of change tells a different story, with annual sales' growth rates now frequently in the range of 100 percent or more.

Product availability

On the supply side, this increasing demand will be met with a broader set of choices. Today, new EV models are launching at a rate of approximately

1 Russell Hensley, Patrick Hertzke, Stefan M. Knupfer, Nicolaas Kramer, Nicholas Laverty, and Patrick Schaufuss, "Electrifying insights: How automakers can drive electrified vehicle sales and profitability," January 2017, McKinsey.com; "AAA: 1-in-5 U.S. drivers want an electric vehicle," AAA NewsRoom, May 8, 2018, newsroom.aaa.com;"; Hoang Nguyen, "Middle of the road: An analysis of the automotive sector," YouGov, January 9, 2019, today.yougov.com.

2 Russell Hensley, Patrick Hertzke, Stefan M. Knupfer, Nicolaas Kramer, Nicholas Laverty, and Patrick Schaufuss, "Electrifying insights: How automakers can drive electrified vehicle sales and profitability," January 2017; "Electric Vehicles Survey results," Dalia Research, November 1, 2016, daliaresearch.com.

3 "Consumers in China increasingly enthusiastic about new-energy vehicles and eager for battery technology advancement, J.D. Power Survey finds," J.D. Power, February 26, 2018, jdpower.com; China Youth Daily, August 2018, cyol.net.

120 a year, providing significantly more options regarding vehicle segment, performance, feature set, and value. Compare this with the prior seven years, during which new plug-in-hybrid-EV (PHEV) and battery-EV (BEV) launches globally averaged about 20 per year, often with premium prices. Historically, domestic Chinese OEMs provided the widest selection of models, but by 2020, most global OEMs across China, Europe, and the United States will offer a broad range of vehicles and price points.

Electric-vehicle economics

Our survey from 2017 also revealed that an EV's purchase price and driving range are the biggest hurdles to wider consumer adoption—and both are linked inextricably to battery economics.[4] Today, a typical BEV in the United States, priced around $30,000, does not provide a reasonable payback period for many buyers, given the size and cost of a battery pack; to recoup the price premium for an EV versus an ICE vehicle through savings on fuel and maintenance, the payback period is five to six years for an average US buyer driving 13,000 miles a year. For high-mileage drivers exceeding 30,000 miles per year—such as full-time cab, Uber, and Lyft drivers—EVs are already "in the money" during a typical two- to three-year ownership or lease period. Looking ahead, each 20 to 25 percent improvement in battery cost reduces payback by one year, but OEMs will need to take other actions to accelerate profitability.

Regulatory tailwind

The role of the regulator in today's EV landscape cannot be overstated. Ever-tightening government emissions regulations act as direct stimuli for OEM EV investments, and current subsidies and tax exemptions help bridge gaps between OEM pricing and consumer willingness to pay. In China, for example, the 2018 regulatory-incentive system, including supply and demand incentives and restrictions, pushed global EV sales above one million units.[5] However, China is not the only major market increasing regulatory pressure. In December 2018, the European Union's 28 member states agreed to new carbon-dioxide regulations that would set a target of 37.5 percent reduction in car emissions by 2030 when compared with 2021. This was significantly more aggressive than the European Commission's original proposal of a 30 percent reduction.

[4] Russell Hensley, Patrick Hertzke, Stefan M. Knupfer, Nicolaas Kramer, Nicholas Laverty, and Patrick Schaufuss, "Electrifying insights: How automakers can drive electrified vehicle sales and profitability," January 2017, McKinsey.com.

[5] Total EV sales in China from January to November 2018 was approximately 730,000.

Accelerating toward profitability

At the beginning of this article, we highlighted the fact that today's EVs are costlier to produce, and consumers have a rather limited willingness to pay a premium for EVs. The combination of these two factors leads to lower profitability of today's EVs versus today's ICE vehicles.

However, based on our analyses, it is possible to use today's technology to design a profitable EV—one that would be cost-competitive with ICE vehicles by the early to mid-2020s. In our study, we analyze the example of a small- to midsize EV that is today approximately $12,000 more costly, and therefore less profitable, than a similar ICE vehicle. The challenge: find cost and revenue levers to narrow the gap.

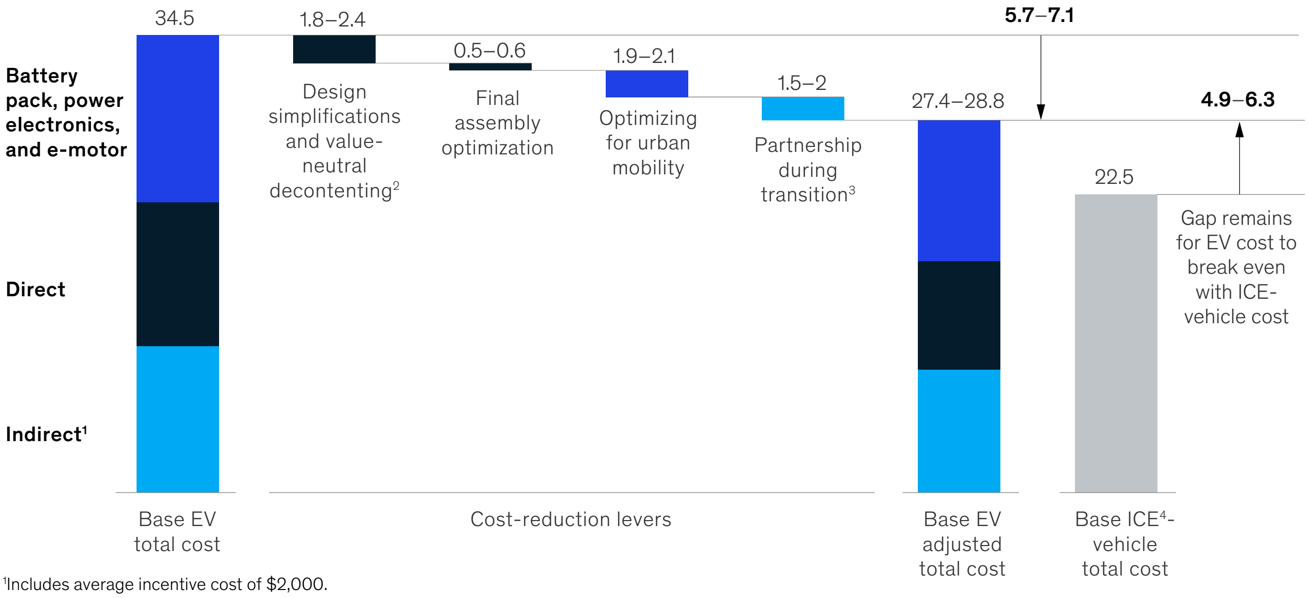
Optimize electric-vehicle designs for the market

We believe OEMs can reduce their EV costs by $5,700 to $7,100 by pursuing strategic decontenting paired with a dedicated EV platform (Exhibit 2). This could be accomplished leveraging new freedom in design unlocked by using electric rather than ICE subsystems and applying leading strategies in low-cost ICE design and from cutting-edge EV-focused OEMs.

Exhibit 2

Cost-reduction levers could bring down electric-vehicle costs considerably

Base electric-vehicle (EV) total cost, with cost-reduction levers in 2019,
estimated average per vehicle, $ thousand



[1]Includes average incentive cost of $2,000.
[2]Reduction in non–internal-combustion-engine (ICE) content that does not affect safety.
[3]Assumes combined average annual production of ~150,000 units.
[4]Internal combustion engine.
Source: Industry experts; McKinsey analysis

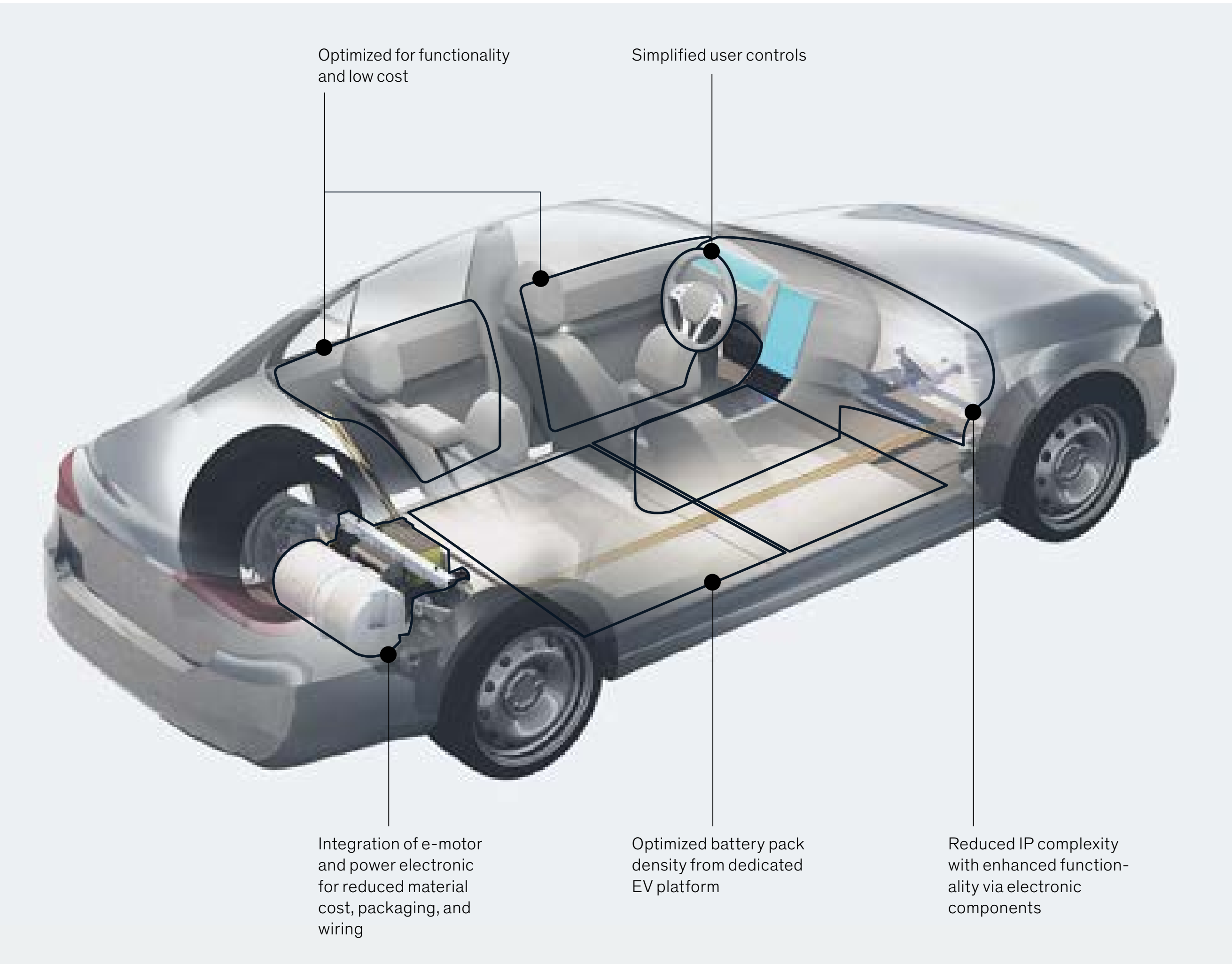
Design simplifications and value-neutral decontenting

OEMs can take lessons from leading e-vehicle concepts, for which our proprietary teardown study revealed that cockpit, electronics, and body simplifications netted up to $600 in reduced costs, without removing core feature content tied to value generation for the OEM.[1] Eliminating extra displays, buttons, switches, wiring, modules, and additional structural components, as well as reducing the overall design complexity, drove major savings. Our experts also noted that OEMs can only capture all of these material cost savings when using a dedicated EV platform that enables better packaging of interior cabin space, power electronics, motors, and battery packs. However, we also gain insights by benchmarking low-cost designs from the non-EV world. Our analysis shows that OEMs can apply these learnings and create fun-to-drive and simple vehicles costing $1,300 to $1,800 less through smart feature choices, design-specification adjustments, and manufacturing improvements—all without compromising safety. Some of these content choices include using more basic vehicle electronics with fewer powered options, straightforward body styling and lighting, uncomplicated seat designs, and simplified interior trim (Exhibit 3). Our work suggests that companies can extract component savings of 20 to 30 percent with these design approaches, including by adjusting material specifications and negotiating with suppliers with the shared objective of EV profitability.

1 Antoine Chatelain, Mauro Erriquez, Pierre-Yves Moulière, and Philip Schäfer, "What a teardown of the latest electric vehicles reveals about the future of mass-market EVs," March 2018, McKinsey.com.

Exhibit 3

Decontenting or design revision may be an opportunity for electric vehicles



Source: McKinsey

Optimizing for urban mobility

For many customer segments, today's EVs offer either too little driving range, such as smaller EVs with ranges of fewer than 100 miles, or too much, such as luxury EVs with ranges of approximately 300 miles, when compared to actual driving patterns. The average vehicle-miles traveled (VMT) for an urban population is around 20 miles per day in the United States, and it increases to around 30 miles per day when accounting for demographic groups that drive more.[2] Assuming today's battery efficiency in kilowatt-hours (kWh) per mile, a potential sweet spot for urban customers is approximately 25 kWh of energy. However, if we account for consumer preference to use the same vehicle for suburban and occasional rural travel, the optimal battery capacity increases to approximately 40 kWh, equating to~250 kilometers, or about 160 miles, based on average VMT in rural areas. A reduction in battery capacity to 40 kWh, from 50 kWh, would save $1,900 to $2,100 today, while the range would still enable most consumers, especially those in urban environments, to complete trips without any sacrifice to their daily routines.

Final assembly optimization

Our recent study of EV design also suggests that a purpose-built EV platform is simpler to assemble and could deliver up to $600 in savings per vehicle in lower fixed-cost allocation.[3] That savings come from having fewer components to assemble in an optimized EV platform and requiring less capital in EV-only plants versus complex plants that combine ICE-vehicle and EV lines.

Partnership during the transition

During the next five to seven years, as the industry transitions toward electrification but struggles with profitability, automakers should more strongly consider partnering and collaborating with competitors. At a time when OEMs face the possibility of retooling numerous models and platforms for electrification, collaborating with other OEMs can reduce the fixed-cost burden of R&D, tooling, and plants. Benefits will be especially high if OEMs can share EV platforms and plants, which can still enable multiple model variants. These alliances will also be most beneficial when they enable higher-volume procurement of the same battery cells and power electronics to take advantage of scale that is otherwise elusive when going it alone. In fact, some automakers have already announced a range of different global partnerships focused on reducing the cost of designing and producing EVs.[4] In our analysis, we examined the impact of two OEMs codeveloping a dedicated EV platform, which could lead to two to three times the volume spread across a similar fixed-cost base—reducing costs by $1,500 to $2,000 per vehicle.

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2 Summary of travel trends: 2017 National Household Travel Survey, US Department of Transportation, July 2018, nhts.ornl.gov.

3 Antoine Chatelain, Mauro Erriquez, Pierre-Yves Moulière, and Philip Schäfer, "What a teardown of the latest electric vehicles reveals about the future of mass-market EVs," March 2018, McKinsey.com.

4 In August 2017, Mazda Toyota announced a joint-venture plant in the United States at the cost of $1.6 billion, where the two companies will work together on EVs, in-car electronics, and advanced safety, with projected annual production capacity of 300,000. In January 2019, Ford and VW announced a memorandum of understanding to explore partnership options for EV development.

Boosting margins beyond cost cutting

OEMs could explore several other efforts to improve margins.

Communicating electric-vehicle economics to customers

Per insights from EV-consumer surveys, some consumer subsegments may present the opportunity to boost take rates and pricing.[1] This analysis suggests that more than 40 percent of EV shoppers may be willing to pay a small premium, but history shows that convincing even the most enthusiastic customers to pay a more significant premium is difficult.

We see more opportunities in a targeted “value-selling” approach, in which OEMs find ways to explain better the full economic benefits of an EV. For example, a consumer paying 10 percent more for an EV than for an ICE vehicle will achieve breakeven with a comparable ICE vehicle in close to one year if he or she also includes fueling and maintenance costs in the calculation. However, our dealer surveys show that this approach is rarely used. OEMs must do a better job in informing all stakeholders in the sales channel to educate buyers regarding the benefits of EV ownership. For instance, spending an extra $20 per month in financing or lease payments juxtaposed with saving about $60 per month in fuel and maintenance costs should be a great deal for most consumers. This assumes annual mileage of roughly 14,000 miles, with consumers who drive more experiencing even larger paybacks.[2]

The economics for EV owners will also be better in cities like London, where EV drivers do not pay the congestion charge of £24 per day in 2019.

Exploring new business models

Automakers that take a bolder approach to closing the profitability gap can also experiment with a range of new business models for niche segments. Example ideas include targeted direct sales to fleets and battery leasing (Exhibit 4).

Economically, it makes sense to target fleet customers with EV models, given that these fleets typically fall into a high-mileage category in which the total cost of ownership (TCO) of EVs is beneficial—and they prioritize TCO higher than other buying factors. Direct selling to these customers can reduce selling costs by about $1,000 per vehicle by circumventing showroom costs. Given the positive business case for fleet customers and their more predictable and simple charging logistics, these customer segments are early use cases for high EV take rates.

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1 Russell Hensley, Patrick Hertzke, Stefan M. Knupfer, Nicolaas Kramer, Nicholas Laverty, and Patrick Schaufuss, “Electrifying insights: How automakers can drive electrified vehicle sales and profitability,” January 2017, McKinsey.com.

2 According to ADAC, EVs are already reaching TCO parity at different segments in Germany (for example, smart EQ fortwo coupe versus smart fortwo 0.9 turbo and Tesla Model X 100D versus Audi SQ7 TDI), considering operating and maintenance costs, energy cost, and depreciation with an assumed holding period of five years with 15,000-kilometer annual mileage.

OEMs could offer to lease batteries separately from the vehicle and resell older batteries to the stationary storage market for secondary use. Battery leasing has a potential to attract consumers who shy away from purchasing an EV due to uncertainty in performance and degrading capacity of batteries today. OEMs operating a successful battery-leasing program could add more than $1,000 in revenue per vehicle during the assumed lease term of five years. A customer would be paying a monthly fee to lease the battery, with an assumption of added margin on the depreciated value of the battery pack.[3] This could be an increasingly viable profit-generating idea, but we still assume that this will only appeal to a minority of customers today.

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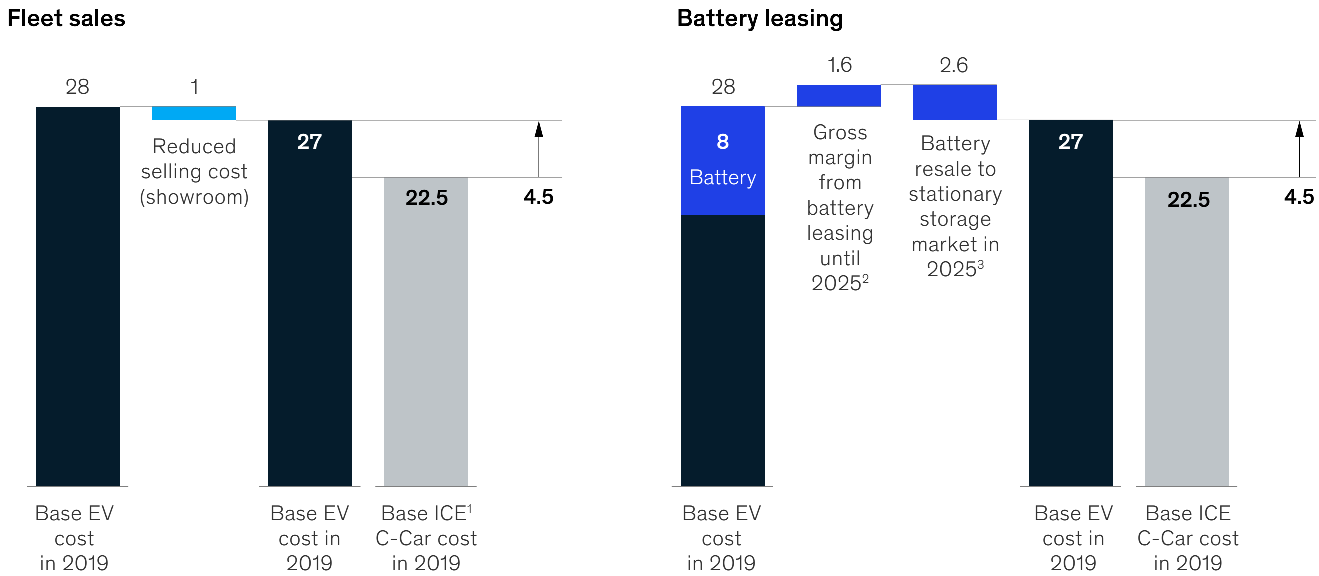
[3] Renault ZOE offers battery-leasing options to customers on its 41-kilowatt-hour battery-pack model, starting at £59 per month for 4,500 annual mileage up to £110 per month for unlimited mileage.

Exhibit 4

New business models, such as fleet sales and battery leasing, could improve profitability

Base electric-vehicle (EV) total cost with new business models for improved profitability, price per vehicle, $ thousand



[1]Internal combustion engine.
[2]Assumes 5-year leasing period; assumes 30% gross margin on depreciated value of battery pack.
[3]Assumes 70% original capacity; assumes resale to remanufacturer at ~$65 per kilowatt-hour in 2025 (assume no margin by OEM on resale of battery pack; remanufacture could potentially derive margin from repurposing battery pack).
Source: Industry experts; McKinsey analysis

Operating in an increasingly complex environment

Beyond cost and regulatory pressures, OEMs must also contend with an increasing complex set of choices in product design, capital allocation, and changing mobility dynamics in cities.

Product design

OEMs have reached a crossroads on vehicle-platform design, with a number starting to invest in "native," or purpose-built, EV platforms, while others primarily produce EVs based on modified ICE-vehicle platforms. Purpose-built EV platforms are lower in material cost and allow better performance in range, acceleration, and interior space. They do, however, come with additional investments in new, stand-alone platforms, leading to higher fixed-cost allocation, especially when initially produced in lower volumes.

Each automaker would need to save more than $4,000 per vehicle in direct materials cost to recoup the estimated $1 billion in incremental fixed costs for a dedicated platform if selling about 50,000 units per year over five years. Today's mass-market EVs typically sell at volumes between about 30,000 and 80,000 vehicles globally.[1] Significant debate, especially for passenger-car segments, resides around the choice of a pure EV platform versus a versatile platform that can house both EV and ICE power trains.

[1] 2018 Nissan Leaf sales are approximately 80,000 per year; Chevy Bolt sales are approximately 30,000 per year.

OEMs that choose to make a BEV or PHEV from a modified ICE platform to limit capital investment will often have to sacrifice higher material costs driven by the "overdesigned" platform and face challenges in battery packaging, not only in the same capacity (sacrificing range), but also in a less cost-efficient manner, potentially making them less exciting to consumers.

Capital allocation

In addition, we have witnessed bolder actions by cities to address air-quality challenges, and pressure will increase as demographic shifts favor migration of more people to urban areas. Cities are counting on EVs to be part of the solution, and, in many cases, individual-city emission regulations will be stricter and will require higher EV adoption than will national regulations. (See sidebar, "Changing mobility dynamics in cities: Micromobility's role," for a view on another part of the solution.) For example, in Beijing, license-plate restrictions continue to shift consumer demand to EVs, and taxi fleets are also going electric, with 70,000 EV taxis now on the streets. In Europe, London is expanding ultra-low-emission zones with daily fees and pushing to add charging stations at one out of every five parking spots. In the United States, cities such as San Jose offer consumer-purchase incentives of $2,500 on top of federal incentives to improve consumer economics, and California emission regulations are more stringent than regulations on the US federal level.

Changing mobility dynamics in cities: Micromobility's role

Microvehicle segments offer possible solutions but are not sufficient.

In parts of Asia, especially China and Southeast Asia, two-wheel and three-wheel e-scooters and e-rickshaws are playing an increasing role in electrifying transport. One example of a microvehicle is a low-speed electric vehicle (LSEV): these three- or four-wheel vehicles outsell mainstream EVs two to one, with approximately two million in sales per year in China.

However, consumers unfamiliar with two-wheel driving are not likely to switch, and LSEVs are limited to very low driving speeds and would not pass Western crash tests. The Chinese government is also debating more restrictions for LSEVs, as these vehicles are clogging roadways, require no licenses, and are threatening traditional EV growth.

Fast-forward to 2025: Electric-vehicle cost parity

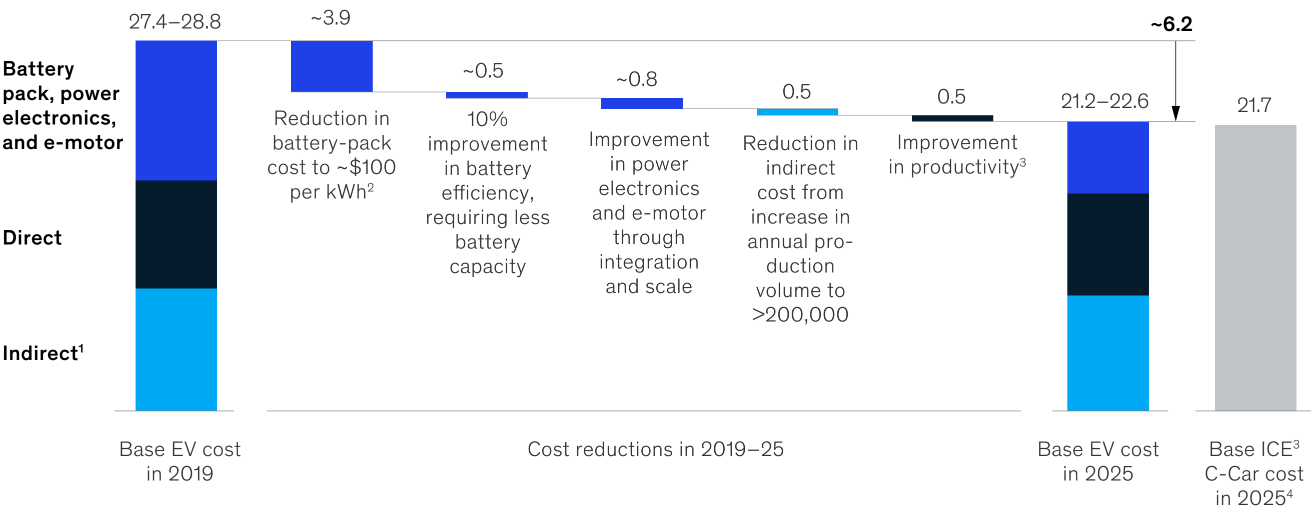
While not as profitable as ICE vehicles today, our analysis shows that EVs have the potential to reach cost parity with and become equally—or even more—profitable as ICE vehicles by around 2025 (Exhibit 5). McKinsey and other industry experts have conducted detailed studies on the potential cost trajectory for EVs, including battery-cost and efficiency improvements, power-electronics scale economies, and indirect cost reduction based on increased volume production. We believe these can unlock $5,100 to $5,700 in cost reductions per vehicle. We assume battery-cost and related price declines will continue, driven by chemistry and scale improvements, although it is fair to assume that we may witness short-term upward price movement in markets with constrained supply. Alternatively, we may see even faster price declines if competitive intensity rises among battery makers seeking volume.

Based on our analyses, an OEM could expect to break even in cost with EVs compared to ICE vehicles, and thus even achieve a profit margin of 2 to 3 percent per vehicle, in 2025. This scenario holds true in the absence of any premiums in pricing paid by consumers or any subsidies provided by governments. Application of the newer business models described above are also excluded here.

Exhibit 5

By 2025, cost reductions could greatly improve electric-vehicle profitability

Base electric-vehicle (EV) total estimated cost per vehicle in 2025 under the aggressive scenario, $ thousand



[1]Includes average incentive cost of $2,000.
[2]Kilowatt-hour; includes battery-management system.
[3]Internal combustion engine.
[4]Assumes 1% annual productivity improvement—reduced from historical value of 2–3% because of OEM investments in emerging technologies (eg, autonomous vehicle, electric power train, connectivity, shared mobility).
Source: Industry experts; McKinsey analysis

Conclusion

While it is true that the majority of EVs are not generating profits today, our analysis shows that OEMs should not be fatalistic about their plight, nor can they afford to wait for reductions in battery costs to change this dynamic. We believe there are multiple levers that automakers can pull, even today, to help accelerate their path toward mass-market EV profitability. Taken together, we believe that OEMs can reach a break-even cost basis for mass-market EVs compared to ICE vehicles in the next few years—and for some targeted customer segments, even achieve earlier and higher profitability with EVs.

Based on our analyses, accelerating EV profitability will, however, require some bold steps, including the following:

— making tough choices around EV-platform design, including balancing lower material cost with higher capital allocation and maximizing volume where possible

— applying more ambitious cost-reduction approaches to EVs, including design simplification, value-neutral decontenting, and aggressive purchasing strategies

— evaluating new potential partnerships with competitors to share R&D, tooling, and production costs for new EV platforms

— considering more creative use of alternative EV-specific business models that can boost margins

There is no debating that the next five years will be a challenging transition period for automakers and suppliers alike. Consumers, city dynamics, regulators, and competitors will increase pressure on most OEMs to switch more quickly from ICE vehicles to EVs, often with little consideration of EV economics.

The key debates are thus: Which automakers will crack the code of EV profitability first, what bold actions and visions will they pursue, and, as a result, how will the global automotive industry be permanently reshaped?

Authors

Yeon Baik is an associate partner in McKinsey's Chicago office, Russell Hensley and Patrick Hertzke are partners in the Detroit office, and Stefan Knupfer is a senior partner in the Stamford office.

Micromobility's 15,000-mile checkup

Will the micromobility market boom or bust? With billions already invested, here's an assessment of its potential.

January 2019

by Kersten Heineke , Benedikt Kloss, Darius Scurtu, and Florian Weig

Is the buzz surrounding shared micromobility[1] overwhelming its real-world potential? The business model has gained tremendous attention recently, as interest builds and new investment dollars flood into the space. But questions concerning the ultimate size and scope of the shared micromobility market have also emerged.

Micromobility rapidly attracts cash and customers

Stakeholders have invested more than $5.7 billion in micromobility start-ups since 2015, with more than 85 percent targeting China. The market has already attracted a strong customer base and has done so roughly two to three times faster than either car sharing or ride hailing. In just a few years, for instance, several micromobility start-ups have amassed valuations that exceed $1 billion.

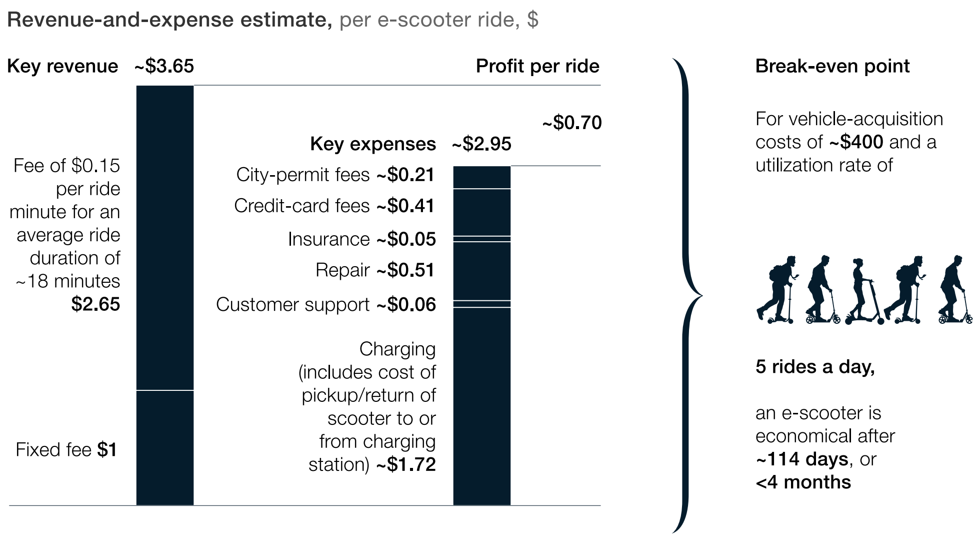
Two circumstances have driven this accelerated expansion. First, most launches of shared micromobility take place in conducive environments. Urban consumers already value and use solutions for shared mobility, such as car sharing, ridesharing, and e-hailing. What's more, micromobility appears to make people happy—it's faster than car-based trips in many situations, and users often say the freedom of being in the fresh air traveling to their destinations while avoiding traffic jams puts a smile on their face. Micromobility is perceived as “intuitive mobility” by design —it’s easy and liberating to buzz through traffic. It’s really quite simple: people feel rejuvenated, and the experience takes them back to their first time riding a bicycle or a scooter.

Favorable economics ensure lower break-even points

Second, the economics of shared micromobility are largely favorable to industry participants. Companies find it much easier to scale up micromobility assets (for example, electric bikes) compared with car-based sharing solutions. For example, the current acquisition costs of an electric scooter are about $400, compared with the thousands of dollars required to purchase a car. Thus, while today’s car-sharing solutions need several years to become economically viable, an outside-in business-case estimate of a leader in shared mobility shows that an e-scooter could break even in less than four months (Exhibit 1).

Exhibit 1

An e-scooter is economical after four months.



Source: Expert interviews; McKinsey analysis

More than a quarter of the world's population lives in cities with more than one million inhabitants. And vehicle traffic speeds in many of those city centers are now averaging as little as 15 kilometers an hour (9 miles per hour). This can be a frustrating and stressful experience. Micromobility offers some city dwellers an escape from that stress: higher average speeds, less time spent waiting or parking, a lower cost of ownership, and the health benefits of being outdoors.

How big is the market?

How big is it? Micromobility could theoretically encompass all passenger trips of less than 8 kilometers (5 miles), which account for as much as 50 to 60 percent of today's total passenger miles traveled in China, the European Union, and the United States. For example, about 60 percent of car trips are less than 8 kilometers and could benefit from micromobility solutions, which could also cover roughly 20 percent of public-transport travel (in addition to closing the first- and last-mile gap) as well as all trips done by private bike, moped, scooter, or walking today.

However, we estimate that shared micromobility will cannibalize only about 8 to 15 percent of this theoretical market. Constraints include its suitability for relevant mobility use cases (for example, limited space when going shopping), customer adoption, weather conditions, age fit, and micromobility's lower presence in rural areas.

Modeling a base-case market

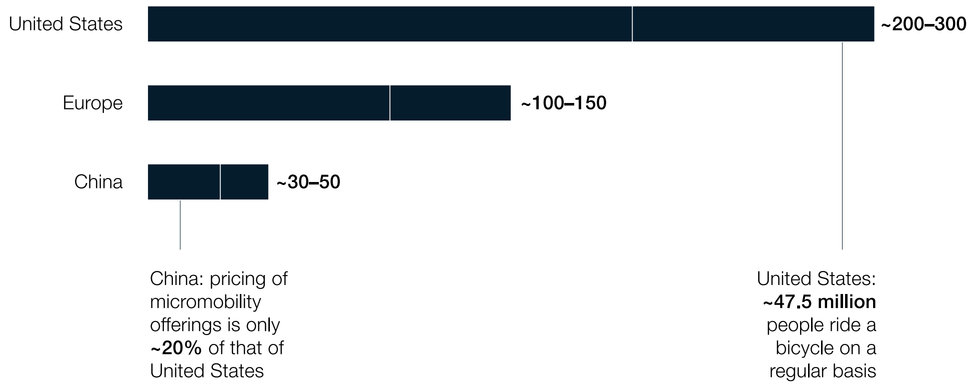
We modeled the baseline shared micromobility market and created a forecast, which revealed a 2030 market potential of roughly $200 billion to $300 billion in the United States, $100 billion to $150 billion in Europe, and $30 billion to $50 billion in China. The main differences across regions stem from unique pricing-per-kilometer strategies when comparing today's micromobility businesses. For instance, EU pricing is about half that in the United States, while China's is only roughly 20 percent of US pricing. In the future, such differences might shrink as pricing in some regions, such as China, increases.

Our base-case estimate of the shared micromobility market across China, the European Union, and the United States is, thus, $300 billion to $500 billion in 2030 (Exhibit 2). To put that into perspective, it equals about a quarter of our forecasted global shared autonomous-driving market potential of roughly $1,600 billion in 2030.

Exhibit 2

The shared micromobility market in China, Europe, and the United States could reach $300 billion to $500 billion by 2030.

Estimated size of micromobility market, by region, in 2030, $ billion



While the base case represents a healthy market, the question arises: What would you need to believe to grow the shared micromobility market into a truly disruptive trillion-dollar business?

For this market potential and mileage cannibalization to become a reality, cities need to support shared micromobility proactively. They could, for example, boost the micromobility business model further to resolve traffic pain points and congestion problems. Actions might include banning cars (but not e-scooters) from congested or polluted districts, or creating incentives for the use of micromobility for short trips by significantly increasing prices for car-based shared mobility. Cities could also install intermodal hubs to make the interchange between micromobility and public transport more convenient. However, micromobility players must tread carefully, since some cities today have been hesitant to adopt the service. Issues include customers who abandon old or damaged scooters on the street; safety concerns, which still play an important role; and the low entry barriers, which means that competitors could simply invest a bit more money to steal a player's entire customer base.

The micromobility phenomenon has the potential to disrupt the industry. Whether the disruption it causes matches the hype generated so far will largely depend on how cities react to the service. While the industry is hoping urban governments view micromobility favorably as an antidote to congestion and pollution, and a way to provide consumers with an enjoyable alternative to gridlock, cities could instead see it negatively. In fact, some anecdotal evidence of the latter has already surfaced. Consequently, in addition to building their businesses, micromobility players will likely have to take proactive roles in lobbying for and shaping the industry in key urban areas.

1. We define the shared micromobility market as shared electric bicycles, electric scooters, and electric mopeds, either in station-based or free-floating offerings.

About the author(s)

Kersten Heineke is a partner in McKinsey's Frankfurt office, where **Benedikt Kloss** is a consultant; **Darius Scurtu** is an analyst in the Munich office, where **Florian Weig** is a senior partner.

How sharing the road is likely to transform American mobility

Increased passenger density and decreased vehicle footprint should bring strong growth for ridesharing in the decade ahead.

April 2019

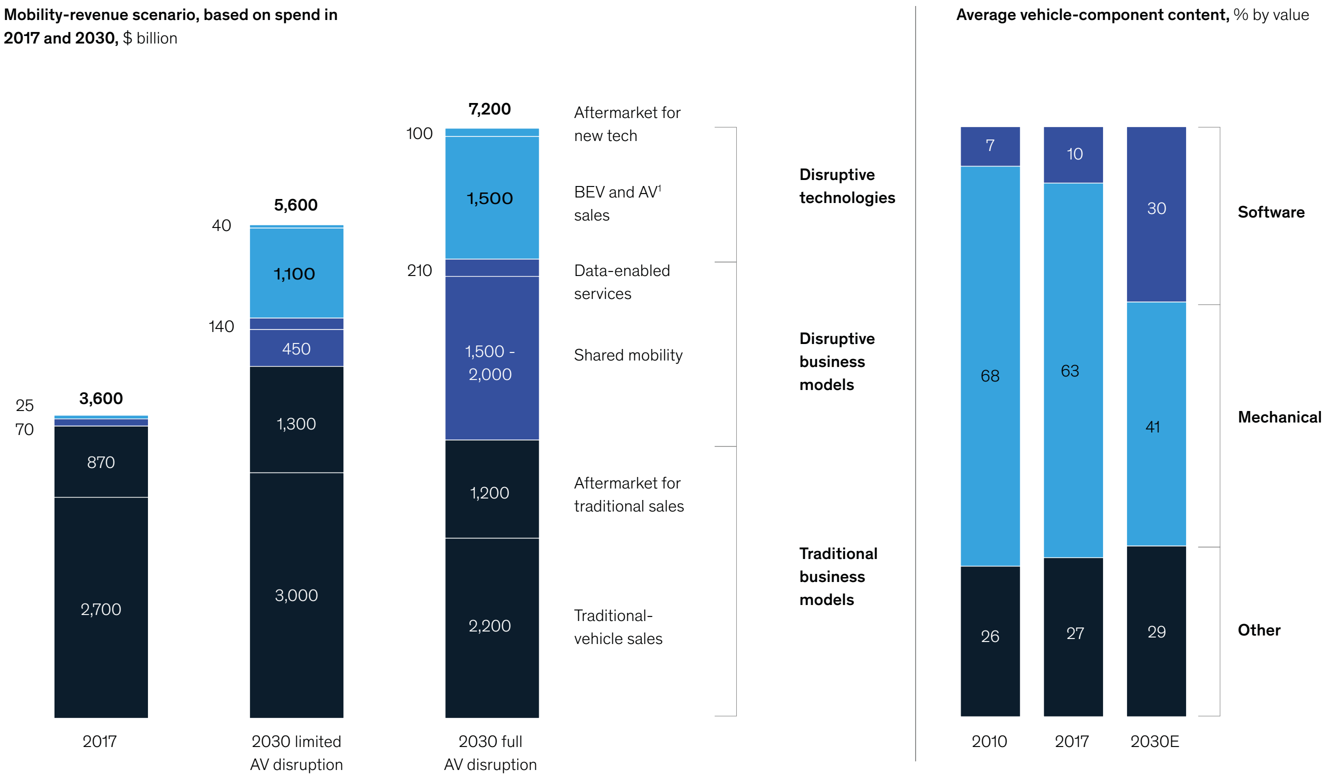
by Troy Baltic, Alex Cappy, Russell Hensley, and Nathan Pfaff

Getting around is about to get a lot more interesting. The mobility sector could well undergo a major overhaul in the next ten years, significantly upsetting traditional elements of the transportation industry and accelerating the shift from purchasing (or leasing) a vehicle as a product to consuming mobility as a service.

Four essential innovations are rapidly redefining modern mobility: autonomous vehicles (AVs), connected cars, electric vehicles (EVs), and shared-mobility services. These technologies will likely converge—think autonomous, electric-powered robo-taxis—and contribute to a new era of personal mobility (Exhibit 1).

Exhibit 1

Electric and autonomous vehicles will unlock new potential as revenues fragment from traditional streams and software content increases.



Note: Figures may not sum to 100%, because of rounding.
[1]Battery electric vehicle and automated vehicle.

When those technologies at last take hold, shared mobility—driven by fleets of autonomous robo-taxis —could generate the biggest slice of new revenues. That prize could amount to some $1.5-2.0 trillion in 2030. But while the dozen or so years until 2030 is not exactly a lifetime, it's still a long time, especially when the larger ridesharing companies continue to make significant billion-dollar investments each year and have not yet reached profitability.[1] Currently, a rideshare driver's net income consumes half of the total fares collected, and he or she must book two to three rides of 5-6 miles in distance to net $14 to $15 per hour—a pay level that's increasingly available for less demanding jobs in a tightening labor market. Driver retention is also one of the biggest costs in a rideshare company's profit-and-loss statement, and that cost can only go up.

Factor in that ridesharing currently only represents about 1 percent of US passenger-miles traveled (PMT) and that ridesharing's practicality decreases dramatically the further away from a city you happen to be, and one can understand the doubters. Is ridesharing destined to be confined to a small urban core? Investors might also fairly put the question another way: Just where is all the growth supposed to come from before the robo-taxis arrive?

Yes, the growth is real—and it's spectacular

Actually, ridesharing's growth potential in the near term is considerable. Overall e-hailing revenues have grown 185 percent per annum since 2013, amounting to a $35 billion to $40 billion market in 2018. Those revenues are largely a function of three things: the price of fares, the number of users, and the miles each user travels (itself a function of total trips multiplied by miles per trip).

The first input, number of users, has been growing rapidly. In the United States, e-hailing is offered in more than 260 cities. Indeed, user numbers have been well-nigh exponential up until 2018, roughly doubling in 2015, 2016, and 2017 before moderating in 2018. User convenience is a primary attraction.

The second input, fare price per mile, has indeed been running flat, and it now sits at approximately $2.50 per mile. For many users, the price isn't cheap. By comparison, the average cost of vehicle ownership is about $0.65 per mile if the vehicle drives around 12,000 to 13,000 miles annually. That's not to say that ridesharing users are dissatisfied, however. In fact, most customers report that they intend to use ridesharing even more frequently in the future. Historical numbers back up that assertion.

It's not surprising, then, that the third growth input, miles traveled, is growing rapidly and has much more room to run. Total US ridesharing trips now exceed two and a half billion per year, having increased at a compound annual growth rate of 160 percent from 2013 to 2018. Average ride distance has also been climbing, at a rate of 5 to 10 percent annually.

Unlocking the congestion paradox

Growth brings challenges, however, particularly the problem of congestion (Exhibit 2). E-hailing is already having a major impact on cities and suburban areas. Ridesharing is not simply a substitute for traditional modes of automobile transportation, such as personal vehicles, taxis, and rental cars. On the contrary, fully one-half of all ridesharing trips would not have been taken but for ridesharing. In the face of such challenges, some cities are taking aggressive action,[2] including capping total hailing licenses and setting wage floors for drivers.

Consider pooling as a potential solution. Shared commutes are relatively unpopular; many users, particularly businesspeople on the go, don't want to share their rides with strangers. Purpose-built shuttles, however, would offer greater individual comfort and privacy. Since standard individually e-hailed services still compose about 95 percent of all e-hailing trips, there are likely additional opportunities for shared rides to grow.

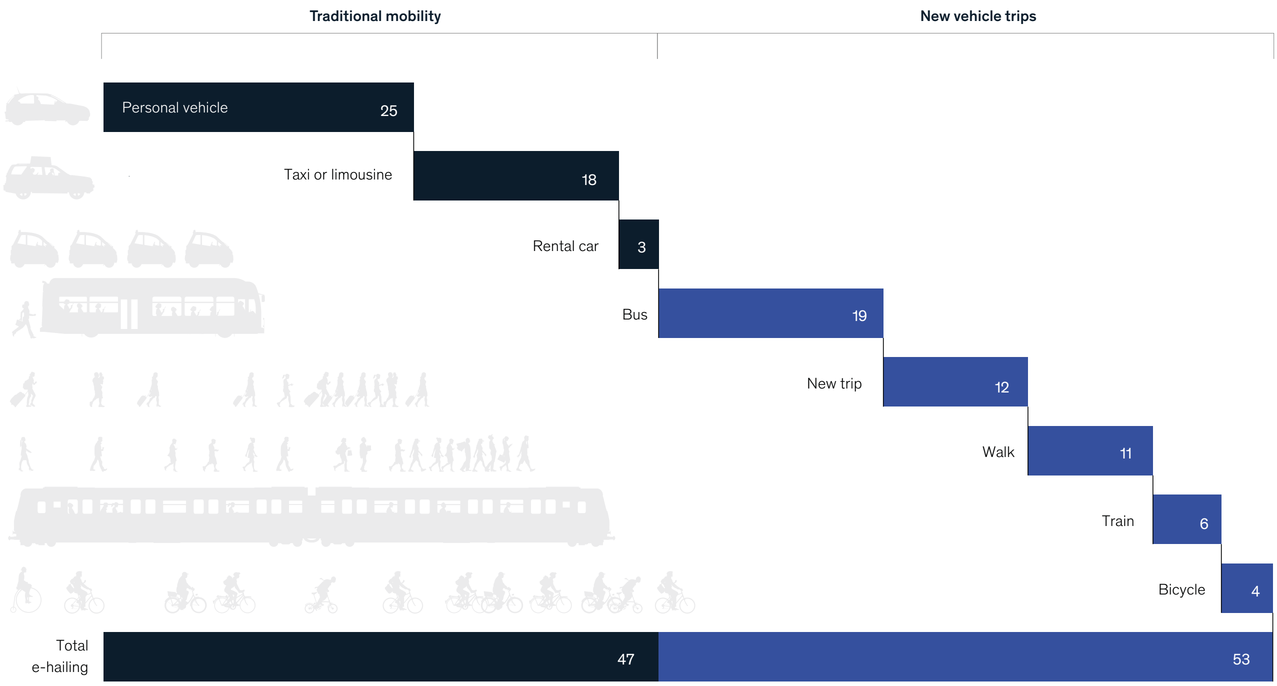
[1] Eric Newcomer, "Uber CEO embraces losing money with revenue growth slowing," Bloomberg, August 15, 2018, bloomberg.com.
[2] Peter Holley, "New York City sets $17 minimum wage for Uber, Lyft drivers," Chicago Tribune, December 5, 2018, chicagotribune.com.

The 'dockless' key to unlocking micromobility's appeal
Micromobility is one avenue to reducing vehicle footprint and relieving congestion on the roads, and it is boosting growth even more. Fares for these small, one- or two-passenger vehicles, most commonly bicycles, mopeds, and e-scooters, reached a modest $70 million in 2017 across more than 60 cities. However, the emergence of "dockless" e-bikes and e-scooters has changed the growth trajectory and interest; across 2017 and 2018, they logged a staggering ten times more trips during their first 12 months than did traditional-vehicle-based e-hailing solutions during the same early stages.

Exhibit 2

More than half of e-hailing trips are new passenger-vehicle miles, causing public concerns over growth in traffic and congestion.

E-hailing growth sources, % of trips that would have been taken by alternative mode of transport



Note: Figures may not sum to 100%, because of rounding.
Source: US Department of Transportation; McKinsey analysis

These new solutions allow users to pick up and park their vehicles anywhere along the sidewalk or at a bike rack within a defined district. That reduces infrastructure costs and allows for a greater number of the microvehicles to be deployed on streets closer to where consumers can easily use them. Just as important in building a passionate customer base, these solutions bring fun to the commute. Also, they offer a low-cost alternative, at $1.00 to $1.50 per mile, for first- and last-mile commuting trips of one to three miles in length.

Obviously, it's still early days. Early unit economics suggest a payback period of just four to seven months on e-scooters if they get five or more trips per charge cycle—but time will tell if the uncertainties about maintenance, charging, and redistribution expenses can work within feasible unit economics.

The dockless challenge with public perception

The externalities of micromobility are obvious to anyone reading the news regularly, as pushback has been vocal in some cities for very real reasons. Examples of measures already taken by cities include capping the total number of units, setting minimum-age conditions for use, and requiring special licensing for vehicles deemed too fast moving. Significant consumer pull, however, may temper the regulations—or, as proved to be the case for e-hailing automobiles, help roll back or even eliminate restrictions.

Through the looking glass

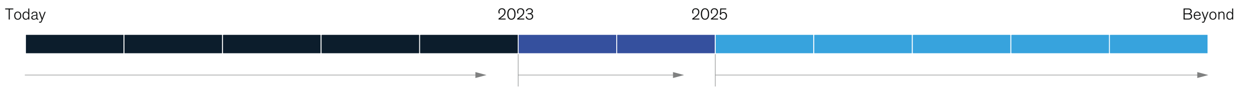
Most likely, the future will unfold as it always does: in stages. We expect to see three development horizons for shared mobility (Exhibit 3).

To start, look for additional growth in the core business to continue until about 2023 (or until autonomous solutions fully emerge), with shared mobility increasing to roughly 2 to 3 percent of all PMT (even if growth cools considerably). The primary growth driver will be trips taken—and even more trips, from a range of conceivable use cases, can be realized with cost-effective improvements in vehicle-interior design and by more widespread implementation of purpose-built vehicles beyond 2023. While growth in this initial phase could be higher, practically, some major cities will probably take increased action to check congestion.

Exhibit 3

Shared-mobility growth is likely to follow three horizons over the next decade, as we move toward autonomous vehicles.

Horizons, signposts, and what you have to believe



Growth of core

- Likely to increase to 2–3% of passenger-miles traveled, even if growth cools to 25% per annum
- City pushback likely to continue, based on congestion concerns
- Cost of ~$2.50 per mile likely remains same or is lower, based on cost of personal car; surge pricing is important element of economics

Expansion to last-mile, multimodal, and denser-occupancy solutions

- Potential for incremental increase of 2–5% in passenger-miles traveled—pooled and micromobility solutions emerge at scale and help alleviate congestion concerns
- Further upside if cities create environment and incentives for solutions to succeed
- Cost ~$1.00–$1.50 per mile

Game changing with autonomy

- Potential to address >20% of passenger-miles traveled
- Level 4 autonomy expected to be technically capable and address 60–75% of all miles traveled in United States, in both urban and suburban areas, by 2025
- Costs expected to fall to $0.60–$0.70 per mile by 2030—significant move, as it brings cost per mile lower than with personal-vehicle ownership

Building on—and to some extent running in parallel with—this initial horizon, the ridesharing industry will likely seek to expand to last-mile and multimodal solutions through 2025. The introduction of more pooled and micromobility services at scale during this second horizon has the potential to add more than two to five percentage points to PMT. The key to growth rests with cities. While some cities may actively encourage micromobility and create room for smart growth or adopt a laissez-faire position (or at least a wait-and-see stance), it remains uncertain how much pushback cities will ultimately apply in the face of increasing numbers of e-bikes and scooters.

Finally, in the third horizon, the industry will approach escape velocity toward vehicle autonomy, starting to reach scale around 2023. (Self-driving cars are already on streets today.) Achieving SAE International Level 4 autonomy capabilities could help ridesharing companies reach, and even exceed, more than 20 percent of shared-mobility PMT in urban and suburban areas.

The impact could be profound for the auto industry, consumers, and cities. Early data suggest that high-income urban households are already shedding cars in favor of other mobility choices, while younger generations use ridesharing two to three times more than do those older than 55 and are increasingly less likely to get driver's licenses (according to a McKinsey US consumer survey). These data points suggest an openness to replace owned cars—or at least, use one's owned car much less—because of shared mobility.

As Niels Bohr was reputed to have said, prediction is always difficult, especially about the future. Shared mobility's growth could be incremental, or it could be quantum. In fact, it could well be both. With opportunities to increase passenger density, minimize vehicle footprint, and tack to favorable demographics, the arrow for ridesharing is almost certainly pointing up. How far, and how fast, will become apparent even before the AVs arrive.

Troy Baltic is an associate partner in McKinsey's Chicago office, **Alex Cappy** is an associate partner in the Amsterdam office, **Russell Hensley** is a partner in the Detroit office, and **Nathan Pfaff** is an associate partner in the Cleveland office.

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