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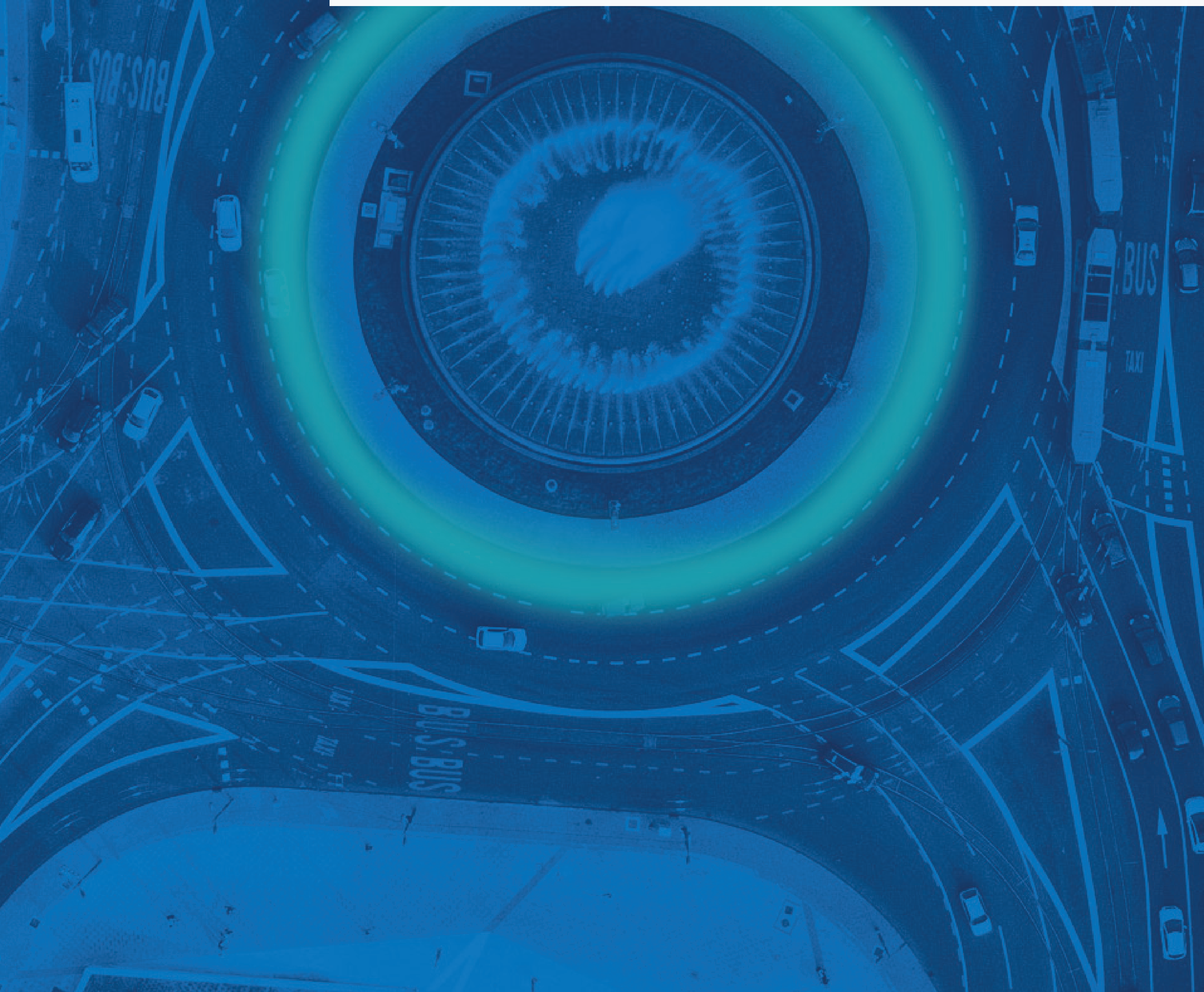
RESERVE A SEAT - THE FUTURE OF MOBILITY IS ARRIVING EARLY

2018 compendium



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Timo Moeller,
Asutosh Padhi,
Dickon Pinner,
Andreas Tschiesner

December 2018

What happened in 2018, and what can we expect in 2019?

We believe 2018 could represent a distinct tipping point from thinking, talking about, and planning for future mobility to implementing it. It's the year when a firework of electric-vehicle (EV) launches began and charging infrastructure became solid in key regions; when cars enabled by artificial intelligence (AI) began to replace "dumb" ones; when we moved from advanced driver-assistance systems to autonomous vehicles (AVs) in real life; when the automotive and mobility industries shifted from a driver- or owner-focused value proposition to a customer-centered one; and when micromobility started to scale up.

You can make the case that **all four ACES trends**—autonomous driving, connected cars, electrification, and smart mobility—made appreciable advances in 2018, despite some setbacks. It was the year when theoretical discussions about the future of mobility turned into concrete actions across businesses, cities, and key world regions. Please join us in reviewing some of the highlights from this singular year and exploring what the future could bring.

Autonomous vehicles

Possibly the furthest into the future measured by large-scale commercialization, **AVs still appear on track** in terms of technology. While manufacturers are still working to ensure safety requirements are met, they seem to have overcome major technology hurdles and most of them made exciting moves in 2018. OEMs are seriously considering AVs as a business. They reallocate capacity and their vehicle portfolio to free up cash for AV investments, restructure their organizations by moving key executives to AV business units and are most aggressive in forming partnerships with cities and local municipalities.

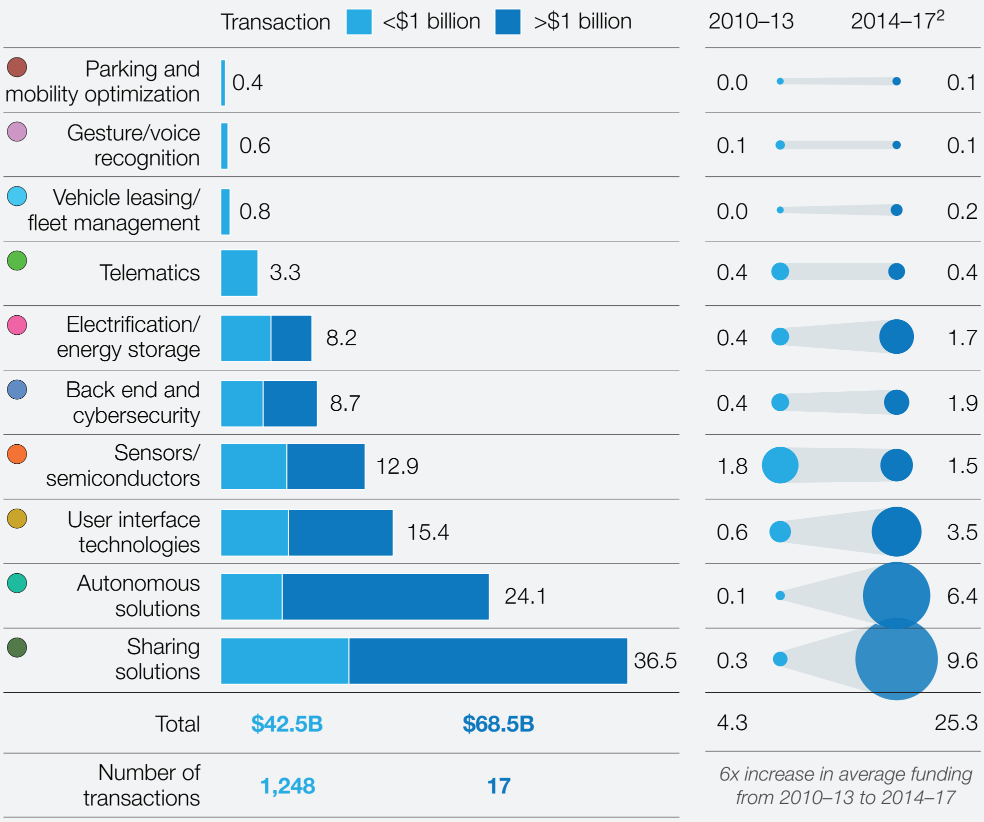
High cost is an ongoing concern, however, which is one reason major automotive, high-tech, and mobility players are teaming up (Exhibit 1). The field is becoming more crowded as well—for example, with all three of China's big tech players now pursuing AVs.

Exhibit 1

Investment activities have accelerated, with a few industry-shaping moves and many small investments.

Investment amount by technology cluster since 2010,[1] $ billions

Average yearly investment, $ billions



[1] Analysis of 1,076 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). Companies used were pulled from Capital IQ and were filtered by year founded, starting after 1990.
[2] Through Sept 2017.

McKinsey&Company | Source: Capital IQ; Pitchbook; McKinsey Center for Future Mobility

As Exhibit 1 shows, the pace of overall investment in future mobility technology is accelerating greatly: between the periods of 2010 to 2013 and 2014 to 2017, the average annual investment across all technologies jumped nearly sixfold, to $25.3 billion per year, from $4.3 billion per year. While investments in sharing and autonomous solutions account for much of this acceleration, investments in hardware like sensors and semiconductors are rather stable, showing a steady trend of consolidation. (For a deeper dive on the topic, see "Analyzing start-up and investment trends in the mobility ecosystem.")

Overall, regulation remains supportive of AVs. In 2018, many regions adopted new definitions that pave the way for vehicles without steering wheels. We have also noted that industry players are engaging in self-regulation when AV crashes occur by voluntarily suspending testing activities.

Such responsibility apparently does not go unnoticed by consumers: in McKinsey's recent ACES survey, 42 percent of respondents had a positive view of the technology.

Mobility and automotive players increasingly focus on use cases to understand the imminent AV market, as growing numbers of them concentrate on bringing viable products to market as soon as possible. Early target cities include Phoenix and San Francisco, and we are hearing much more about so-called "geofenced" applications for use in airports and other similarly enclosed venues. Companies are also working out the bugs on specific AV applications, such as those enabling AV fleets to relocate autonomous carsharing vehicles at night in places like Eindhoven in the Netherlands. It has become clear that different players explore different use-cases – from robo-taxis, autonomous shuttles, to private campus autonomous shuttles - which indicates that this market gives a wide room for multiple players to exist.

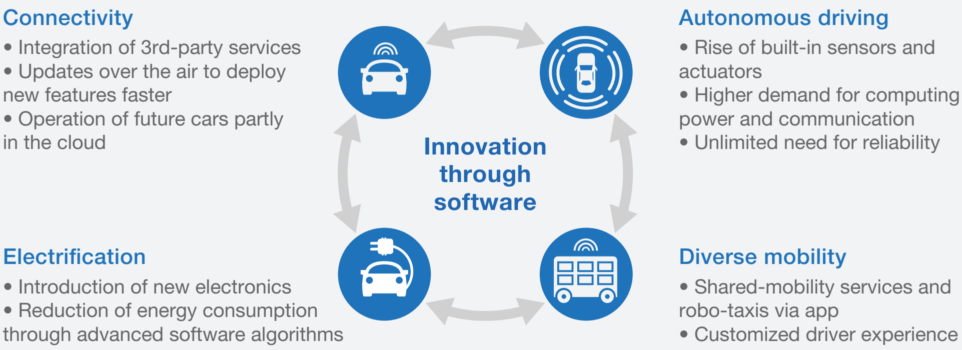
It becomes clearer that most AV companies plan to operate the fleet without major infrastructure measures.

As the automotive industry transitions from hardware- to software-defined vehicles, the average software and electronics content per vehicle is rapidly increasing (Exhibit 2). Software represents 10 percent of overall vehicle content today for a D-segment, or large, car (approximately $1,220), and the average share of software is expected to grow at a compound annual rate of 11 percent, to reach 30 percent of overall vehicle content (around $5,200) in 2030. Not surprisingly, players across the digital automotive value chain are attempting to capitalize on innovations enabled through software and electronics. *(For more, see "Rethinking car software and electronics architecture.")*

Exhibit 2

Software enables critical automotive innovations.

Software innovation examples



Source: Automotive Electronics Initiative; HAWK; IEEE, "This car runs on code"; McKinsey analysis

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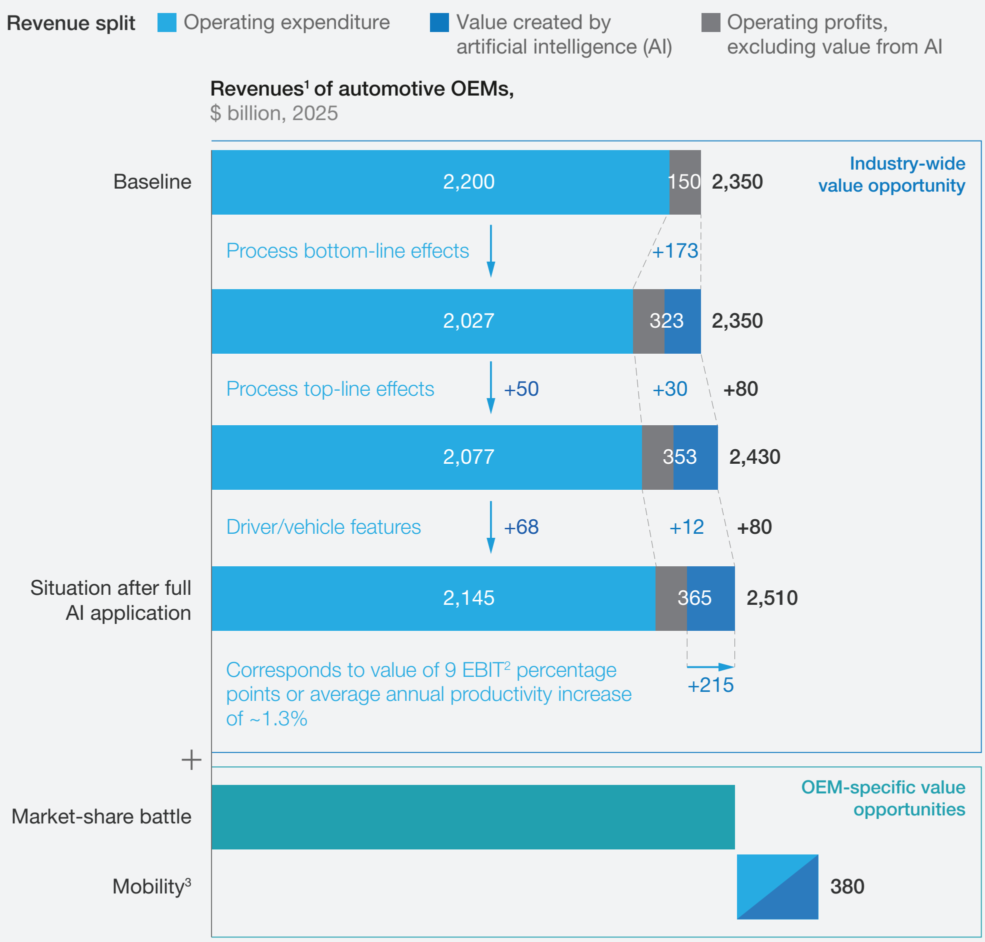
Finally, a note on AI. AI is creating value not only in the vehicle itself but also in the company: in the short to medium term, there is a substantial, AI-enabled opportunity that by 2025 could reach an annual value of about $215 billion for automotive OEMs worldwide (Exhibit 3). This *corresponds to nine percentage points of earnings before interest and taxes for the whole automotive industry, or a theoretical average-annual-productivity increase of approximately 1.3 percent over seven years—a significant value to boost the industry's regular productivity aspiration of about 2 percent annually. (For more, see "Artificial intelligence as auto companies' new engine of value.")*

Exhibit 3

AI-enabled process optimization will drive industry-wide value through 2025.



[1]From vehicle and aftermarket sales, excluding other business segments, such as financial services.
[2]Earnings before interest and taxes.
[3]Market size for entire mobility market, eg, including companies that are not automotive OEMs but rather specialized in car rental or ride-sharing services.

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Connected cars

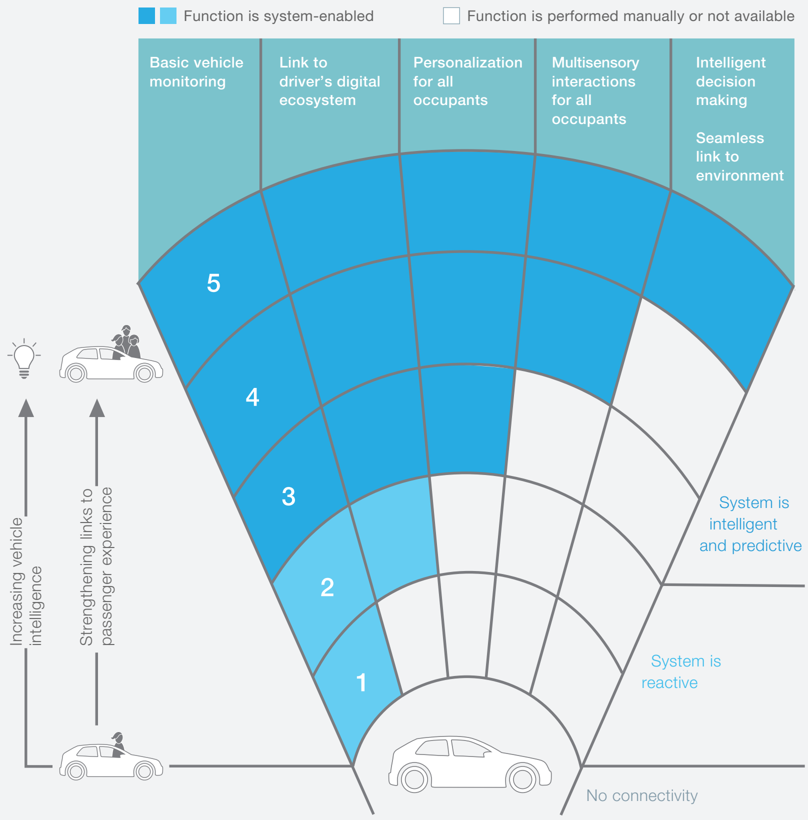
This is another trend in which the industry focus is shifting from discussing to doing. **Monetizing all that car data** is a hot topic in this area, with more companies exploring the prospects for in-car payments. McKinsey's ACES survey suggests that consumers expect to spend nearly 30 percent of their time in an AV focused on entertainment offers and online shopping.

Industry stakeholders (and governments) increasingly seek to "stack hands" on standards while also finding new ways of cooperating and sharing data streams and cybersecurity. In one case, two ridesharing companies have joined forces to share data with cities.

Although most recognize that today's and tomorrow's car will increasingly be connected, there is no clear-cut standard yet to define what "connectivity" means. This lack of clarity is hindering the development of connectivity use cases, as there is no standard language for industry, and it is difficult for customers to compare features and understand how the capability of the cars matches their needs. To address the issue, McKinsey developed a Connected Car Customer Experience (C3X) framework (Exhibit 4). The C3X framework describes five levels of user experience in connected cars—ranging from the most basic to the highly complex. *(For more, see "Setting the framework for car connectivity and user experience.")*

Exhibit 4

The McKinsey Connected Car Customer Experience (C^3X) framework describes five levels of user experience in connected cars, ranging from the most basic to the highly complex.



1 **General hardware connectivity**
Driver able to track basic vehicle usage and monitor technical status

2 **Individual connectivity**
Driver uses personal profile to access digital services via external digital ecosystems and platforms

3 **Preference-based personalization**
All occupants enjoy personalized controls, their own infotainment content, and targeted contextual advertising

4 **Multimodal live dialogue**
All occupants interact live with vehicle and receive proactive recommendations on services and functions

5 **Virtual chauffeur**
All occupants' explicit and unstated needs fulfilled by cognitive AI that predicts and performs complex, unprogrammed tasks

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Connected-car advances are forcing traditional automotive companies to **rethink car software and electronics architecture**, and several have launched AI-supported human–machine interfaces with a totally different level of user experience and truly modular infotainment platforms, enabling also over-the-air updates at scale. Some players keep pushing the boundaries of software and computing power, with one EV company installing the most advanced centralization of computing power in a water-cooled supercomputer. Another key challenge involves efforts to integrate future fifth-generation telecom technologies into connected car platforms.

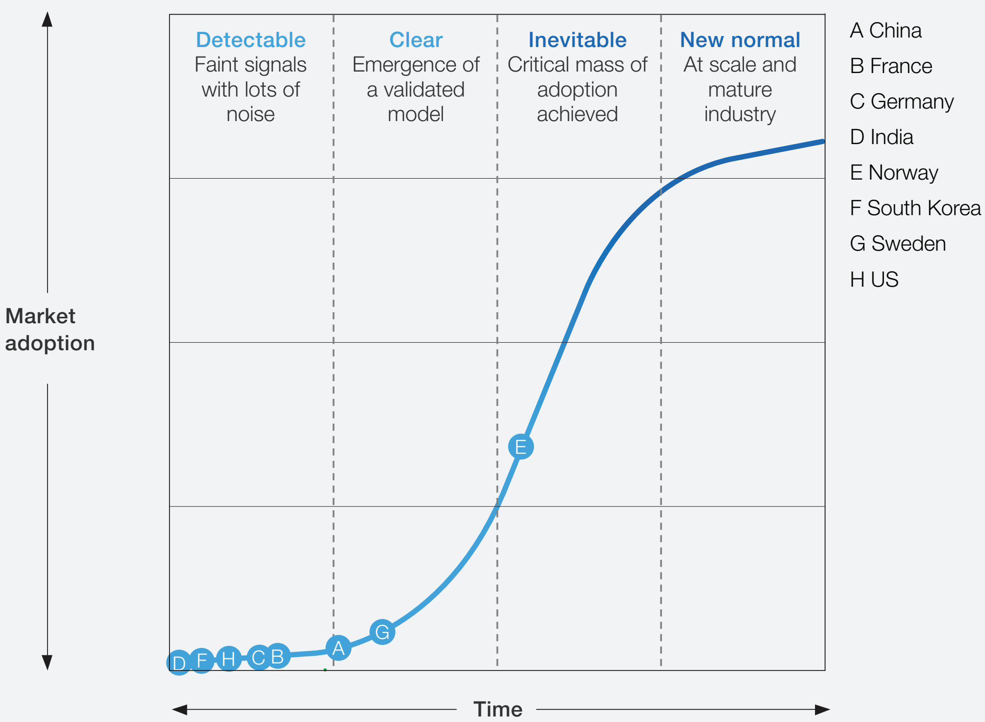
Electric vehicles

Regulation remains the primary market maker for EVs, offering substantial incentives as well as noncash benefits, such as special-highway-lane access and favorable licensing arrangements. This strong regulatory "push" helps to make the EV tipping point the most visible among the four ACES trends (Exhibit 5). More countries and cities are announcing plans to ban the internal combustion engine, and while the European Union has proposed ambitious passenger-car and truck carbon-dioxide (CO_2) reductions through 2030 this year, the United States is the only major government focused on unwinding its aspirational CO_2 targets.

Exhibit 5

In Norway—which is clearly ahead of other countries—the electric-vehicle disruption is inevitable.

The 4 stages of a disruptive trend—focus on electric-vehicle market adoption



Source: Chris Bradley, Martin Hirt, and Sven Smit, Strategy Beyond the Hockey Stick, McKinsey, 2018

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As Exhibit 5 shows, electric mobility follows the same four-step evolution as other disruptive trends do. Having reached a critical mass of EVs, Norway is clearly ahead of other countries—

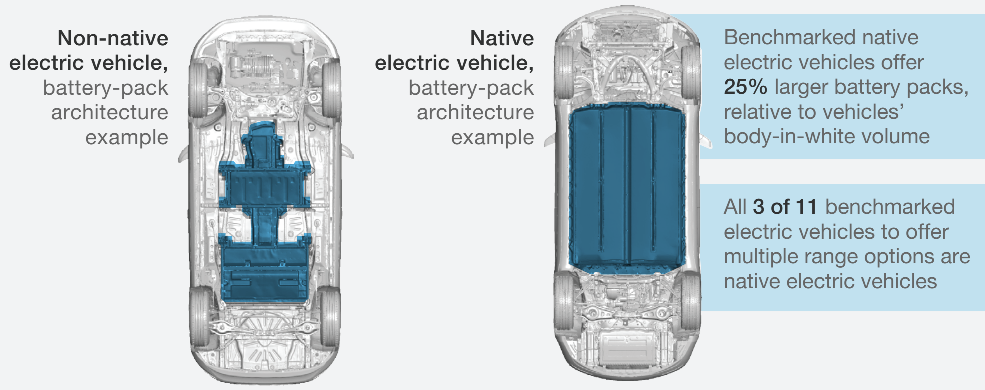
the EV disruption is inevitable. Most other countries are still in the first stage, except for China and Sweden, which have already advanced to the second: disruption is somewhat more clear, with the EV emerging as a validated model. *(For more, see "The global electric-vehicle market is amped up and on the rise.")*

From a technology perspective, the EV industry has moved from a wait-and-see mode to one focused on doing—building plants, forging alliances, and making acquisitions. Batteries and **the raw materials to produce them** remain a key EV challenge, and a wide variety of companies around the world are establishing production capacity. They are also hammering out details regarding greater technological cooperation via joint ventures and other types of alliances with governments (as seen with **charging infrastructure**) and new mobility-industry players, such as tech giants, chip makers, and battery producers.

For batteries in particular, despite higher up-front investments—in the form of engineering hours, new tooling, and so on—native EV platforms have proved advantageous over nonnative models in multiple ways (Exhibit 6). Designing the vehicle architecture entirely around an EV concept, without combustion-engine-legacy elements, means fewer compromises and more flexibility, on average. (For more, see "What a teardown of the latest electric vehicles reveals about the future of mass-market EVs.")

Exhibit 6

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

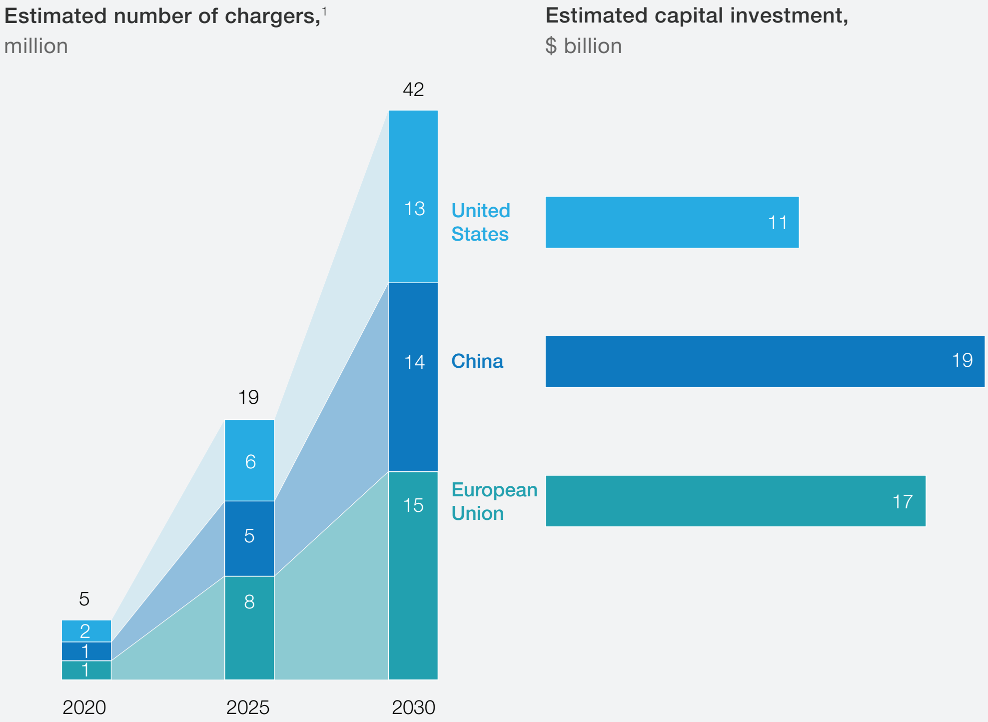


McKinsey&Company | Source: A2Mac1; McKinsey Center for Future Mobility

It is also worthwhile to pause on charging infrastructure. Based on charging profiles and available technologies, the industry could require approximately 40 million chargers across China, Europe, and the United States, representing an estimated $50 billion of cumulative capital investment through 2030 (Exhibit 7). (For more, see "Charging ahead: Electric-vehicle infrastructure demand.")

Exhibit 7

The industry may need to invest $50 billion in the four regions studied through 2030 to meet the need for chargers.



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

McKinsey&Company | **Source:** McKinsey analysis

Several new EV OEMs opened for business in 2018 (there are now more than 60 EV brands in China alone), and more are slated to begin production in 2019. Focused primarily on passenger vehicles, a variety of players will also concentrate on commercial vehicles. Traditional OEMs are introducing an increasingly rich and attractive array of EV models, including cars, SUVs, **buses**, and medium- and heavy-duty trucks. From a regional perspective, China remains the EV-market leader, with companies there gaining a 46 percent production-market share.

While EVs remain one of the most visible ACES trends, it became more and more clear this year that we need a broad power-train portfolio for a long time. For example, **hydrogen has gained increasing currency** as one of the key ways to make the transition to clean energy happen. Look for more on hydrogen over the next 12 months.

Smart or shared mobility

The “next big thing” in shared mobility could be rather small: micromobility. It involves the use of shared electric scooters, bicycles, and other simple conveyances, facilitated via special apps. The industry has already attracted more than $1 billion in investments. However, as bikesharing services in China show, successful micromobility plays require robust organization and strong community and local government support.

In general, shared mobility offers cities an outsize opportunity to solve some critical problems, but left unmanaged, it could create some equally large challenges. Meanwhile, several major automakers are pushing to take active shared-mobility roles and restructuring their current mobility organizations to create entirely new business models, sometimes in league with major competitors. Other OEMs are pushing new mobility-subscription models as well.

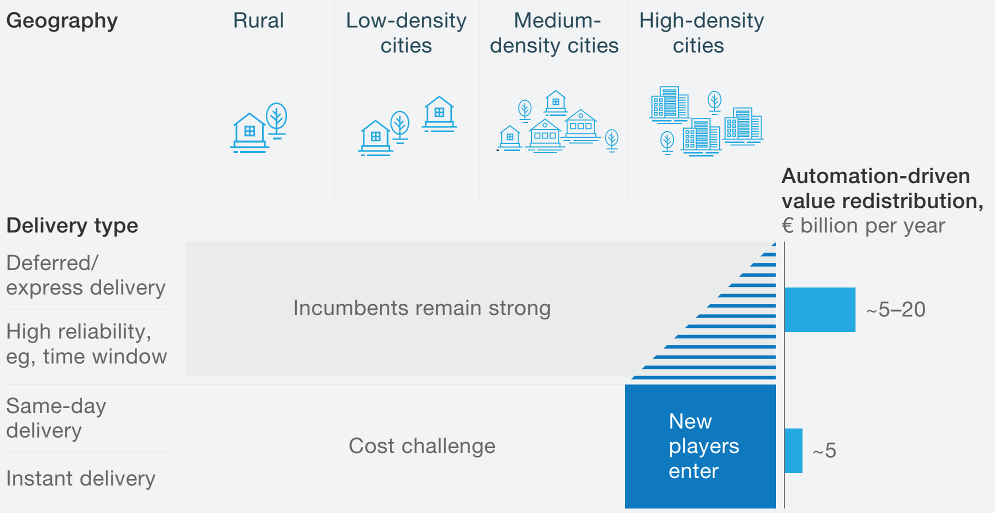
The ride-hailing market continued to evolve in 2018, with major players focusing on fewer markets with greater market shares. The overall lack of profitability of carsharing and ride-hailing businesses remains a central industry challenge—one that will become a more visible issue as major players prepare to launch initial public offerings.

A parallel industry development involves freightsharing or trucksharing, especially when dealing with "last mile" deliveries (Exhibit 8). Customers are demanding more from their delivery providers, and a highly competitive environment combined with customer sensitivity to high cost has pushed forward the development of technology that will help the industry deliver on these demands. Combined, these trends mandate immediate adoption of these new technologies by last-mile players. The growing importance of technology in the last-mile industry will affect the overall ecosystem, including its competitive dynamics and the distribution of value across industry players. (For more, see "Technology delivered: Implications for cost, customers, and competition in the last-mile ecosystem.")

Exhibit 8

Incumbents will likely continue to dominate the industry core, where the bulk of value redistribution from automation will occur, but new entrants have the opportunity to emerge in the same-day and instant-delivery segments.

Competitive dynamics in different geographies and product segments



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2018 has also been a very exciting year for Urban Aerial Mobility (UAM), Personal Air vehicles (PAV) electric Vertical Takeoff and Landing (eVTOL) or just flying car, whichever term you prefer to describe these new vehicles transporting people through the air in cities and its surrounding. On the investment side we have seen the first triple digit investment round. Fueled by the increased funding and awareness we now have over 100 companies exploring different designs and operational models. At the same time we are seeing the pioneers in this field move towards operational testing, with one player announcing flight tests in the center of Singapore in the second half of 2019. All these advances are pushing the regulators to move at speeds unheard of before. Creating a safe and reliable new mode of transportation in the urban environment will continue to push all players to its limits.

All eyes on 2019

As the next 12 months unfold, and the pace of change in the mobility sector likely quickens, we would like to raise several key questions regarding the future of mobility as a whole and of the four ACES trends in particular. First, the general question: Will cities build integrated seamless mobility plans and, in the process, orchestrate ecosystems and drive the four ACES trends to completion as elements of their own visions of **smart cities**?

For AVs, how will the experiences of the first real-life applications influence the subsequent industry, and should mobility players focus on managing the public debate on the levels of technology failure users will accept? Likewise, will we see a convergence of driving systems, and will clear "winners" emerge in the tech stack?

As for connected cars, will increasing connectivity enable breakthroughs in certain use cases, such as predictive maintenance? Will players create business models around connectivity that create new levels of value for consumers?

Regarding electrification, how will the availability of many more EVs play out? Will it seem like a general market ramp-up, or will market shares of established OEMs versus new players change the retail market in fundamental ways? What will happen to industry profitability?

Regarding smart and shared mobility, will use cases emerge that can scale up shared mobility in areas like commuting? Will established platform providers become the winners behind mobility as a service and new mobility platforms? And finally, what will it take to establish a successful micromobility business?

As the future of mobility begins to unfold, companies, regulators and society alike will need to keep both eyes on the street in 2019 to manage the technological disruptions.

□ □ □

Timo Möller is a senior expert 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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ANALYZING START-UP AND INVESTMENT TRENDS IN THE MOBILITY ECOSYSTEM

ANALYZING START-UP AND INVESTMENT TRENDS IN THE MOBILITY ECOSYSTEM

Matthias Kässer,
Thibaut Müller,
Andreas Tschiesner

November 2017

How can companies identify and source the technologies that will be critical for crafting a strategy to keep up in the shifting automotive landscape?

The automotive industry is in the early phases of what is expected to be rapid and fundamental change. The emergence of four trends, in particular, will lead to massive shifts in the business models of traditional automotive companies and open the door for other players who have, until recently, only been indirectly tied to the industry:

- Autonomous driving. As of 2016, only one in 100 vehicles sold were equipped with technology that enabled basic, Level-2 **autonomous-driving (AD) features.** (Here, we use SAE International's definitions as laid out in SAE J3016; Level 2 refers to partial automation.) However, **47 percent of consumers surveyed in a 2017 McKinsey survey on mobility** said they would feel good if their family members used AD technology.

- Connectivity. Internet-connected infotainment systems are the platforms for **delivering a growing set of services to drivers.** Most OEMs are already equipping their premium vehicles with fully connected systems, but monetization is weak. However, 40 percent of car owners would switch to another brand for better connectivity—a figure that is twice as high as it was three years ago.

- Electrification. Less than 5 percent of vehicles sold in 2016 had some type of electric motor. However, in a recent survey, 77 percent of respondents said **the electrification of vehicles** would make a material difference in reducing environmental impact, and 23 percent would consider an electric car for their next purchase.

- Smart mobility. The range of alternative models for vehicle ownership and usage is diverse and includes **car sharing** and e-hailing. The fraction of passenger miles traveled using these services today is small, but our customer surveys showed that 67 percent of car owners plan to increase their use of car sharing in the next two years. Technology is the key to further penetration of all these trends, as well as the developing business models that allow companies to capitalize on them. The industry players—traditional automotive companies and new entrants alike—that identify and secure those technological resources will be best positioned to benefit in the new mobility landscape. Thus, industry players need to think about sourcing underlying technologies rather than acquiring single products or services.

Hunting for technology

New competitors will challenge incumbents by quickly rolling out new business models, as well as by bringing new technologies to the market and capitalizing on them. The big question for all involved will be how to identify which technology capabilities are required for which areas of the new mobility value chain, and how to source them once they have been identified.

Sourcing options include, among others, developing new capabilities internally, hiring talent, or acquiring players with certain technological expertise. In many cases, competing successfully will also require cooperation—sometimes even in situations of simultaneous competition. **New ecosystems will form along the value chain,** as companies with complementary capabilities (for example, software development on one side and deep automotive-embedding capabilities on the other) partner in order to develop and deliver comprehensive offerings.

The first steps in building technological capabilities are gaining an understanding of which technologies are most appropriate and differentiating, given a company's desired role in the new mobility ecosystem, and then finding out where those capabilities exist. Taking an investment view in that journey can be of tremendous value. Investments are usually a good predictor of the future significance of certain technological assets. We have developed an approach that analyzes the landscape to dive deeper.

Start-up and Investment Landscape Analysis: A big data tech-finding tool

McKinsey's Start-up and Investment Landscape Analysis 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 it identifies implicit technological similarities between organizations. The output can be displayed at the level of single investments or at an aggregated company view. It can also be tailored to include analyses of specific technologies, use cases, subsets of companies, or types of companies.

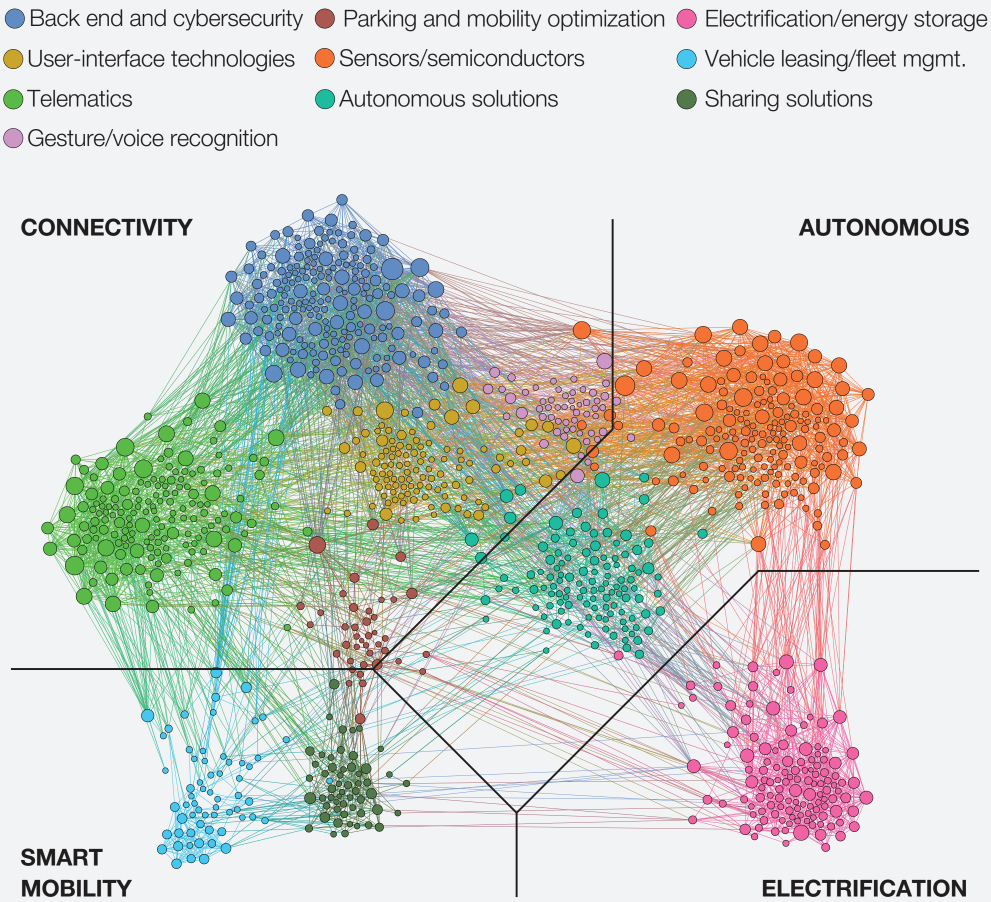
This information helps to identify trends in the emerging tech-driven mobility landscape and to locate technology capabilities. Of course, it takes into account only the external investment view; it does not cover internal investments, such as R&D expenses.

Understanding where the money is going

Overall, our Start-up and Investment Landscape Analysis (SILA) tool reveals significant investment activities in new mobility technologies—nearly $111 billion in disclosed transactions since 2010 in more than 1,000 companies across ten technology clusters (Exhibit 1). Surprisingly, less than a third of these relate to shared-mobility companies; the rest focus on the trends of automation and connectivity. Out of the $111 billion, more than 60 percent come from large investments with disclosed transaction values greater than $1 billion, and the rest from small investments. However, one can learn much more from these smaller investments because they are related to smaller companies with special capabilities or technology. The large transactions, on the other hand, tend to be industry-shaping moves made aiming at established companies. Understanding small players and start-ups is crucial to efficient technology sourcing.

Exhibit 1

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



McKinsey&Company | Source: Capital IQ; Pitchbook; McKinsey Center for Future Mobility

To get more granular, we can also break down investments by trend. Of the ten clusters identified, the largest investments were in autonomous solutions and sharing solutions (Exhibit 2). It's also worth noting that the pace of overall investment is accelerating greatly: between the periods of 2010–13 and 2014–17, the average annual investment across all technologies jumped nearly sixfold, from $4.3 billion per year to $25.3 billion per year. Investments in 2017 to date are as large as the total between 2010 and 2014. While investments in sharing and autonomous solutions account for much of this acceleration, investments in hardware like sensors and semiconductors are rather stable, showing a steady trend of consolidation.

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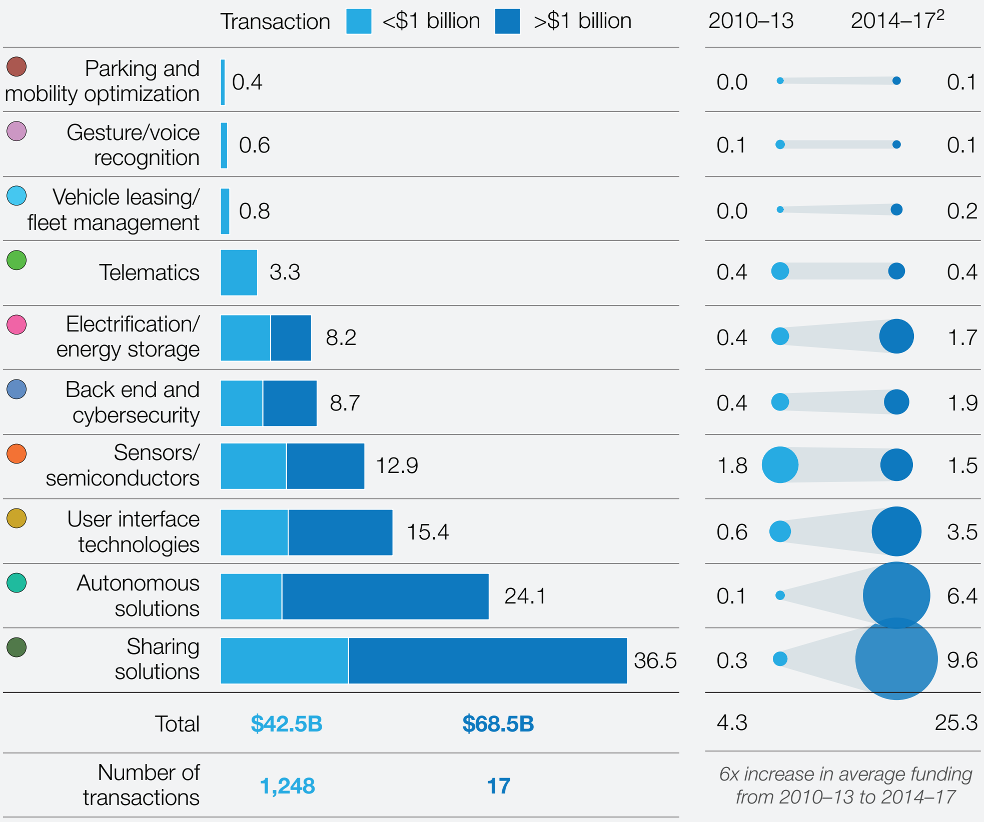

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McKinsey&Company | Source: Capital IQ; Pitchbook; McKinsey Center for Future Mobility

Interestingly, the median annual investment amount per transaction grew by more than a factor of three from 2010 to today—rising from $4.5 million to $15.8 million. Technology is becoming more expensive, and it is getting more difficult to source it, as many are competing for the same players. OEMs with only a few technology-sourcing activities in the past years now face steep costs if they want to access technology via investments in start-ups and medium-sized companies.

It is also instructive to look at the links between clusters (shown by physical proximity on the node map). The strong interconnectedness of the ten clusters shows the strong links between underlying technologies, revealing their wide-ranging applicability—for example, **machine learning that is the underlying technology** for autonomous-driving software, as well as voice recognition. This is a clear indicator to structure thinking around technology rather than actual services.

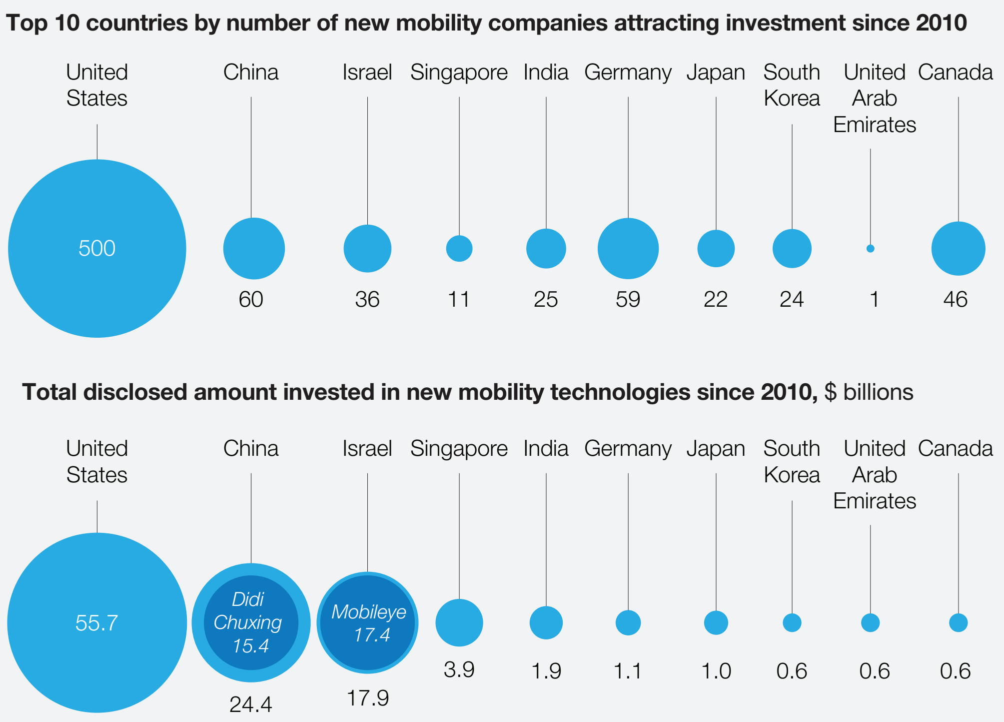
In addition to where investments are happening, our analysis also illustrates how they are being made. An analysis of all disclosed investments shows that their structure differs significantly by cluster. Investment in autonomous driving is dominated by a few large deals focused on end-to-end solutions (for example, Intel's acquisition of Mobileye), with a long tail of smaller investments. In the sensor and semiconductor cluster, consolidation characterizes the investment approach, while in user interface or experience technologies, numerous smaller, specialized players are active.

Geographically, investments are quite concentrated. The majority of investment activity has targeted companies located in the United States (Exhibit 3). Of those, more than half are in the San Francisco Bay Area alone. China and Israel come next. Investments in European companies are small, with German companies accounting for the largest portion, coming in at just over $1 billion. Funding is relatively limited in Germany, though—60 companies there are active in mobility technologies, a number similar to China, which has investments that are over 20 times higher.

This means that non-American mobility players likely will require a footprint in the United States, not just to invest in technology but also to stay attuned to trends, as many are already doing.

Exhibit 3

Investments in mobility technologies vary by country, with the United States, China, and Israel far ahead.



McKinsey&Company | Source: Capital IQ; Pitchbook; McKinsey Center for Future Mobility

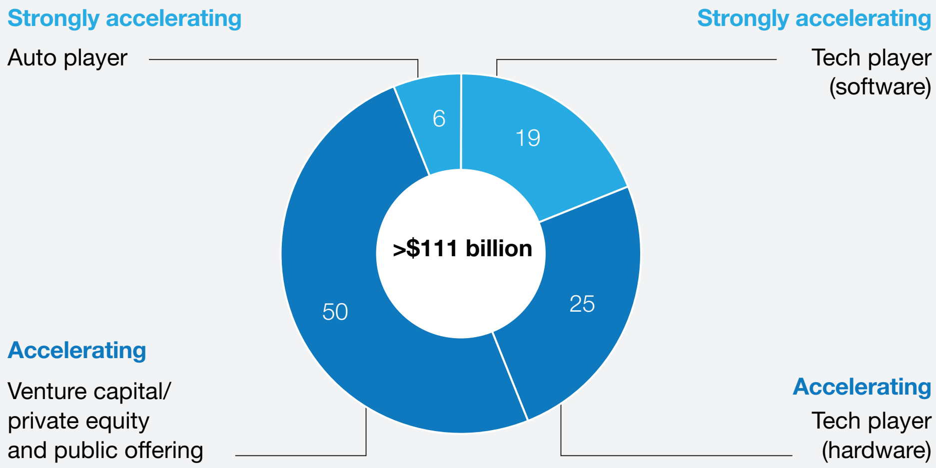
Mapping changes in mobility players

As digital technology becomes a bigger force in automotive and mobility, the face of the "typical" industry player is also changing. SILA affirms this trend in showing that more than 90 percent of investments in the mobility space were made by players not traditionally seen as automotive companies—mainly technology companies, but also venture capitalists and private-equity players (Exhibit 4).

Exhibit 4

Tech players invest significantly more in technology start-ups than automotive players do.

Disclosed amount invested in new mobility technologies since 2010, % of total



McKinsey&Company | Source: Capital IQ; Pitchbook; McKinsey Center for Future Mobility

These new entrants are clearly committed to staking their claim in the mobility market, and they are leveraging their digital expertise to make it happen. Of the total investments of $111 billion since 2010, $31 billion was invested in 2016 alone. And of this $31 billion, automotive players invested less than $2 billion (about 6 percent). However, the R&D budgets of auto players in 2016 were $77 billion—more than twice as high as the total investments identified, and nearly 40 times higher than investments by auto OEMs. These players need to take action if they want to stay in the race for technology.

Setting a winning pace in the tech race

Our analysis shows that the race for technology is intense and gaining speed, with major external players entering the space. As it gets more crowded and more diverse, the cost of that technology rises—only investments in hardware are not accelerating. This does not necessarily mean that incumbents need to attempt to outspend new entrants. They will, however, need to position themselves relative to tech companies and define their own technology strategy, including securing access to the technologies they have identified as potential differentiators.

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Setting a winning pace in the tech race

Our analysis shows that the race for technology is intense and gaining speed, with major external players entering the space. As it gets more crowded and more diverse, the cost of that technology rises—only investments in hardware are not accelerating. This does not necessarily mean that incumbents need to attempt to outspend new entrants. They will, however, need to position themselves relative to tech companies and define their own technology strategy, including securing access to the technologies they have identified as potential differentiators.

To do this successfully, companies must move beyond an anecdotal approach and towards a structured method of technology sourcing. In this respect, traditional automotive players may employ strategies such as purchasing or investing in companies, forming partnerships or alliances, or developing new kinds of tier-one relationships (such as close collaboration partnership houses). The sourcing approach should depend on the dynamics of each technology cluster, as well as the individual company's strategy. Many small players, for instance, develop innovations in the field of user interface technologies, making an M&A-like approach possible. On the other hand, large technology players dominate the voice-recognition technology space (for example, BMW plans to integrate Amazon's Alexa technology), making partnership approaches viable.

The first step, however, will be for automotive companies to **identify the use cases** and technologies that matter to them and that will be differentiating in the long term. By identifying the relevant technological control points along the value chain—say, driving software, connected services, or human–machine interfaces—they can pinpoint required capabilities. With clarity regarding these decisions, automotive companies can then determine potential sources of such technologies. This path is applicable to suppliers and OEMs alike, as both will need to invest significant resources in all four disruptive automotive trends.

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Developments in autonomous driving, connectivity, electrification, and smart mobility **are fundamentally changing the mobility sector.** Mastering the underlying technologies will make it possible for companies to extract the value of these trends. By identifying relevant technologies and investment trends in the new mobility landscape, and by cultivating an understanding of the use cases they would like to develop and the control points they would like to own, automotive players can then strategize about acquiring the required technology capabilities.

Matthias Kässer is a Partner in McKinsey's Munich office, where **Andreas Tschiesner** is a Senior Partner; **Thibaut Müller** is an associate partner in the Geneva office.

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RETHINKING CAR SOFTWARE AND ELECTRONICS ARCHITECTURE

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Ondrej Burkacky,
Johannes Deichmann,
Georg Doll,
Christian Knochenhauer

As the car continues its transition from a hardware-driven machine to a software-driven electronics device, the auto industry's competitive rules are being rewritten.

The engine was the technology and engineering core of the 20th-century automobile. Today, software, large computing power, and advanced sensors increasingly step into that role; they enable most modern innovations, from efficiency to connectivity to autonomous driving to electrification and new mobility solutions.

However, as the importance of electronics and software has grown, so has complexity. Take the exploding number of software lines of code (SLOC) contained in modern cars as an example. In 2010, some vehicles had about ten million SLOC; by 2016, this expanded by a factor of 15, to roughly 150 million lines. Snowballing complexity is causing significant software-related quality issues, as evidenced by millions of recent vehicle recalls.

With cars positioned to offer increasing levels of autonomy, automotive players see the quality and security of vehicle software and electronics as key requirements to guarantee safety. And this is requiring the industry to rethink today's approaches to vehicle software and electrical and electronic architecture.

Addressing an urgent industry concern

As the automotive industry is transitioning from hardware- to software-defined vehicles, the average software and electronics content per vehicle is rapidly increasing. Software represents 10 percent of overall vehicle content today for a D-segment, or large, car (approximately $1,220), and the average share of software is expected to grow at a compound annual rate of 11 percent, to reach 30 percent of overall vehicle content (around $5,200) in 2030. Not surprisingly, players across the digital automotive value chain are attempting to capitalize on innovations enabled through software and electronics (Exhibit 1). Software companies and other digital-technology players are leaving their current tier-two and tier-three positions to engage automakers as tier-one suppliers. They're expanding their participation in the automotive technology "stack" by moving beyond features and apps into operating systems. At the same time, traditional tier-one electronic system players are boldly entering the tech giants' original feature-and-app turf, and premium automakers are moving into areas further down the stack such as operating systems, hardware abstractions, and signal processing in order to protect the essence of their technical distinction and differentiation.

One consequence of these strategic moves is that the vehicle architecture will become a service-oriented architecture (SOA) based on generalized computing platforms. Developers will add new connectivity solutions, applications, **artificial-intelligence elements**, advanced analytics, and operating systems. The differentiation will not be in the traditional vehicle hardware anymore but in the user-interface and experience elements powered by software and advanced electronics.

Exhibit 1

Software enables critical automotive innovations.

Software innovation examples

Connectivity
- Integration of 3rd-party services
- Updates over the air to deploy new features faster
- Operation of future cars partly in the cloud

Autonomous driving
- Rise of built-in sensors and actuators
- Higher demand for computing power and communication
- Unlimited need for reliability

Electrification
- Introduction of new electronics
- Reduction of energy consumption through advanced software algorithms

Diverse mobility
- Shared-mobility services and robo-taxis via app
- Customized driver experience

Source: Automotive Electronics Initiative; HAWK; IEEE, "This car runs on code"; McKinsey analysis

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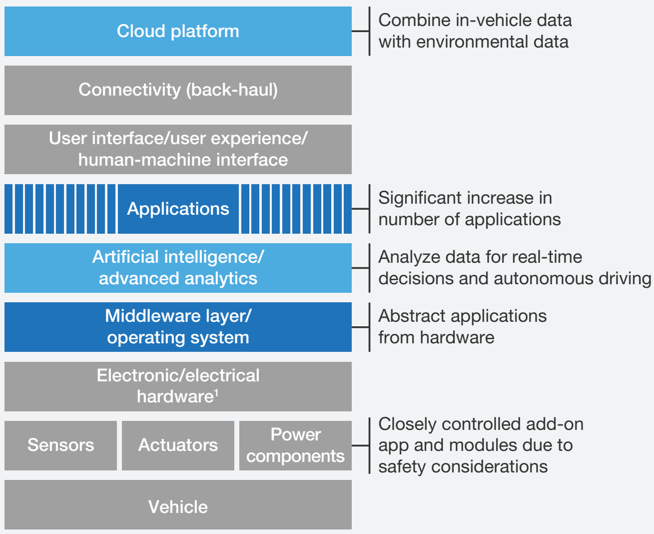
Tomorrow's cars will shift to a platform of new brand differentiators (Exhibit 2). These will likely include infotainment innovations, **autonomous-driving capabilities**, and intelligent safety features based on "fail-operational" behaviors (for example, a system capable of completing its key function even if part of it fails). Software will move further down the digital stack to integrate with hardware in the form of smart sensors. Stacks will become horizontally integrated and gain new layers that transition the architecture into an SOA.

Exhibit 2

Architecture will become service oriented, with new factors for differentiation.

Future layered in-vehicle and back-end architecture

Existing layer | Modified layer | New layer



Future factors for brand differentiation:

- **Infotainment features** requiring "plug and play" capabilities
- **Autonomous capabilities** including sensor-fusion algorithms as a complement to hardware
- **Safety features** based on "fail-operational" behavior

- Software will move further down the stack to hardware (smart sensors)
- Stacks become horizontally integrated
- New layers will be added to the stack

[1]Including operating system in status quo.

McKinsey&Company

Ultimately, the new software and electronic architecture will result out of several game-changing trends that drive complexity and interdependencies. For example, new smart sensors and applications will create **a "data explosion" in the vehicle** that players need to handle by processing and analyzing the data efficiently if they hope to remain competitive. A modularized SOA and over-the-air (OTA) updates will become key requirements to maintain complex software in fleets and enable new function-on-demand business models. Infotainment, and, to a lesser degree, **advanced driver-assistance systems (ADAS)**, will increasingly become "appified" as more third-party app developers provide vehicle content. Digital-security requirements will shift the focus from a pure access-control strategy to **an integrated security concept** designed to anticipate, avoid, detect, and defend against cyberattacks. The advent of highly automated driving (HAD) capabilities will require functionality convergence, superior computing power, and a high degree of integration.

Exploring ten hypotheses on future electrical or electronic architecture

The path forward for both the technology and the business model is far from fixed. But based on our extensive research and insights from experts, we developed ten hypotheses regarding tomorrow's automotive electrical or electronic architecture and its implications for the industry.

There will be an increasing consolidation of electronic control units (ECUs)

Instead of a multitude of specific ECUs for specific functionalities (the current "add a feature, add a box" model), the industry will move to a consolidated vehicle ECU architecture.

In the first step, most functionality will be centered on consolidated domain controllers for the main vehicle domains that will partially replace functionality currently running in distributed ECUs. These developments are already under way and will hit the market in two to three years' time. This consolidation is especially likely for stacks related to ADAS and HAD functionality, while more basic vehicle functions might keep a higher degree of decentralization.

In the evolution toward autonomous driving, virtualization of software functionality and abstraction from hardware will become even more imperative. This new approach could materialize in several forms. One scenario is a consolidation of hardware into stacks serving different requirements on latency and reliability, such as a high-performance stack supporting HAD and ADAS functionality and a separate, time-driven, low-latency stack for basic safety features. In another scenario, the ECU is replaced with one redundant "supercomputer," while in a third, the control-unit concept is abandoned altogether in favor of a smart-node computing network.

The change is driven primarily by three factors: costs, new market entrants, and demand through HAD. Decreasing costs, both for the development of features as well as the required computing hardware, including communication hardware, will accelerate the consolidation. So too will new market entrants into automotive that will likely disrupt the industry through a software-oriented approach to vehicle architecture. Increasing demand for HAD features and redundancy will also require a higher degree of consolidation of ECUs.

Several premium automakers and their suppliers are already active in ECU consolidation, making early moves to upgrade their electronic architecture, although no clear industry archetype has emerged at this point.

The industry will limit the number of stacks used with specific hardware

Accompanying the consolidation will be a normalization of limited stacks that will enable a separation of vehicle functions and ECU hardware that includes increased virtualization. Hardware and embedded firmware (including the operating system) will depend on key nonvehicle functional requirements instead of being allocated part of a vehicle functional domain. To allow for separation and a service-oriented architecture, the following four stacks could become the basis for upcoming generations of cars in five to ten years:

- **Time-driven stack.** In this domain, the controller is directly connected to a sensor or actuator while the systems have to support hard real-time requirements and low latency times; resource scheduling is time based. This stack includes systems that reach the highest Automotive Safety Integrity Level classes, such as the classical Automotive Open System Architecture (AUTOSAR) domain.

- **Event- and time-driven stack.** This hybrid stack combines high-performance safety applications, for example, by supporting ADAS and HAD capability. Applications and peripherals are separated by the operating system, while applications are scheduled on a time base. Inside an application, scheduling of resources can be based on time or priority. The operating environment ensures that safety-critical applications run on isolated containers with clear separation from other applications within the car. A current example is adaptive AUTOSAR.

- **Event-driven stack.** This stack centers on the infotainment system, which is not safety critical. The applications are clearly separated from the peripherals, and resources are scheduled using best-effort or event-based scheduling. The stack contains visible and highly used functions that allow the user to interact with the vehicle, such as Android, Automotive Grade Linux, GENIVI, and QNX.

- **Cloud-based (off-board) stack.** The final stack covers and coordinates access to car data and functions from outside the car. The stack is responsible for communication, as well as safety and security checks of applications (authentication), and it establishes a defined car interface, including remote diagnostics.

Automotive suppliers and technology players have already begun to specialize in some of these stacks. Notable examples are in infotainment (event-driven stack), where companies are developing communications capabilities such as 3-D and augmented navigation. A second example is artificial intelligence and sensing for high-performance applications, where suppliers are joining with key automakers to develop computing platforms.

In the time-driven domain, AUTOSAR and JASPAR are supporting the standardization of these stacks.

An expanded middleware layer will abstract applications from hardware

As vehicles continue to evolve into mobile computing platforms, middleware will make it possible to reconfigure cars and enable the installation and upgrade of their software. Unlike today, where middleware within each ECU facilitates communication across units, in the next vehicle generation it will link the domain controller to access functions. Operating on top of ECU hardware in the car, the middleware layer will enable abstraction and virtualization, an SOA, and distributed computing.

Evidence already suggests automotive players are moving toward more flexible architectures, including an overarching middleware. AUTOSAR's adaptive platform, for example, is a dynamic system that includes middleware, support for a complex operating system, and state-of-the-art multicore microprocessors. However, current developments appear restricted to a single ECU.

In the middle term, the number of onboard sensors will spike significantly

In the next two to three vehicle generations, automakers will install sensors with similar functionalities to ensure that sufficient safety-related redundancies exist (Exhibit 3). In the long term, however, the automotive industry will develop specific sensor solutions to reduce the number of sensors used and their costs. We believe that a combined solution of radar and camera might be dominant for the next five to eight years. As autonomous-driving capabilities continue to rise, the introduction of lidars will necessary to ensure redundancy for both object analysis and localization. Configurations for SAE International L4 (high automation) autonomous driving, for example, will likely initially require four to five lidar sensors, including rear-mounted ones for city operation and near-360-degree visibility.

Exhibit 3

Sensor fusion will provide redundancy for autonomous functions.

Sensor function ratings

Good · Fair · Poor

	Camera	Radar	Lidar	Ultra-sonic	Radar + lidar	Lidar + camera	Radar + camera
Object detection	Fair	Good	Good	Good	Good	Good	Good
Object classification	Good	Poor	Fair	Poor	Fair	Good	Good
Distance estimation	Fair	Good	Good	Good	Good	Good	Good
Object-edge precision	Good	Poor	Good	Good	Good	Good	Good
Lane tracking	Good	Poor	Poor	Poor	Poor	Good	Good
Range of visibility	Fair	Good	Fair	Poor	Good	Fair	Good
Functionality in bad weather	Poor	Good	Fair	Good	Good	Fair	Good
Functionality in poor lighting	Fair	Good	Good	Good	Good	Good	Good
Cost	Good	Good	Poor	Good	Poor	Poor	Good
Production readiness	Good	Good	Poor	Good	Poor	Poor	Good

Radar and camera most likely combination in next 5–8 years, although solid-state lidar and camera[1] will be dominant in the long term when proven and integrated into mass-production designs

[1]Comparison with other technologies not yet possible due to low maturity of technology.

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In the long term, we see different possible scenarios concerning the number of sensors in vehicles: further increase, stable numbers, or decrease. Which scenario will come to pass depends on regulation, the technical maturity of solutions, and the ability to use multiple sensors for different use cases. Regulatory requirements might, for example, enforce closer driver monitoring, resulting in an increase of sensors inside the vehicle. It can be expected that more consumer-electronics sensors will be used in the automotive interior. Motion sensors and health monitoring of measures such as heart rate and drowsiness, as well as face recognition and iris tracking, are just a few of the potential use cases. However, as an increase or even a stable number of sensors would require a higher bill of materials, not only in the sensors themselves but also in the vehicle network, the incentive to reduce the number of sensors is high. With the arrival of highly automated or fully automated vehicles, future advanced algorithms and machine learning can enhance sensor performance and reliability. Combined with more powerful and capable sensor technologies, a decrease of redundant sensors can be expected. Sensors used today might become obsolete as their functions are overtaken by more capable sensors (for instance, a camera- or lidar-based parking assistant could replace ultrasound sensors).

Sensors will become more intelligent

System architectures will require intelligent and integrated sensors to manage the massive amounts of data needed for highly automated driving. While high-level functions such as sensor fusion and 3-D positioning will run on centralized computing platforms, preprocessing, filtering, and fast reaction cycles will most likely reside in the edge or be done directly in the sensor. One estimate puts the amount of data an autonomous car will generate every hour at four terabytes. Consequently, intelligence will move from ECUs into sensors to conduct basic preprocessing requiring low latency and low computing performance, especially if weighting costs for data processing in the sensors versus costs for high-volume data transmission in the vehicle. Redundancy for driving decisions in HAD will nevertheless require a convergence for centralized computing, likely based on preprocessed data. Intelligent sensors will supervise their own functionality while redundancy of sensors will increase reliability, availability, and hence safety of the sensor network. To ensure correct sensor operation in all conditions, a new class of sensor-cleaning applications—such as deicing capabilities and those for dust or mud removal—will be required.

Full power and data-network redundancy will be necessary

Safety-critical and other key applications that require high reliability will utilize fully redundant circles for everything that is vital to safe maneuvering, such as data transmission and power supply. The introduction of **electric-vehicle technologies**, central computers, and power-hungry distributed computing networks will require new redundant power-management networks. Fail-operational systems to support steer-by-wire and other HAD functions will require redundancy system designs, which is a significant architectural improvement on today's fail-safe monitoring implementations.

The 'automotive Ethernet' will rise and become the backbone of the car

Today's vehicle networks are insufficient for the requirements of future vehicles. Increased data rates and redundancy requirements for HAD, safety and security in connected environments, and the need for interindustry standardized protocols will most likely result in the emergence of the automotive Ethernet as a key enabler, especially for the redundant central data bus. Ethernet solutions will be required to ensure reliable interdomain communication and satisfy real-time requirements by adding Ethernet extensions like audio-video bridging (AVB) and time-sensitive networks (TSN). Industry players and the OPEN Alliance support the adoption of Ethernet technology, and many automakers have already made this leap.

Traditional networks such as local interconnected networks and controller area networks will continue to be used in the vehicle, but only for closed lower-level networks, for instance, in the sensor and actor area. Technologies such as FlexRay and MOST are likely to be replaced by automotive Ethernet and its extensions, AVB and TSN.

Going forward, we expect the automotive industry to also embrace future Ethernet technologies such as high-delay bandwidth products (HDBP) and 10-gigabit technologies.

OEMs will always tightly control data connectivity for functional safety and HAD but will open interfaces for third parties to access data

Central connectivity gateways transmitting and receiving safety-critical data will always connect directly and exclusively to an OEM back end, available to third parties for data access, except where obliged by regulation. In infotainment, however, driven by the "appification" of the vehicle, emerging open interfaces will allow content and app providers to deploy content, while OEMs will keep the respective standards as tight as possible.

Today's on-board diagnostics port will be replaced with connected telematic solutions. Physical maintenance access to the vehicle network will not be required anymore but can go through the

OEMs' back ends. OEMs will provide data ports in their vehicle back end for specific use cases such as lost-vehicle tracking or individualized insurance. Aftermarket devices, however, will have less and less access to vehicle internal data networks.

Large fleet operators will play a stronger role in the user experience and will create value for end customers, for example, by offering different vehicles for different purposes under one subscription (such as weekend or daily commute). This will require them to utilize the different OEMs' back ends and start consolidating data across their fleets. Larger databases will then allow fleet operators to monetize consolidated data and analytics not available on the OEM level.

Cars will use the cloud to combine onboard information with offboard data

Nonsensitive data (that is, data that are not personal or safety related) will increasingly be processed in the cloud to derive additional insights, though availability to players beyond OEMs will depend on future regulation and negotiations. As the volumes of data grow, **data analytics will become critically important** for processing the information and turning it into actionable insights. The effectiveness of using data in such a way to enable autonomous driving and other digital innovations will depend on data sharing among multiple players. It's still unclear how this will be done and by whom, but major traditional suppliers and technology players are already building integrated automotive platforms capable of handling this new plethora of data.

Cars will feature updateable components that communicate bidirectionally

Onboard test systems will allow cars to check function and integration updates automatically, thus enabling life-cycle management and the enhancement or unlocking of aftersales features. All ECUs will send and receive data to and from sensors and actuators, retrieving data sets to support innovative use cases such as route calculation based on vehicle parameters.

OTA update capabilities are a prerequisite for HAD; they also will enable new features, ensure cybersecurity, and enable automakers to deploy features and software quicker. In fact, it's the OTA update capability that is the driver behind many of the significant changes in vehicle architecture described previously. In addition, this capability also requires an end-to-end security solution across all layers of the stack outside the vehicle to the ECUs in the vehicle. This security solution remains to be designed, and it will be interesting to see how and by whom this will be done.

To achieve smartphone-like upgradability, the industry needs to overcome restrictive dealer contracts, regulatory requirements, and security and privacy concerns. Here too, a variety of automotive players have announced plans to deploy OTA service offerings, including over-the-air updates for their vehicles.

OEMs will standardize their fleets on OTA platforms, working closely with technology providers in this space. As vehicle connectivity and OTA platforms will become increasingly mission critical, we can expect OEMs to take more ownership in this market segment.

Vehicles will receive software and feature upgrades as well as security updates for the designed life span. Regulators will likely enforce software maintenance to ensure the safety integrity of the vehicle designs. The obligation to update and maintain software will lead to new business models for maintenance and operations of vehicles.

Assessing the future implications of vehicle software and electronic architecture

While the trends affecting the automotive industry today are generating major hardware-related uncertainties, the future looks no less disruptive for software and electronic architecture. Many strategic moves are possible: automakers could create industry consortia to standardize vehicle architecture, digital giants could introduce onboard cloud platforms, mobility players could produce their own vehicles or develop open-source vehicle stacks and software functions, and automakers could introduce increasingly sophisticated connected and autonomous cars.

The transition from hardware-centric products to a software-oriented, service-driven world is **especially challenging for traditional automotive companies**. Yet, given the described trends and changes, there is no choice for anyone in the industry but to prepare. We see several major strategic pushes:

- **Decouple vehicle and vehicle-functions development cycles.** OEMs and tier-one suppliers need to identify how to develop, offer, and deploy features largely apart from vehicle-development cycles, both from a technical and organizational perspective. Given current vehicle-development cycles, companies need to find a way to manage innovations in software. Further, they should think about options to create retrofitting and upgrade solutions (for example, computing units) for existing fleets.

- **Define the target value add for software and electronics development.** OEMs must identify the differentiating features for which they are able to establish control points. In addition, it is crucial to clearly define the target value add for their own software and electronics development and to identify areas that become a commodity or topics that can only be delivered with a supplier or partner.

- **Attach a clear price tag to software.** Separating software from hardware requires OEMs to rethink their internal processes and mechanisms for buying software independently. In addition to the traditional setup, it is also important to analyze how **an agile approach to software development** can be anchored in procurement processes. Here suppliers (tier one, tier two, and tier three) also play a crucial role as they need to attach a clear business value to their software and system offerings to enable them to capture a larger revenue share.

- **Design a specific organizational setup around new electronics architecture (including related back ends).** Next to changing internal processes in order to deliver and sell advanced electronics and software, automotive players—both OEMs and suppliers—should also consider a different organizational setup for vehicle-related electronics topics. Mainly, the new “layered” architecture asks for potentially breaking up the current “vertical” setup and introducing new “horizontal” organizational units. Further, they need to ramp up dedicated capabilities and skills for their own software and electronics development teams.

- **Design a business model around automotive features as a product (especially for automotive suppliers).** To remain competitive and capture a fair share of value in the field of automotive electronics, it is crucial to analyze which features add real value to the future architecture and therefore can be monetized. Subsequently, players need to derive new business models for the sale of software and electronics systems, be it as a product, a service, or something completely new.

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As the new era of automotive software and electronics begins, it's drastically changing a wide variety of prior industry certainties about business models, customer needs, and the nature of competition. We are optimistic about the revenue and profit pools that will be created. But to benefit from the shifts, all players in the industry need to rethink and carefully position (or reposition) their value propositions in the new environment.

This article was developed in collaboration with the Global Semiconductor Alliance.

Ondrej Burkacky is a partner in McKinsey's Munich office, where **Georg Doll** is vice president, IoT; **Johannes Deichmann** is an associate partner in the Stuttgart office; and **Christian Knochenhauer** is an associate partner in the Berlin office.

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ARTIFICIAL INTELLIGENCE AS AUTO COMPANIES' NEW ENGINE OF VALUE

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January 2018

Matthias Kässer,
Asutosh Padhi,
Andreas Tschiesner,
Dominik Wee

What opportunities does AI open up for mobility, and how can OEMs capture them in the short and long run?

For more than two years now, the automotive industry has been talking about four disruptive and mutually reinforcing major trends—autonomous driving, connectivity, electrification, and shared mobility. These trends are expected to fuel growth within the market for mobility, **change the rules of the mobility sector**, and lead to a shift from traditional to disruptive technologies and innovative business models.

Artificial intelligence (AI) is a key technology for all four of the trends. **Autonomous driving**, for example, relies on AI because it is the only technology that enables the reliable, real-time recognition of objects around the vehicle. For the other three trends, AI creates numerous opportunities to reduce costs, improve operations, and generate new revenue streams. **For shared-mobility services**, for example, artificial intelligence can help to optimize pricing by predicting and matching demand and supply. It can also be used to improve maintenance scheduling and fleet management. Improvements realized through AI will play an important role for automotive companies, enabling them to finance innovation and cope with the trends ahead of them.

One expected result of the four major trends is a marked shift in the industry's value pools. This change will have an especially large impact on big automotive original equipment manufacturers (OEMs) and their business models, but the impact will be felt throughout the industry and beyond. The products and services made possible by the trends will not only affect the business of all incumbent and traditional industry players but also open up the market to new entrants. Many companies such as technology players, which previously focused on other industries, **are heavily investing in the mobility trends** and the underlying technologies. As a result, **a new ecosystem of players** is emerging. New players will be important partners for traditional automotive companies. While automotive OEMs can use the technology expertise of new players to unlock the potential value of artificial intelligence, new players will have opportunities to claim their share of automotive and mobility markets. To master the four trends, OEMs need to invest substantially in each of the trends and in successfully integrating them.

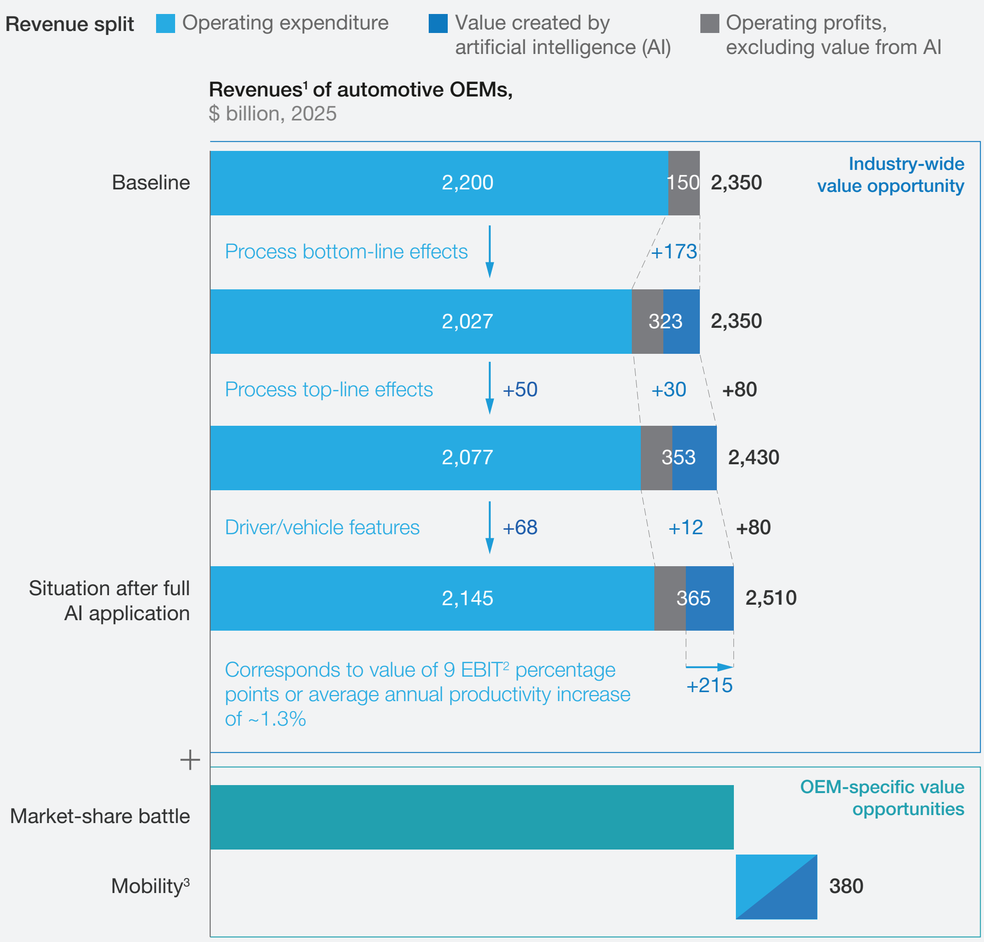
Some of our earlier work has focused on **artificial intelligence in mobility** and **in the industrial sector**. The report on which this article is based continues that effort, drawing on insights from a multipronged methodological approach (see sidebar, "How we derived insights: Sources and methodology"). First, it maps artificial intelligence–enabled value opportunities for automotive OEMs along the three application areas of process, driver or vehicle features, and mobility services. Next, it breaks down and quantifies these opportunities. Finally, the report outlines the strategic actions that OEMs should take to fully capture the AI-enabled value opportunities in both the short and long run.

Our analyses yielded the following key insights, which the report discusses in more detail:

- In the short to medium term, there is a substantial, industry-wide, artificial intelligence–enabled opportunity that by 2025 could reach an annual value of about $215 billion for automotive OEMs worldwide (exhibit). This corresponds to nine percentage points of earnings before interest and taxes for the whole automotive industry, or a theoretical average annual productivity increase of approximately 1.3 percent over seven years[1]—a significant value to boost the industry's regular productivity aspiration of about 2 percent annually. Most of this value is derived from the optimization of core processes along the value chain.

Exhibit

AI-enabled process optimization will drive industry-wide value through 2025.



[1]From vehicle and aftermarket sales, excluding other business segments, such as financial services.
[2]Earnings before interest and taxes.
[3]Market size for entire mobility market, eg, including companies that are not automotive OEMs but rather specialized in car rental or ride-sharing services.

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1 While this value is generated around the automotive OEMs' business, not all of this value can be captured by OEMs exclusively, because other players such as suppliers, system integrators, and technology players will try to capture some share of it. Fierce competition between automotive OEMs may also result in passing some of the value on to customers. In addition, there are some investments required for the initial implementation of artificial-intelligence use cases, and some (comparably low) costs arise for the operation of artificial intelligence. Nevertheless, we expect automotive OEMs can capture the largest share of the value.

- Even in the short term, artificial intelligence can lead to efficiencies and cost savings across the entire value chain. It can also create additional revenues from vehicle sales and **aftermarket sales**. Most of the value is generated in four core processes. In procurement, supply-chain management, and manufacturing, efficiencies lead to cost savings of $51 billion, $22 billion, and $61 billion, respectively. In marketing and sales, AI-based efficiencies both reduce cost and generate revenue, leading to a total value potential of $31 billion.

- While AI-enabled driver or vehicle features and mobility services can generate substantial industry-wide value in the long term, these create limited value at the industry level in the short term. However, individual OEMs that outperform competitors with their driver or vehicle features and mobility services can gain substantial market share. These gains in market share by technology leaders are, nevertheless, small compared with the risk of losing a significant part of the customer base for OEMs that are falling behind on these features.

- Four success factors enable OEMs to prepare for the AI transformation and to capture value from artificial intelligence in the short term: collecting and harmonizing data from different sources, setting up a partner ecosystem, establishing an AI operating system, and building up core AI capabilities and an AI team to drive the required transformation.

- OEMs need to start their transformation now by implementing pilots to gain knowledge and capture short-term value. Then, they should establish the AI core to develop an integrated view on AI across the organization. This will enable OEMs to scale up and roll out an end-to-end transformation to systematically capture the full value potential from AI and build up capabilities for their long-term strategies in confronting the four disruptive trends.

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Download Artificial intelligence—automotive's new value-creating engine, the full report on which this article is based.

Matthias Kässer is a partner in McKinsey's Munich office, **where Andreas Tschiesner** is a senior partner; **Asutosh Padhi** is a senior partner in the Chicago office. **Dominik Wee** is a McKinsey alum.

SETTING THE FRAMEWORK FOR CAR CONNECTIVITY AND USER EXPERIENCE

SETTING THE FRAMEWORK FOR CAR CONNECTIVITY AND USER EXPERIENCE

Michele Bertoncello,
Asad Husain,
Timo Möller

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The connectivity experience of drivers and passengers will soon be transformed, with the potential for significant value creation. Here is a framework to measure progress.

In the automotive sector, as elsewhere in the economy, digital forces are blurring traditional industry boundaries, spurring the formation of new ecosystems, and placing large profit pools up for grabs. Vehicle data, spun off by surging vehicle connectivity, will be critical for generating revenue, reducing costs, and increasing safety and could represent a value pool of up to $750 billion by 2030.

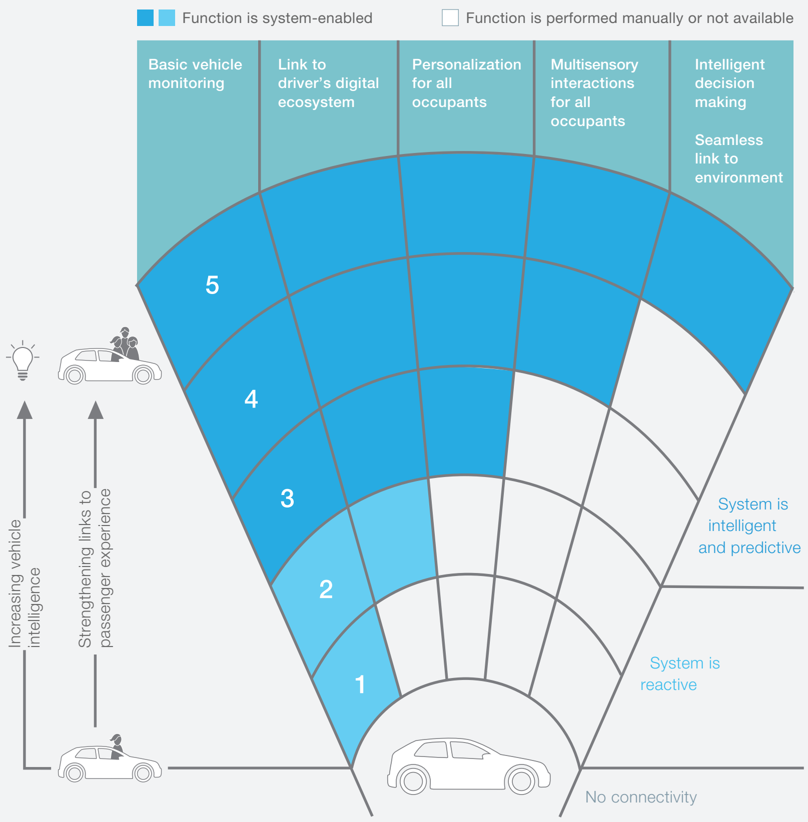
The value of this data will depend in part on the acceptance of clear-cut standards. A common understanding and shared language will help players across the ecosystem communicate about current and emerging opportunities. It will also make it easier for consumers to compare features and capabilities of different offerings. No such standard exists today for user experience in a connected car, one of the key foundations for data-driven value creation in mobility. As connectivity systems become progressively more complex, understanding the changes underway will become increasingly problematic in the absence of a universal framework. In this article, drawn from years studying this topic, we propose one.

The role of frameworks

To understand the role of generally accepted standards, look no further than the framework for levels of vehicle autonomy, advanced by the Society of Automotive Engineers (SAE) automation taxonomy. The SAE taxonomy is at once comprehensive and simple. At each ascending level of automation capability, only one new element is introduced at a time. Such stark classification reflects an engineering-oriented approach—yes or no, zero or one. Through three years of cross-industry research, multiple global roundtables, 3,000 consumer interviews and more than 100 interviews of executives from companies ranging from start-ups to large corporations, as well as our experience serving clients on this topic, the McKinsey Center for Future Mobility has been seeking to bring similar clarity to each distinct step change in connectedness achievable in the coming months and years. The product of those efforts is a framework to measure vehicle connectivity and the user's experience: the McKinsey Connected Car Customer Experience (C3X) framework (exhibit).

Exhibit

of user experience in connected cars, ranging from the most basic to the highly complex.



1 General hardware connectivity
Driver able to track basic vehicle usage and monitor technical status

2 Individual connectivity
Driver uses personal profile to access digital services via external digital ecosystems and platforms

3 Preference-based personalization
All occupants enjoy personalized controls, their own infotainment content, and targeted contextual advertising

4 Multimodal live dialogue
All occupants interact live with vehicle and receive proactive recommendations on services and functions

5 Virtual chauffeur
All occupants' explicit and unstated needs fulfilled by cognitive AI that predicts and performs complex, unprogrammed tasks

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Whereas autonomy and its levels can be defined as the extent to which drivers control how automobiles move (from full driver control to no human intervention at all), connectivity should be defined based on what car riders experience. The distinction is not academic. Connectivity, in large part, will be key to using car data to generate revenue, optimize costs, and improve safety. Artificial intelligence (AI) will be used to anticipate and respond to vehicle occupants' needs and commands, leveraging in-vehicle sensors and data on consumer preferences from multiple digital domains, including social media, connected home, and connected office.

The more seamless a rider's experience becomes, the more opportunities there will be to affect revenue, cost, and safety. As technology in the connected-car ecosystem becomes more sophisticated, consumer expectations will evolve in parallel, creating a need to deliver higher-value user experiences. The C3X framework makes it easier to quantify value-creation opportunities associated with increased connectivity. Players across the entire ecosystem will be able to understand with greater precision what's necessary to take user experience to (quite literally) the next level and how much value they will be able to generate through a connected vehicle across these levels.

Breaking down vehicle connectivity

Under the C3X framework, general hardware connectivity (level one) means that the vehicle allows for only basic monitoring of its use and technical status, and individual connectivity (level two) means that the vehicle can use a driver's personal profile to access services on external digital platforms such as Android Auto and Apple CarPlay. The data monetization for these levels is already core to how multiple businesses make money, particularly (but not exclusively) digital natives. Automakers too are starting to monetize connectivity; consumers are coming to demand and pay for basic connectivity features such as in-vehicle hot spots and usage-driven maintenance checkups.

Moving up the scale, when the user experience shifts from reactive to intelligent and predictive thanks to artificial intelligence, the value-creation opportunities are amped up significantly. At level three, focus expands beyond the driver and onto all occupants, who are afforded personalized controls, infotainment, and advertising. Level four provides live interaction through various modes (such as voice and gestures), allowing drivers and passengers to have a "dialogue" that feels natural with the vehicle and that enables them to receive proactive recommendations on services and functions. At the top of the scale, level five, the system becomes a "virtual chauffeur"—cognitive AI performs highly complex communication and coordination tasks, enabling it to anticipate needs and fulfill complicated, unplanned tasks for the riders.

Connectivity today—and tomorrow

About four out of five of vehicles on the road today are at or below level one of the C3X framework. This demonstrates significant space for improvements. Many vehicles in the premium segment, such as the Audi Q7, BMW 7 Series, Cadillac Escalade, Lexus LX, Mercedes-Benz GLE, and Tesla Model X, to name a few, already meet the criteria for level two, delivering a compelling connected in-vehicle experience to consumers. Currently, no commercialized vehicles meet full level-three capabilities as a standard offering yet, though some models have these features in select trims only. Our research shows, however, that by 2030, nearly half of new vehicles sold worldwide could be at level three or higher.

A common standard for connected-car user experience would go a long way toward enabling that reality. The C3X framework allows disparate players across industries to speak the same language, brings clarity to complexity, and sets clear markers for what comes next: a seamless, connected, and intelligent in-vehicle experience. Now, consumers and ecosystem players alike can share a common understanding of exactly what that means.

□ □ □

Michele Bertoncello is a partner in McKinsey's Milan office, **Asad Husain** is an associate partner in the Toronto office, and **Timo Möller** is a senior expert in the Cologne office. The authors are members of the McKinsey Center for Future Mobility.

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THE GLOBAL ELECTRIC-VEHICLE MARKET IS AMPED UP AND ON THE RISE

THE GLOBAL ELECTRIC-VEHICLE MARKET IS AMPED UP AND ON THE RISE

Patrick Hertzke,
Nicolai Müller,
Stephanie Schenk,
Ting Wu

May 2018

China remains firmly in the lead on our Electric Vehicle Index. But other pockets of growing public- and private-sector commitment to these vehicles have emerged.

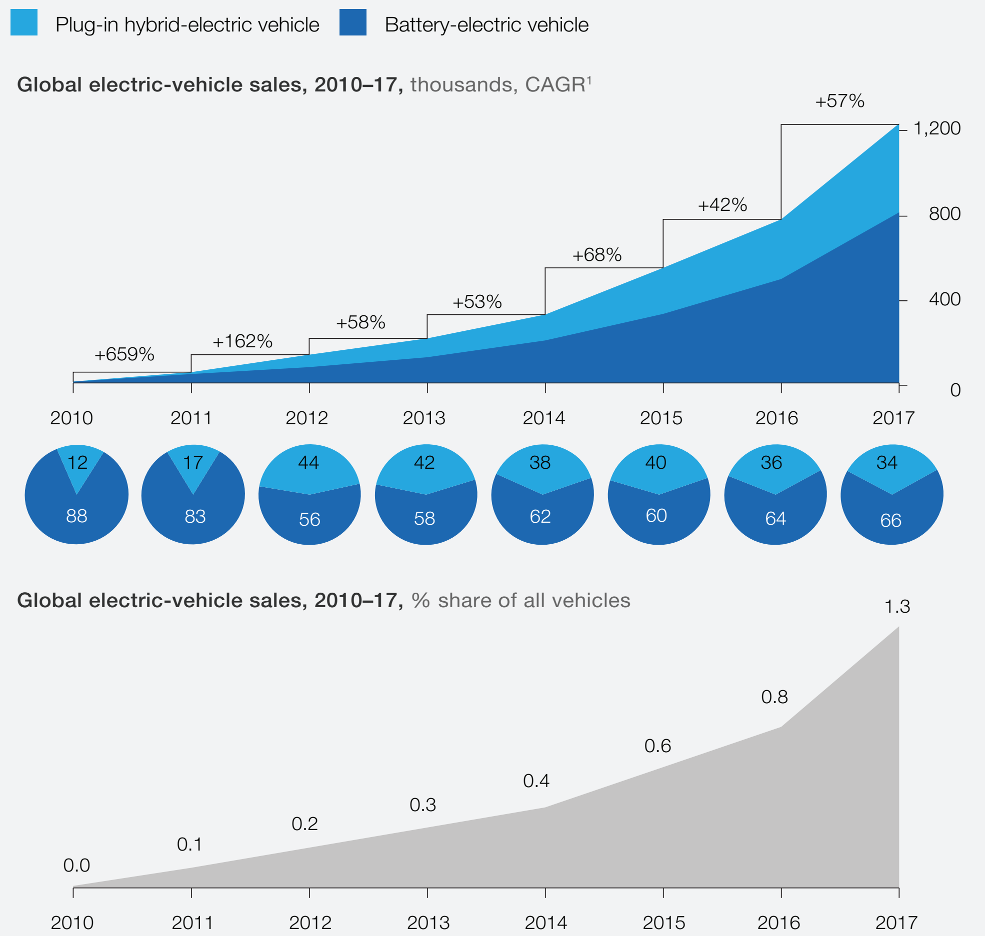
Last year, for the first time, global sales of new electric vehicles (EVs)[1] passed a million units (Exhibit 1), according to McKinsey's Electric Vehicle Index (see box "What is the Electric Vehicle Index?" below). Under the current growth trajectory, EV producers could almost quadruple that achievement by 2020, moving 4.5 million units, around 5 percent of the overall global light-vehicle market.

Pure electric vehicles (BEVs) currently make up 66 percent of the global EV market. BEV sales are growing faster than those of plug-in hybrid vehicles (PHEV). However, specific markets have very different powertrain preferences, which are influenced by regulatory actions, customer choice, and the availability of specific models.

1 Electric vehicles are defined as light vehicles that are either pure electric vehicles (BEVs), range-extended electric vehicles, or plug-in hybrid vehicles (PHEVs).

Exhibit 1

Last year, for the first time, global sales of new electric vehicles passed a million units.



[1]Compound annual growth rate.

McKinsey&Company | **Source:** EV-volumes.com; McKinsey analysis

China solidifies its leadership position in EV sales

The Chinese market expanded by 72 percent over the previous year in 2017, solidifying China's leadership position in EV sales. The country now has a larger EV market—primarily BEVs—than Europe and the United States combined. With a sales share of around 94 percent, domestic OEMs currently dominate the Chinese EV market.

Generous subsidies and tight regulation continue to drive much of the growth. Electric vehicles are exempt from license-plate lotteries and auctions in some Chinese cities, and this still plays an instrumental role in promoting EVs. After a successful pilot program in selected cities, the Chinese government decided last year to introduce green license plates for new energy vehicles (NEVs) across the country. At the end of 2017, the plates were rolled out to all provincial capitals and other selected major cities, with the remaining cities to follow in the first half of 2018. Car owners with these license plates will be eligible for preferential treatment.

Furthermore, China's national and local subsidies for electric vehicles are among the world's highest, reducing consumer concerns about the comparatively high up-front cost.

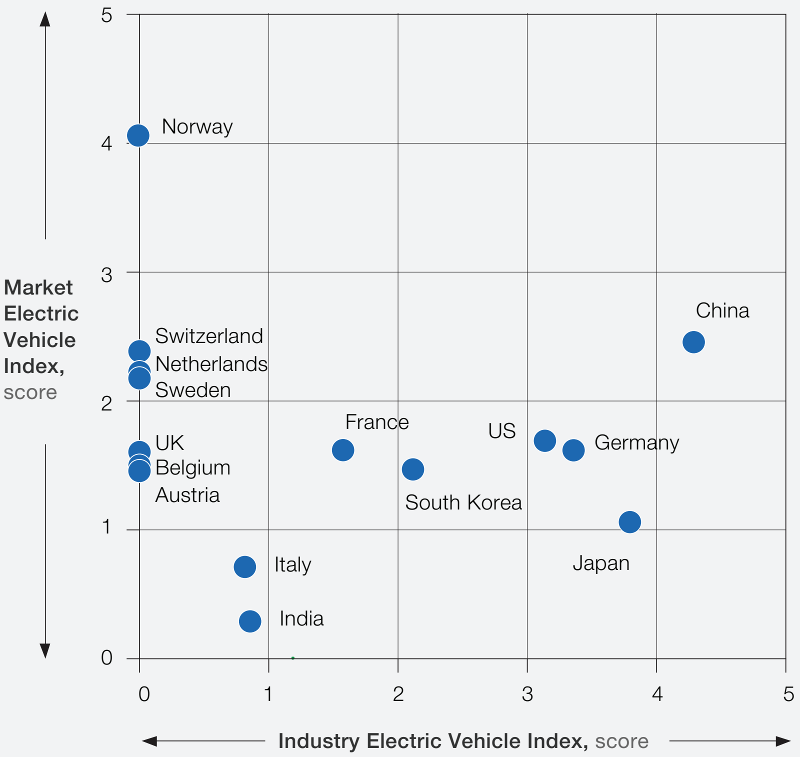
However, in an attempt to reduce spending on subsidies while still encouraging EV sales, the government recently communicated a change in the incentive policy. On the one hand, it raised the minimum range to qualify for any incentive to 150 kilometers (up from 100) and the energy-density requirement to 105 watt-hours per kilogram (up from 90). On the other hand, the subsidies for long-range BEVs (400 kilometers or more) rose by 14 percent, to 50,000 renminbi ($7,900). Monetary support for plug-in hybrid vehicles fell by around 8 percent, to 22,000 renminbi ($3,500).

In absolute terms, China's EV-sales performance is quite remarkable. Yet the adoption rate represents only 2 percent on a national level—a limited number of large cities (such as Beijing, Hangzhou, Shanghai, Shenzhen, and Tianjin) account for a majority of EV sales. Nonetheless, China's positive market performance helped put the country in a strong, well-balanced position in McKinsey's latest overall EVI rankings (Exhibit 2): it was outperformed only by Norway in the EVI market score and reinforced its leading position—ahead of Japan, Germany, and the United States—in the industry EVI analysis (the "supply" side of the equation). However, given today's EV-battery economics, leadership in EVI scores comes at a price: China and Norway have some of the world's highest levels of spending on consumer and supply-side subsidies, at the taxpayers' expense.

Exhibit 2

China moves into the lead in global electric mobility.

Electric Vehicle Index (EVI) development of selected countries, score out of five



Market Electric Vehicle Index, rank

1 Norway
2 China
3 Switzerland
4 Sweden
5 Netherlands
6 US
7 France
8 UK
9 Austria
10 Belgium
11 South Korea
12 Germany
13 Japan
14 Italy
15 India

Industry Electric Vehicle Index, rank

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

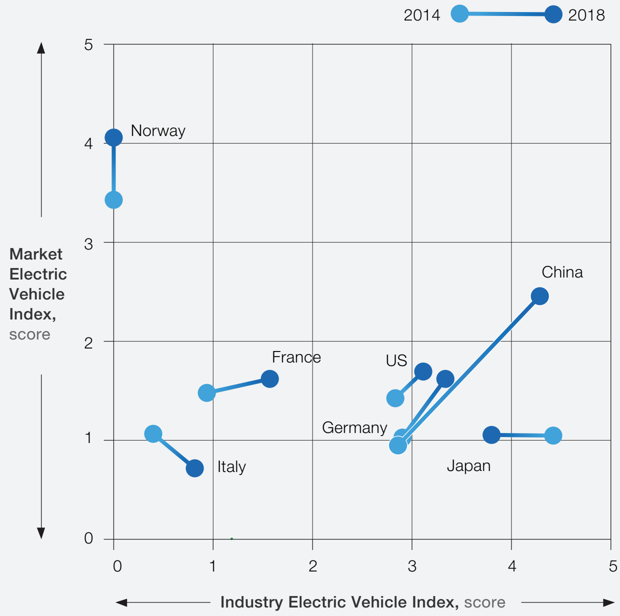
McKinsey&Company | **Source:** McKinsey analysis

A comparison of EVI performance over time reveals that China has rapidly overtaken the United States and Germany in combined EVI scores. Exhibit 3 shows China and Germany occupying roughly the same position in 2014, for example. Yet by 2018, China had far outpaced Germany in both market and industry EVI scores. In the market EVI scoring, China improved through higher EV sales, significant monetary and nonmonetary incentives, a greater variety of models, and the investment intensity of the charging infrastructure. China also excelled on industry scoring, significantly increasing its EV production and component shares. Major restrictions on local content—especially approved battery suppliers—keep a large portion of China's EV profit pool locally based.

Exhibit 3

China's positive performance put the country in a strong position in McKinsey's latest overall Electric Vehicle Index rankings.

Electric Vehicle Index (EVI) development of selected countries, score out of five



Examining the details

China is outperforming other countries on both market side (EV penetration rose from 0.3% to 2.2%, available models number almost 100, intense investment in charging infrastructure) and industry side (higher EV and component share)

France's EV market increased slowly, from 0.7% to 1.7% adoption rate; gains on industry side driven by insourcing of EV components

Germany had equal though slow improvement on both market and industry side as a result of higher sales (from to 0.4% to 1.5%) and vehicle production

Italy's market-side performance decreased because of stagnant market; missing industry focus on e-mobility slowed progress on supply side

Japan lost ground on industry side because of falling market share in EV and component production; slight improvement on market side given slow sales development (from 0.6% to 1.1%)

Norway increased EV penetration from 11% to 32% in 4 years, thanks mainly to significant monetary and nonmonetary incentives and larger choice of EV models

The **US** had few positive dynamics on both market and industry side; while EV model availability and market share (from 0.7% to 1.2%) rose slightly, vehicle and component production share decreased

McKinsey&Company | **Source:** McKinsey analysis

Germany and Norway led growth in the European Union

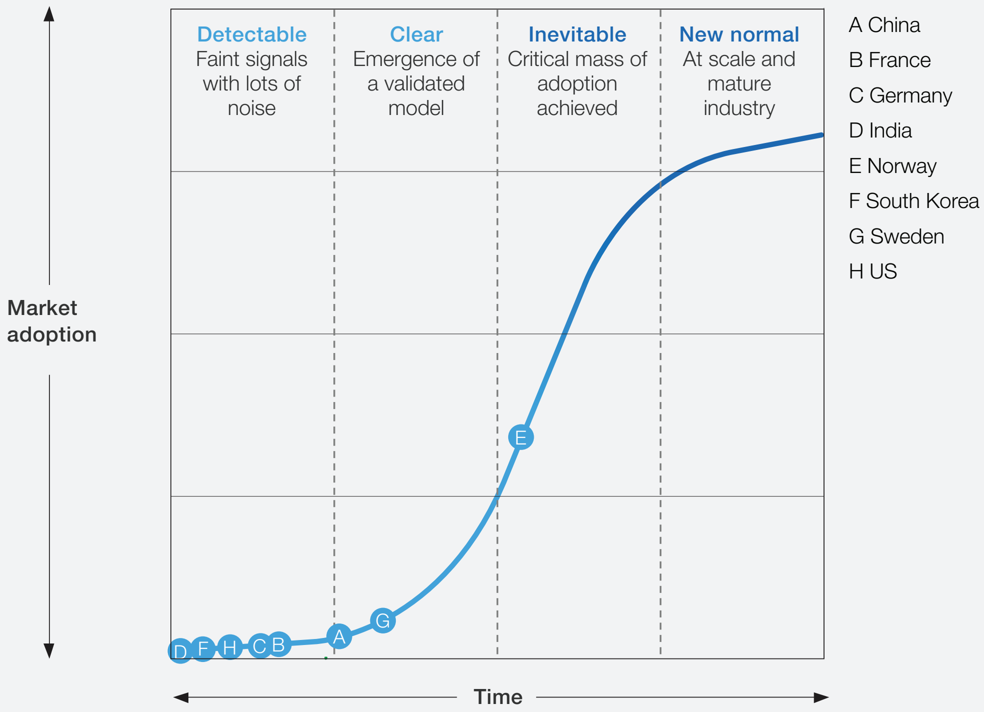
Europe's EV market grew by nearly 40 percent from 2016 to 2017, albeit from a small sales base. A variety of factors contributed, such as the ongoing headwinds for diesel technology and increasing customer interest in EVs. Much of the regional momentum emerged in Germany, where the EV market more than doubled. That country is now Europe's second-largest EV market, outperformed only by Norway.

Excluding the Netherlands, where an incentive shift from PHEVs to BEVs led to a significant drop in overall EV sales, European markets underlined the regional growth trajectory. Norway's EV sales-penetration rate reached 32 percent in 2017, and by December every second passenger car sold there was an EV. Norway stands largely alone in its mass-market embrace of electric vehicles, so it provides a real-world picture of future EV sales proportions that developed markets could experience over the next five to ten years. Exhibit 4 shows the four stages of a disruptive trend. Having reached a critical mass of EVs, Norway is clearly ahead of other countries—the EV disruption is inevitable. Most other countries are still in the first stage, except for China and Sweden, which have already advanced to the second: disruption is somewhat more clear, with EVs emerging as a validated model.

Exhibit 4

In Norway—which is clearly ahead of other countries—the electric-vehicle disruption is inevitable.

The 4 stages of a disruptive trend—focus on electric-vehicle market adoption



Source: Chris Bradley, Martin Hirt, and Sven Smit, Strategy Beyond the Hockey Stick, McKinsey, 2018

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The rollout of more attractive, better-performing EVs in key high-demand segments is another major driver for sales uptake, both in Europe and the United States. Nevertheless, at 27 percent, US growth lagged behind that of China and the European Union, since fuel prices remain low, reducing the operating-cost advantage of EVs. Likewise, the US Environmental Protection Agency recently announced that it would revise existing vehicle-emission standards (set by the previous administration), which require cars and light trucks to average more than 50 miles a gallon by 2025. It is still unclear what the new standards will look like, but the regulations, or the time frame for their adoption, will probably be relaxed. However, California and 12 states that follow its lead are determined to maintain stronger air-pollution standards than the federal government does.

India is new to the EVI this year. Both EV market acceptance and EV industry dynamics are at an early stage: the EV-adoption rate is less than 1 percent and domestic OEMs are just starting to launch EV models. Although the government rolled out a new tax policy to encourage EV adoption, a clear strategic road map is still missing. Demand comes mainly from commercial owners and the public sector, and the country has almost no charging infrastructure. Since India's carbon-dioxide levels from electricity generation are among the world's highest, it also needs more renewable-energy sources for its EVs to achieve true “well-to-wheel” zero-emission status.

New models (and regulations) to stoke markets

Global automakers will reportedly launch approximately 340 BEV and PHEV models in the next three years, significantly reducing supply as a barrier to further market uptake. The OEMs' increased attention mainly reflects tougher emissions targets, especially in China and Europe, and announcements that several countries, as well as cities around the world, will set end dates for the sale of diesel- and gasoline-powered vehicles. Norway, for example, wants BEVs to account for 100 percent of its new-car sales by 2025. California, France, and the United Kingdom have proclaimed that they will end sales of ICEs by 2040.

China too seems to be developing a long-term plan to abandon vehicles powered by fossil fuels: a new EV policy, which will become effective by 2019, requires automakers to comply with a mandatory EV credit target. As a result, several international automakers announced new joint ventures with domestic Chinese brands to develop and produce numerous EVs together.

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Electric vehicles have made meaningful progress in several regions and countries as they passed the milestone of one million sales, in 2017. With demand rising and manufacturers ramping up production capacities, the market will continue to grow. Looking forward, the confluence of government action, greater attention by OEMs, rising customer acceptance, and ingenious suppliers could accelerate the segment's profitability until the early to mid-2020s.

Patrick Hertzke is an associate partner in McKinsey's Detroit office, **Nicolai Müller** is a senior partner in the Cologne office, **Stephanie Schenk** is an analyst in the Munich office, and **Ting Wu** is a partner in the Shenzhen office.

WHAT A TEARDOWN OF THE LATEST ELECTRIC VEHICLES REVEALS ABOUT THE FUTURE OF MASS-MARKET EVS

WHAT A TEARDOWN OF THE LATEST ELECTRIC VEHICLES REVEALS ABOUT THE FUTURE OF MASS-MARKET EVS

March 2018

Antoine Chatelain,
Mauro Erriquez,
Pierre-Yves Moulière,
Philip Schäfer

McKinsey and A2Mac1 analyzed design choices that can help pave the way to profitable mass-market EVs.

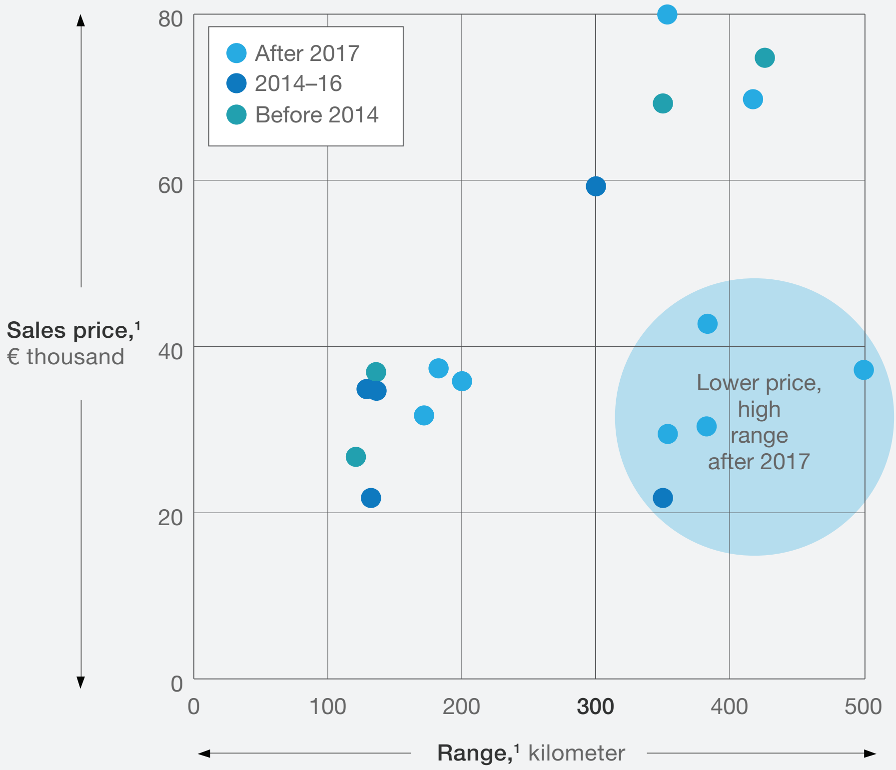
Will 2017 be remembered as the year when electric vehicles (EVs) made the move to become mass producible? A thought-provoking question for the industry, and reason for McKinsey, in partnership with **A2Mac1**, a provider of automotive benchmarking services, to deepen our work in the field. Last year, roughly 1.3 million EVs were sold globally. While this makes up only about 1 percent of total passenger-vehicle sales, it is a 57 percent increase over 2016 sales, and there is little reason to believe this trend will slow down. Established OEMs have announced launches of more than 100 new battery electric vehicle (BEV) models by 2024, further accelerating **automotive and mobility trends**, potentially growing EVs' share of total passenger-vehicle sales to 30 to 35 percent in major markets like China, Europe, and the U.S. (20 to 25 percent globally)by 2030. Moving away from previous "niche roles" such as high-performance sports or midrange city cars, there will also be a sizable share of midsize and volume-segment vehicles among the many new BEV models. A prominent, recently launched example is Tesla's new Model 3, with more than 450,000 preorders.

What will help EVs gain market share is that OEMs have reached ranges with their EVs that allow them to focus on reducing price points, for example, by increasing design efficiency or reducing manufacturing cost in order to become affordable to more customer segments. As shown in Exhibit 1, we find that once the average range of our set of benchmarked EVs has surpassed 300 kilometers (or 185 miles), OEMs seem to be able to concentrate on entering lower-price segments while keeping range up. This indicates that the long-awaited EV volume segment—"midsize EVs for the masses"—may be on the verge of becoming reality.

Exhibit 1

The race for acceptable range seems to be over, and the race for mass-market electric vehicles has begun.

Electric-vehicle price and range by year of launch



[1]Range according to Environmental Protection Agency. Where EPA data not available, New European Driving Cycle or OEM data was used; sales price based on German market OEM data.

McKinsey&Company | Source: A2Mac1; McKinsey Center for Future Mobility

The definition of "good" range varies across the globe, depending on geography and **city archetype**. But average battery range seems to have exceeded the expectations of the **largest customer segments**. This, combined with a decrease in prices for electric vehicles, means **the market for EVs** may be close to a commercial tipping point.

Whether an EV volume segment is (or will be) profitable for OEMs remains a burning question for many in the industry. We estimate that many EV models in their base version, and potentially even including options, still may have low contribution margins, especially compared with current internal-combustion-engine (ICE) levels.

With profitability in mind, and given the fast pace of technological advancements and new design trends in EVs, McKinsey and A2Mac1 undertook a second benchmarking analysis on **trends in electric-vehicle design** (see sidebar, "McKinsey and A2Mac1 on trends in electric-vehicle design").

In this article, we describe success factors on the way to profitable serial production of EVs and discuss essential practices for paving the road toward the EV mass market. This includes four high-level commitments to design and development through the lenses of architecture, integration, technology, and cost that can help realize a positive business case for mass-market EVs.

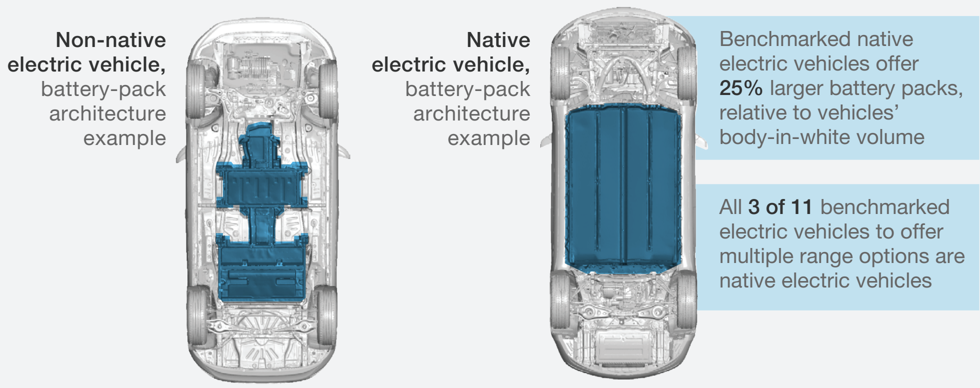
Build a native and inherently flexible electric vehicle

Despite higher up-front investments—in the form of engineering hours, new tooling, and so on—native EV platforms have proved advantageous over non-native models in multiple ways.

Designing the vehicle architecture entirely around an EV concept, without combustion-engine legacy elements, means fewer compromises and more flexibility on average (Exhibit 2).

Exhibit 2

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



McKinsey&Company | Source: A2Mac1; McKinsey Center for Future Mobility

As native EVs have to compromise less, particularly in their architecture and body in white, they can accommodate a bigger battery pack, which in turn correlates with a higher range. This is evidenced by the fact that native EVs have on average a 25 percent larger battery-pack volume (relative to body in white volume) compared with non-native EVs. One reason is that the body structure can be fit around the battery pack and does not have to be integrated in an existing architecture. This additional freedom in design typically resulting in larger batteries also leads to other potential advantages such as higher ranges, more power, or faster charging.

Further, as battery technology evolves quickly, allowing the newest EVs to have ranges which are not a bottleneck anymore, we see early indications that EVs are moving toward practices common in mass-market ICEs, for instance, offering powertrain options. The inherent flexibility of native EVs plays an important role in this as well. For example, battery packs can house a varying number of active cells while keeping the same outer shape and variable drivetrain technologies can allow players to produce rear-wheel, front-wheel, and all-wheel drive on a single platform.

While this may raise the idea that EVs will start moving toward modular strategies, as we know them from ICEs, thereby moving closer to industry-typical mass-production approaches, we still do not see a clear convergence toward one standard in design solutions. Players will need to stay agile on their way to mass-market EVs.

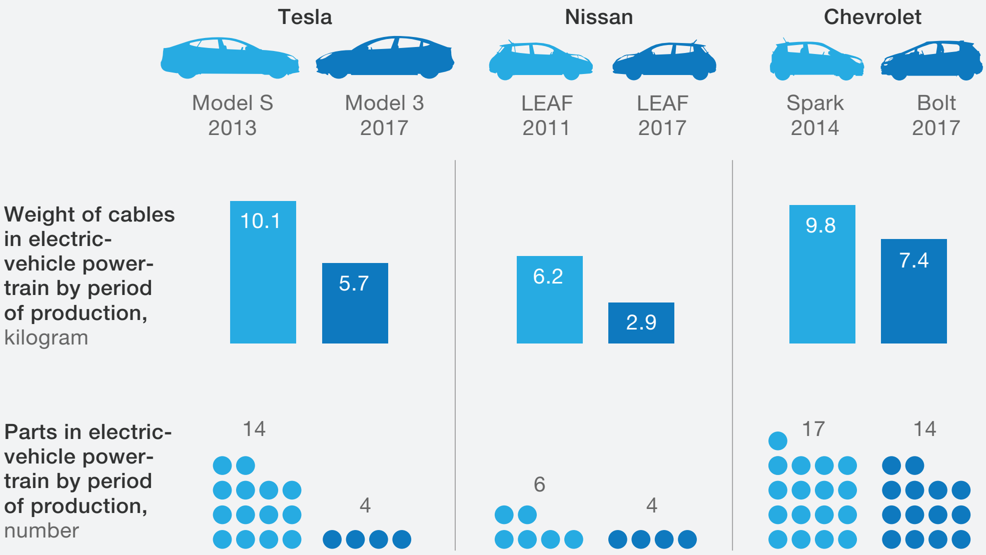
Keep pushing the boundaries of ev powertrain integration

Our benchmarking reveals a continued trend toward EV powertrain integration, with many parts of the power electronics moving closer together and being integrated into fewer modules. Yet, as players keep searching for additional design efficiency, one "mainstream" EV powertrain design has not yet emerged—either for overall architecture or for the design of individual components.

A good indicator of the increased level of integration is the design of the electric cables connecting the main EV powertrain components (that is, battery, e-motor, power electronics, and thermal-management modules). When looking at the weight and total number of parts for these cables across OEMs and their EV models, we observed a decrease in both cable weight and the number of parts in the OEMs' latest models compared with earlier vehicles, which reflects the higher integration of more recent EV powertrain systems (Exhibit 3).

Exhibit 3

The design of wiring elements in electric-vehicle powertrains suggests greater integration with newer models.



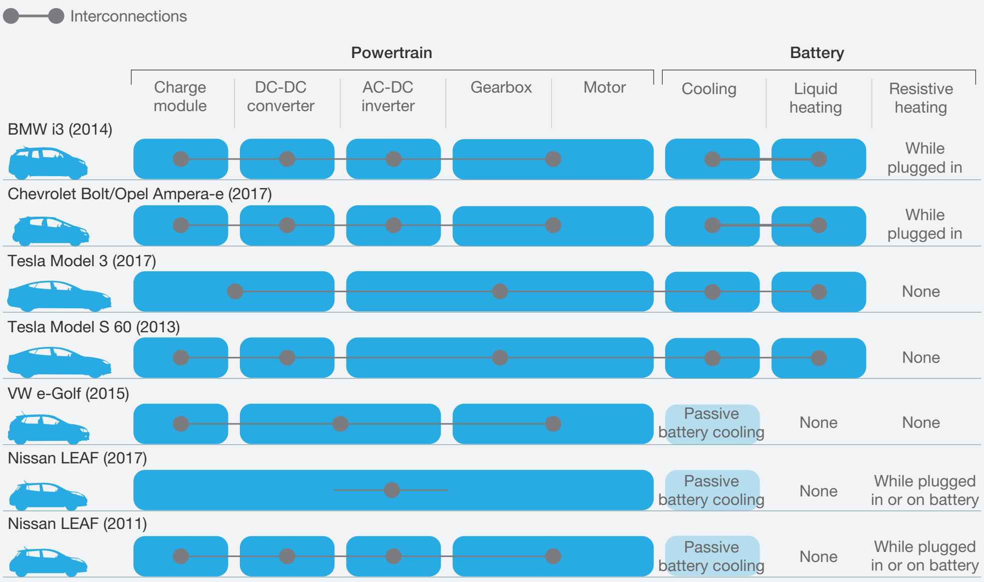
McKinsey&Company | Source: A2Mac1; McKinsey Center for Future Mobility

In addition to the physical integration of main EV powertrain components, we also observed a move toward more simple and efficient thermal-management solutions across said components. However, while some OEMs are on a consolidation charge here too, others still rely on multiple systems, and we do not see a clear convergence of designs yet (Exhibit 4).

Exhibit 4

Design approaches to managing electric-vehicle powertrain and battery thermal management still vary widely among original equipment manufacturers.

Integration and interconnection of electric-vehicle powertrain thermal-management system



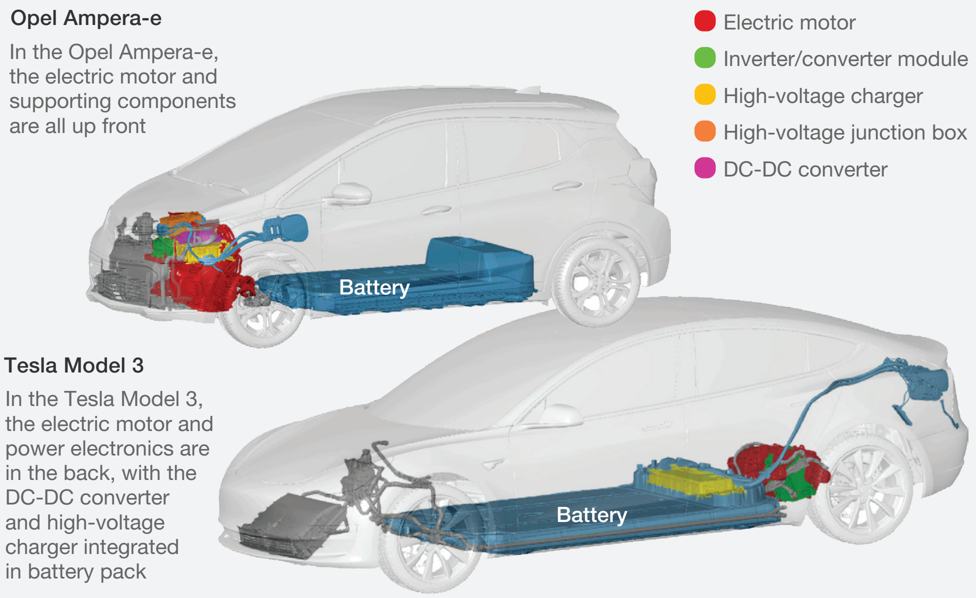
Note: Exhibit is a simplification of more detailed schematics.

McKinsey&Company | Source: A2Mac1; Ricardo; McKinsey Center for Future Mobility

Beyond the fact that technology is still maturing, the EV powertrain design variety may also be aided by its intrinsic, higher level of flexibility, as the components are generally smaller and the degrees of freedom based on available space in the underbody and front and rear compartments are higher than for ICE powertrains. To give just one example of different EV powertrain architectures: the Opel Ampera-e seems to leverage an ICE-like positioning of its powertrain electronics, including ICE-typical body and axle components, whereas the Tesla Model 3 integrated most components on the rear of its battery pack and the rear axle directly (Exhibit 5).

Exhibit 5

Electric-vehicle powertrain architectures vary, even among the newest models.



McKinsey&Company | Source: A2Mac1; McKinsey Center for Future Mobility

It is worth pointing out that such freedom in the positioning of components also gives more flexibility in overall features offered, for example, choosing to have room for a bigger trunk or to offer superior driving performance due to a lower center of gravity.

In their ongoing pursuit of mass marketability, EV players therefore might identify further opportunities in high-level integration of their EV powertrain systems. Doing so could help them capture potential benefits, such as reduced complexity in development, lower material and assembly costs, and weight and energy-efficiency improvements.

Stay ahead in the technology game

McKinsey research has shown that many electric-vehicle customers are very tech savvy. At the same time, new technologies are largely getting mature enough to be put to practice. This creates a great testing field for the new technologies that OEMs and other players hope to push into cars. But it also almost obligates EV manufacturers to equip their vehicles with the highest levels of technology around **advanced-driver-assistance systems (ADAS)**, connectivity, and other trends that are redefining the driver experience and travel strategies.

Next to increasingly introducing ADAS technologies, OEMs meet the needs of their EV customers by **enhancing the user interface and infotainment systems**. Specifically, they are increasingly integrating the control of a wide range of interior functions into a more central, “smartphone-like” user interface (HMI). For example, controls move from buttons to continuously growing touch screens—a concept that was first tried in a few models from US car manufacturers in the late 1980s and now seems to have reached sufficient levels of technological maturity and customer interest. We observed EVs in our benchmark that have as few as seven physical buttons in the interior, compared with 50 to 60 in many standard ICEs.

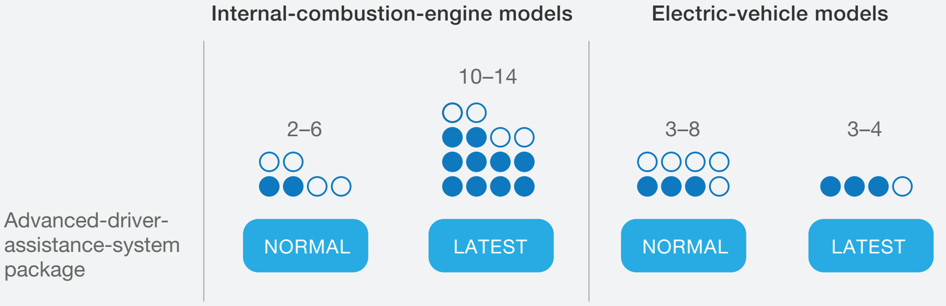
A key enabler of such advancements is the rapid rise in computing power. While traditional cars often show many decentralized and standardized electronic control units (ECUs), the latest EVs seem to rely on ever growing and increasingly centralized computing power.

ADAS technology, for example, requires a lot of computing power for the real-time signal processing of the various sensors. When putting the latest ADAS solutions—such as adaptive cruise control, autonomous braking, and potentially even autonomous driving capability—in the context of increased ECU centralization, it seems that EVs equipped with such ADAS technology further drive consolidation of ECUs in comparison to equally or less ADAS-equipped ICEs or EVs (Exhibit 6).

Exhibit 6

Benchmarking shows a potential trend toward consolidating electronic control units in (some) electric vehicles.

Electronic control units per vehicle by engine type and driver assistance package, range



McKinsey&Company | Source: A2Mac1; McKinsey Center for Future Mobility

An OEM's decision for a centralized or decentralized ECU architecture can be a strategic question and will be driven by different factors. One reason for a centralized approach may be the choice to "own" a key control point in the vehicle by becoming an integrator, which could facilitate advanced software development and potentially open up new revenue streams, for example, from over-the-air updates.

Besides strategic considerations, the ECU architecture may also affect weight and cost. For example, centralization may optimize wiring and sourcing efficiency via increased bundling. Because they require simpler protocols and fewer connections compared with multiple, decentralized ECUs—thereby also reducing the number of operations that could go wrong—centralized ECUs can increase reliability. On the development side, more ECUs also mean more teams who must collaborate and communicate efficiently to ensure quality across systems. Fewer teams and simplified processes can result from centralizing ECUs, and this simplification can lead to shorter development cycles. Further, central, high-power ECUs could be the backbone for developing fully autonomous driving, thereby equipping EVs to be ready for future mass-market characteristics and potential customer expectations.

Ultimately, however, the ECU architecture choice will depend on the OEMs' individual strategy, and as centralization may require significantly building up additional skills in-house, it will always be an individual business-case decision.

Apply design-to-cost levers

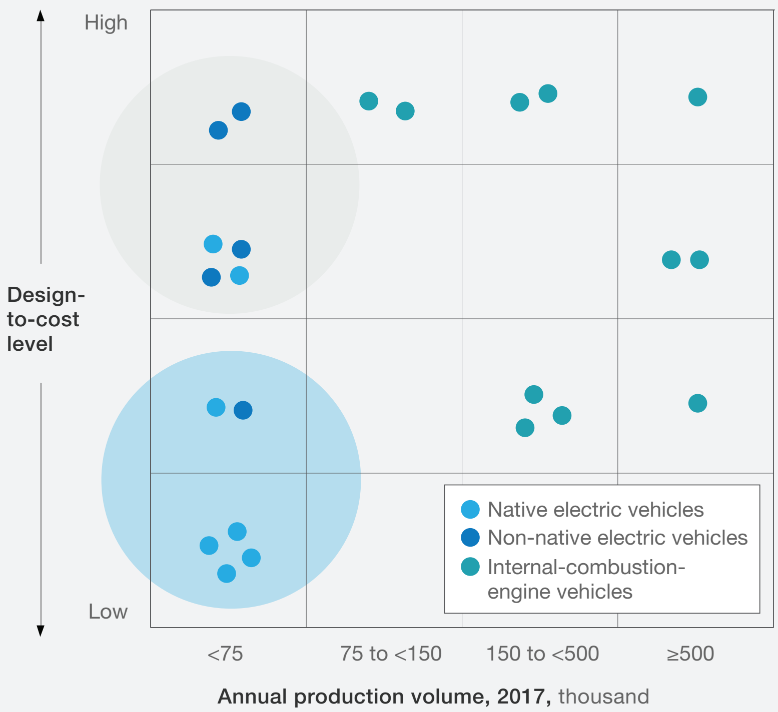
Achieving profitability is still a struggle for EVs, especially due to high powertrain cost. Since OEMs seem to have reached acceptable ranges by now, rigorous design to cost (DTC) will become more important to pave the road for EVs to successfully enter the mass market. That is, it could help achieve an attractive price point, while not jeopardizing margins for the OEM.

Cost efficiency seems to be the home turf of established OEMs and suppliers, who may be in the best position to leverage their experience and knowledge in traditional DTC levers (Exhibit 7).

Exhibit 7

We benchmarked design-to-cost levels across electric vehicles and cars with internal combustion engines.

Design-to-cost-level benchmarking[1]



[1]Assessment along typical design-to-cost levers: integration and part reduction, switching to lower-cost materials, sourcing industry standards, reducing specifications, switching to lower-cost machinery, and reducing quality issues.

McKinsey&Company | Source: A2Mac1; IHS Markit production data; McKinsey Center for Future Mobility

Therefore, it may come as little surprise that ICEs and non-native EVs seem to be more proficient in DTC than native EVs due to the makers' track record of continuous cost optimization and the possibility to carry over highly optimized components from previous models.

Yet the latest native EVs may be able to quickly catch up. For example, because of advantages in battery-pack advancements, native EVs now appear to switch from lightweight to more cost-efficient material solutions, such as steel elements in the body in white. They also seem to apply more rigorous despecification and decontenting (for example, in controls and air vents on the instrument panel) and to invest in mass-production processes, such as high-strength stamped steel instead of bent-pipe seat-structure designs.

As the move toward the mass market continues, EV experiments are increasingly becoming a serial-production game. Nontraditional OEMs will likely study the DTC practices of traditional OEMs, for example, including sourcing industry-standard parts, to identify better ways to close the gap in cost performance and thus increase their profit margins from the product-cost side. Nonetheless, achieving a superior cost performance might still be a competitive advantage for established OEMs and thus comprises an opportunity to step up against potential new market entrants.

Outlook: can OEMs make money in the volume EV market?

Most recently, EVs have gained a significant share in the new product announcements of many OEMs. At the same time, EV models individually have not yet offered much in the way of contributing to overall profitability compared with ICEs. As the global market share of EVs inevitably grows, their margins increasingly move into focus.

Taking the four steps in EV design outlined in this article into consideration may help OEMs to reduce the higher manufacturing costs (including materials, production, and final assembly) of EVs. With a focus on simpler and more flexible platforms, along with a fresh approach to technology and design, we believe that a positive mass-market business case for EVs may exist.

In fact, based on our analysis, the delta from total manufacturing cost to list price for sufficiently well-equipped (including hardware and software options such as nonstandard color, range extension, and different software settings), midsize EVs could potentially reach a level of 40 to 50 percent. While powertrain-independent components and final assembly appear similar in their cost structure to ICEs, major cost drivers still lie in the EV powertrain itself and in related uncertainties in the development of battery cost.

This also highlights that for an overall attractive business case, additional measures—for example, in optimizing the offering logic and channel strategy—will still be necessary.

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In summary, we may see an era of profitable mass-market EVs on the horizon, driven by design trends toward flexibility, integration, and simplification that maximizes customer value, and under the clear governance of cost efficiency for mass producibility.

As noted earlier, this publication presents only consolidated findings—detailed insights from our work are available upon request but would exceed the scope of this article.

Mauro Erriquez is a partner in McKinsey's Frankfurt office, and **Philip Schäfer** is an associate partner in the Düsseldorf office. **Antoine Chatelain** is Head of A2Mac1 Consulting, **Pierre-Yves Moulière** is the founder of A2Mac1.

The authors wish to thank Charles Carcenac, Piotr Cependa, Andreas Cornet, Maximilian Fischer, Stephan Fuchs, Tobias Geisbüsch, Gaël Guilinger, Wolfgang Günthner, Alexander Kienreich, Rupert Lee, Alexandra Mathiolon, Stephan Mohr, Timo Möller, Thomas Morel, Nicolai Müller, Vianney Palade, Amélie Pene, Patrick Schaufuss, Dennis Schwedhelm, Markus Schweier, Cédric Weiss, Hans von Tiedemann, Andreas Venus, Kilian Zedelius, and Klaus Ziemann for their contributions to this article.

McKinsey and A2Mac1 on trends in electric-vehicle design

This piece is part of a series jointly published by McKinsey and A2Mac1. The series aims at discussing teardown- and benchmarking-derived insights on the most current trends in electric-vehicle (EV) design.

The premier issue introduced key insights from a detailed teardown and physical and digital benchmarking of ten first- and second-generation EV models. New issues, like this one, set out to expand on the learnings from our earlier EV benchmarking efforts—above all by including newly launched EV models in the benchmarking pool and introducing a perspective on a new EV trend. In this publication, we present consolidated findings; detailed insights from our work are available upon request but would exceed the scope of this article.

The models analyzed for this article

In this benchmarking, we considered 11 electric-vehicle models:

- NISSAN LEAF 2011, Japan
- Volkswagen e-up! 2013, Europe
- Tesla Model S 60 2013, United States
- Chevrolet Spark 2014, United States
- BMW i3 2014, Europe
- Volkswagen e-Golf 2015, United States
- BYD e6 Jingying Ban 2015, China
- NISSAN LEAF 2017, United States
- Chevrolet Bolt 2017, United States
- Opel Ampera-e 2017, Europe
- Tesla Model 3 2017, United States (new)

The findings presented here

This publication provides observations based on a sample set of EVs. We make no claim to the "generalizability" of these findings. For individual points of comparison, we added outside-in research on other vehicles where relevant. Technologies are evolving quickly, leading to uncertainty, for example, when it comes to assessing the development of EV powertrain components across formats or chemistries.

The differentiation of native and non-native EVs

Entirely native or entirely non-native EVs can be understood as two ends of a range. In non-native EVs, most elements—apart from the battery and specific EV powertrain components—are based on previous internal- combustion- engine (ICE) models, following a logic of deriving the EV architecture from what an OEM has done in the past. Examples could be the VW e-Golf or the Chevrolet Spark. On the other end, we consider native EVs to be an entirely new development effort. Examples could be the Tesla models. As EV design advances quickly, it may become increasingly challenging to make such a clear differentiation.

CHARGING AHEAD: ELECTRIC-VEHICLE INFRASTRUCTURE DEMAND

CHARGING AHEAD: ELECTRIC-VEHICLE INFRASTRUCTURE DEMAND

Hauke Engel,
Russell Hensley,
Stefan Knupfer,
Shivika Sahdev

August 2018

Access to efficient charging could become a roadblock to electric-vehicle uptake. Let's look at the numbers and costs behind the problem.

Ask any electric-vehicle (EV) shopper: poor range and limited attractiveness have long been the two biggest bottlenecks to EV uptake.

Now, however, with more than 350 new, feature-laden EV models to debut by 2025, with ranges that increasingly top 200 miles, these attributes pose less of a hurdle. Instead, if consumers purchase EVs at the expected rates in the next five to ten years, a lack of charging infrastructure could become an obstacle to **EV adoption**.

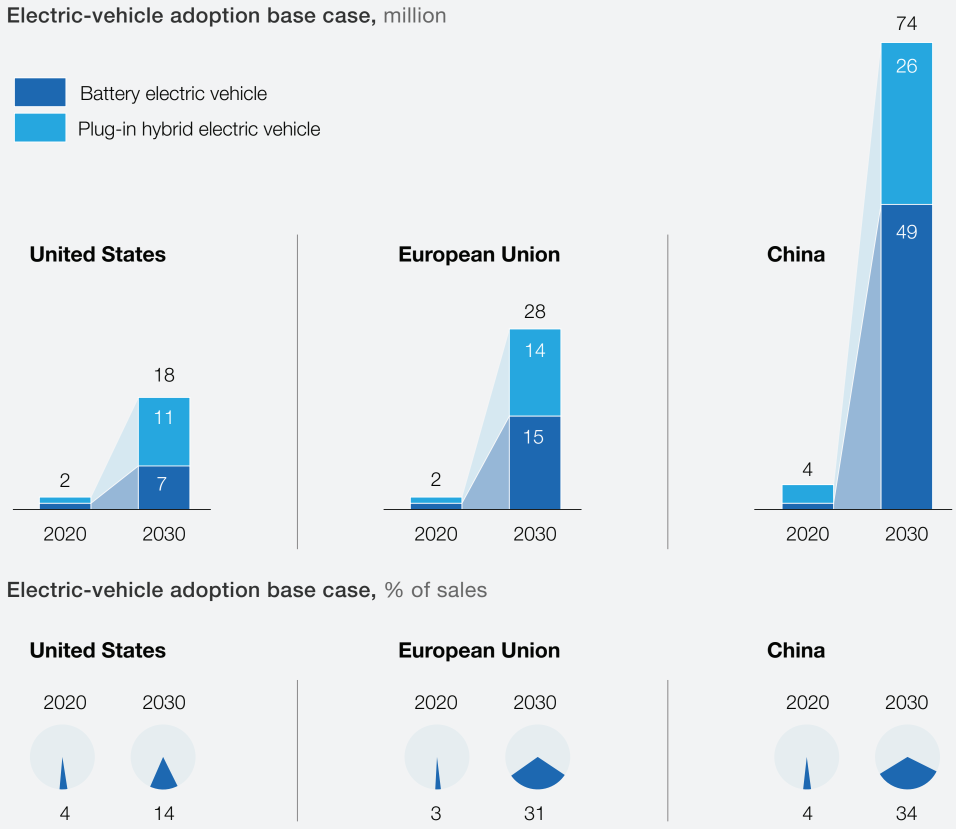
Recognizing the charging-capacity gap

Consumers rank not having enough access to efficient charging stations as the third most serious barrier to EV purchase, behind price and driving range. That's according to McKinsey's **2016 EV consumer survey** of buyers considering battery-powered EV in China, Germany, and the United States. With EV prices declining and ranges expanding, charging could soon become the top barrier.

McKinsey's base-case scenario for EV adoption suggests approximately 120 million EVs could be on the road by 2030 in China, the European Union, and the United States (Exhibit 1). The aggressive-case scenario could see that double. Along with different levels of EV adoption across regions, structural considerations will make charging-station demand highly localized. For example, compare a city like Los Angeles, with many single-family low-rise homes that have parking garages, with Manhattan, where high-rise multi-unit apartment dwellings prevail. These two cities will have extremely different EV charging-infrastructure needs.

Exhibit 1

Our base case for adoption suggests approximately 120 million electric vehicles could be on the road by 2030.



McKinsey&Company | **Source:** McKinsey analysis

Big energy demand, but where to charge?

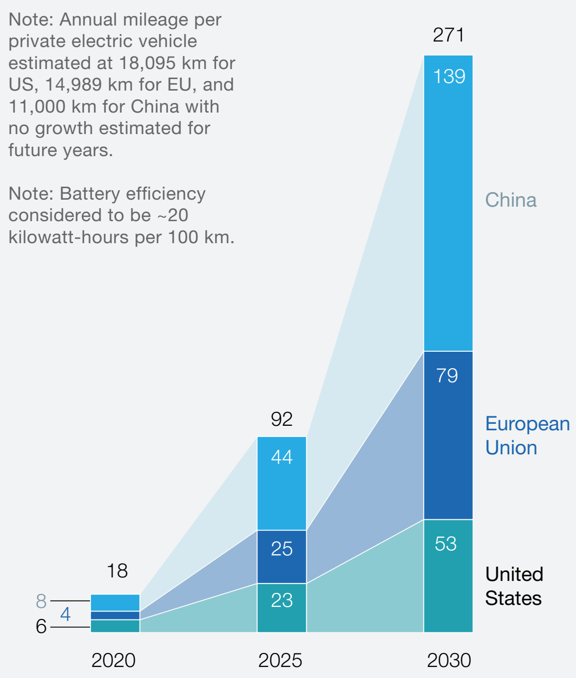
Total charging-energy demand for the EV vehicle population across China, Europe, , and the United States could grow dramatically from 2020 to 2030, increasing from roughly 20 billion kilowatt-hours to about 280 billion kilowatt-hours (Exhibit 2). This estimate reflects assumed EV adoption, total miles driven per year, and the average kilowatt-hours required per mile (a miles-per-gallon equivalent). While 280 billion kilowatt-hours sounds like a big number, it represents less than 8 percent of current US energy demand while reflecting the requirements of all four markets.

Unlike traditional, internal-combustion engine (ICE) vehicles, which typically only refuel at gas stations, EVs can recharge at multiple locations in multiple ways. Our model analyzes charging across four use cases that all assume wired plug-in chargers: at home, at work, in public, and on highways for long-distance trips. Other use cases and technologies are emerging.

Exhibit 2

Charging-energy demand for electric vehicles in the four regions studied could reach 280 billion kilowatt-hours by 2030.

Total energy demand, billion kilowatt-hours



McKinsey&Company | **Source:** McKinsey analysis

For example, wireless charging or streetlight charging, while potentially viable, are not included in this analysis.

The energy consumed at home and in the workplace will depend on the number of chargers installed and the amount of energy those chargers provide. Home charging will depend on whether EV owners have garages and on their income demographics. Charger penetration at work will predominantly reflect employer choice or regulatory requirements.

However, people do not only use their vehicles to drive to and from work. Approximately 3 to 6 percent of total miles driven involve long-distance trips that average more than 100 miles. Even with a full charge leaving home, most of today's EVs cannot make that round-trip without recharging. This makes the case for long-distance chargers.

Combined home, work, and long-distance charging could in theory cover an EV owner's entire energy demand. While potentially true for drivers who use an EV as a second car only for commuting or errands, this scenario is unlikely at scale for several reasons. For instance, drivers without chargers at home or work must charge in public; drivers who exceed their battery range on a given day may need to visit fast-charge stations; and drivers who forget to charge at home or don't have home chargers must rely on other options, making the case for public charging.

From home to work to public charging

People tend to follow a charging hierarchy that starts at home. Most individual passenger cars remain parked for eight to 12 hours at night, and home charging can be easy and often cheaper than charging elsewhere. The reasons: in most countries, residential electricity is cheaper than commercial or industrial electricity, and most charging can happen overnight when off-peak electricity prices are lower.

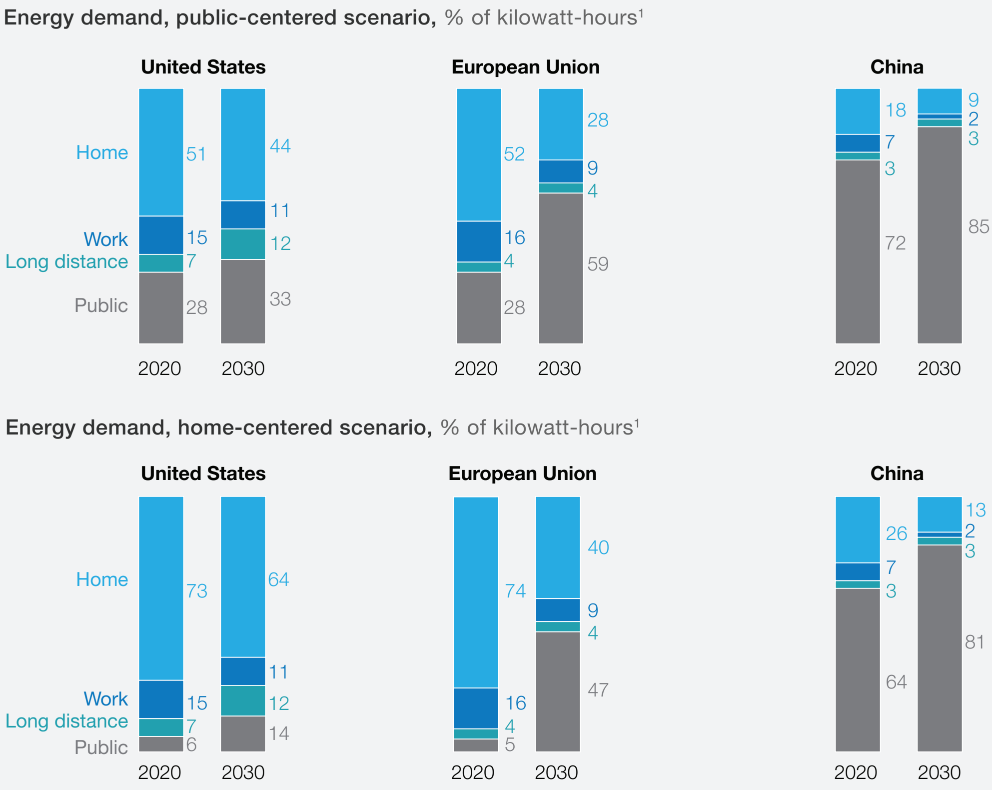
In a home-centered base case, approximately 75 to 80 percent of EV owners in the United States and European Union should have access to home charging, which should provide up to 75 percent of their energy needs in 2020 (Exhibit 3). The high penetration of single-family homes in states with high EV adoption will drive this demand, particularly in California and the Pacific Northwest. China should have much lower penetration of home charging because there are fewer single-family homes. Even when considering public-centered alternatives, the importance of home charging will remain highly relevant in the United States.

In the European Union, as EVs go mainstream, charging will likely shift toward public options and away from the home over time, with the share of home charging declining from approximately 75 percent in 2020 to about 40 percent by 2030. That's because more middle- and lower-income households without home-charging options will buy EVs from 2020 onward. In China, public charging will dominate and increase in importance over time, going from 55 to 60 percent in 2020 to approximately 80 percent by 2030. The structural limitations of highly dense urban cities, which have larger proportions of on-street and large-commercial-garage parking, are the catalysts for increased public-charging demand.

In the near term, low levels of public charging should therefore not significantly hinder EV adoption in the European Union and United States. The situation looks different for China, where over half of the energy will come from public sources. Furthermore, the importance of public charging will likely grow stronger by 2030, reinforcing the need for strategies based on target-market needs.

Exhibit 3

There are home- or public-based scenarios for electric-vehicle charging by region.



[1]Figures may not sum to 100%, because of rounding.

McKinsey&Company | **Source:** McKinsey analysis

Choosing slow, fast, or superfast charging

The next question beyond where people will charge concerns the type of technology they will use. Three broad categories of EV charging infrastructure exist today:

- **Alternate-current (AC) charging, also known as level 1 or level 2.** In this system, an in-car inverter converts AC to direct current (DC), which then charges the battery at either level 1 (equivalent to a US household outlet) or level 2 (240 volts). It operates at powers up to roughly 20 kilowatts.

- **DC charging, also known as level 3 or direct-current fast charging (DCFC).** This charging system converts the AC from the grid to DC before it enters the car and charges the battery without the need for an inverter. Usually called direct-current fast charging or level 3, it operates at powers from 25 kilowatts to more than 350 kilowatts.

- **Wireless charging.** This system uses electromagnetic waves to charge batteries. There is usually a charging pad connected to a wall socket and a plate attached to the vehicle. Current technologies align with level 2 chargers and can provide power up to 11 kilowatts.

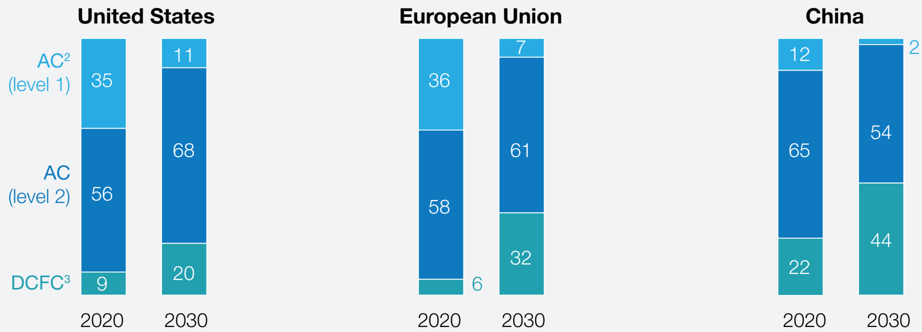
The kilowatt capacity of a charger determines the speed at which the battery receives electricity. AC level 1 and level 2 are most applicable for homes and workplaces because of the long periods cars remain parked and their lower cost: a simple level 2 for a home can cost as little as $500. DCFC chargers are most applicable in situations where time matters, such as on highways and for fast public charging.

Basic AC level 1 and level 2 power will overwhelmingly remain the dominant charging technology through 2030, providing from 60 to 80 percent of the energy consumed. Most of this charging will take place at homes, workplaces, and via slow-charge public stations (Exhibit 4). DCFC will likely play a much larger role in China, which requires more public-charging infrastructure.

Exhibit 4

Level 1 and Level 2 charging will likely remain the dominant source of charging energy demand.

Energy demand by charging technology, % of kilowatt-hours[1], home-centered scenario



[1]Figures may not sum to 100%, because of rounding.
[2]Alternating current.
[3]Direct current fast charging.

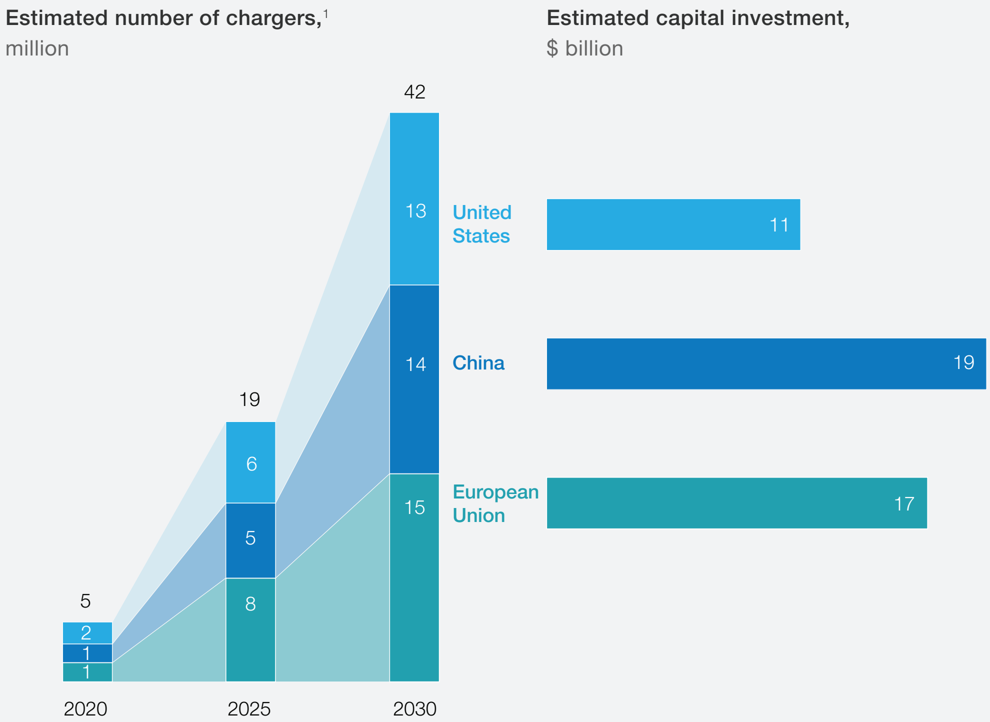
McKinsey&Company | **Source:** McKinsey analysis

Calculating charging's dollars and cents

Based on charging profiles and available technologies, the industry could require approximately 40 million chargers across China, Europe, and the United States, representing an estimated $50 billion of cumulative capital investment through 2030 (Exhibit 5). The US alone will need a cumulative 20 million chargers and approximately $10 billion of investment by 2030. The European Union will need a cumulative 25 million chargers and roughly $15 billion of investment during the same period. In China, the numbers are a cumulative 20 million chargers and $20 billion of investment.

Exhibit 5

The industry may need to invest $50 billion in the four regions studied through 2030 to meet the need for chargers.



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

McKinsey&Company | **Source:** McKinsey analysis

While most chargers—over 95 percent—will be in homes and workplaces from a charger-count perspective, the share of capital investment they represent is closer to roughly 70 percent of the total. This reflects the significantly higher cost of faster chargers. On average, a level 2 charger used in a home costs less than $1,000; one used in a workplace or in public can cost between $3,000 and $5,000. A DCFC starts at about $25,000 and, depending on the power capacity, can rise to more than $200,000 for each unit.

Currently, the business cases for home or workplace level 2 chargers are straightforward, given low up-front capital and operating expenses. Making the business case work for public DCFCs is more difficult. The reasons include higher up-front capital, higher operating costs, and currently low utilization. In the near term, this raises a critical question: Who will provide the necessary capital for public charging while utilization rates remain low, particularly in China and where the need for public charging is higher?

□ □ □

As electric-vehicle demand looks increasingly likely to grow and EVs emerge as viable alternatives to ICE cars, **an ecosystem of industries** needs to stack hands on actions that can enable their broader use. Closing the charging gap is one such action, and resolving it will require a concerted, collaborative effort. That's why finding the answers to the questions raised here should top the agendas of all stakeholders across the EV ecosystem, especially if charging access becomes the number-one impediment to EV penetration. Understanding specific local needs for early demand and adaptation will be the key to making effective targeted investments, matching demand and supply, and enabling quick returns on investments.

Hauke Engel is an associate partner in McKinsey's Frankfurt office, **Russell Hensley** is a partner in the Detroit office, **Stefan Knupfer** is a senior partner in the Stamford office, and **Shivika Sahdev** is an associate partner in the New York office.

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TECHNOLOGY DELIVERED: IMPLICATIONS FOR COST, CUSTOMERS, AND COMPETITION IN THE LAST-MILE ECOSYSTEM

TECHNOLOGY DELIVERED: IMPLICATIONS FOR COST, CUSTOMERS, AND COMPETITION IN THE LAST-MILE ECOSYSTEM

August 2018

Bernd Heid,
Matthias Kässer,
Christoph Klink,
Florian Neuhaus,
Jürgen Schröder,
Simon Tatomir

What's the outlook for the last-mile delivery ecosystem, given rapid development in technology? How will technological advances affect unit economics, customers, and competitive dynamics?

One of the best parts of the e-commerce journey is the moment that you finally get your hands on that long-sought-after, much-anticipated item you ordered. As technology increases customers' expectations of what they can have, it is also widening their options for how those products get delivered. However, **our previous research** shows that customers are not only increasingly demanding but also extremely cost sensitive and have a very low willingness to pay for greater convenience.[1] In the medium term, autonomous delivery vehicles (ADVs) will be the dominant technology in last-mile delivery, with the power to both give consumers greater delivery convenience at lower cost and significantly alter the competitive landscape.

The pace of tech development is faster than expected and is already transforming last-mile delivery

Today, we see examples of technology piloting and testing across the globe. But we are also seeing the beginning of series productions and scaling of technology deployment by several companies. At every stage of development—from concept through testing to rollout—last-mile technology is making rapid gains. In the years ahead, we expect the adoption of a few key technologies to increase in several stages:

- **Short term.** We expect **electric vehicles (EVs)** and the increased presence of unattended delivery technology to form the first wave of technology that transforms last-mile delivery. This change is under way, as these technologies are market-ready and scalable, with each of them contributing to cost effectiveness, customer convenience, or regulatory compliance. As **cities** tighten their emissions standards, it makes sense that the deployment of EVs in last-mile delivery will be among the first technologies to achieve significant adoption.

- **Near term.** In three to five years, large, semiautonomous delivery vehicles that follow parcel-delivery staff are expected to be the next trend to be adopted by companies in the parcel-delivery segment. This first step toward full automation will support delivery staff and increase productivity by cutting the time needed to drive and park vans.

- **Medium term.** In five to ten years, ADVs will likely not need to be accompanied by human delivery staff at all and will represent the third wave of widespread tech-enabled parcel delivery.

- **Long term.** Beyond 2030, it is expected that robots will take packages right to customers' front doors. This technology represents crucial added value—namely customer convenience—as robots will be able to address the "last ten yards" of delivery. The first robot-delivery pilots are already happening. However, this technology is costly today, which means that these solutions are far from widespread deployment.

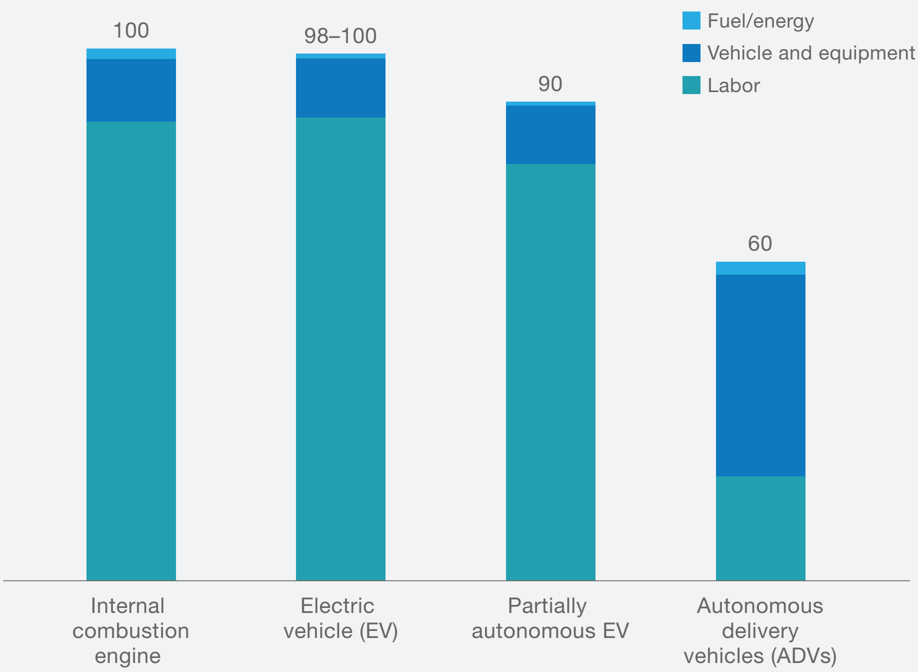
1 For more, see Martin Joerss, Florian Neuhaus, and Jürgen Schröder, "How customer demands are reshaping last-mile delivery," October 2016, McKinsey.com, and Delivering change: *The transformation of commercial transport by 2025,* September 2016, McKinsey.com.

All these technologies have value potential, as well as risks for customers and providers. **Semiautonomous and autonomous vehicles**, for example, reduce delivery costs in cities by approximately 10 to 40 percent (Exhibit 1). EVs, on the other hand, do not yet yield significant cost savings. That is because total vehicle cost, including mileage, accounts for less than 15 percent of total last-mile delivery cost in dense networks and thus offers only a small basis for cost improvement. Therefore, at least in cities, even significant improvements to total cost of ownership from electrification are not expected to improve delivery cost substantially. Nonetheless, as mentioned, the use of EVs will likely become necessary in order to comply with increasingly tight emissions-related regulations.

Exhibit 1

Autonomous-vehicle technology holds the promise of increasingly reducing the per-parcel cost of last-mile delivery.

Last-mile delivery cost per parcel in an average city, indexed[1]



[1]Key assumptions include labor cost of €20/hour, average city-network density, and energy consumption of 0.3 kWh/km for electric vehicles and 12.0 l/km for internal-combustion-engine vehicles.

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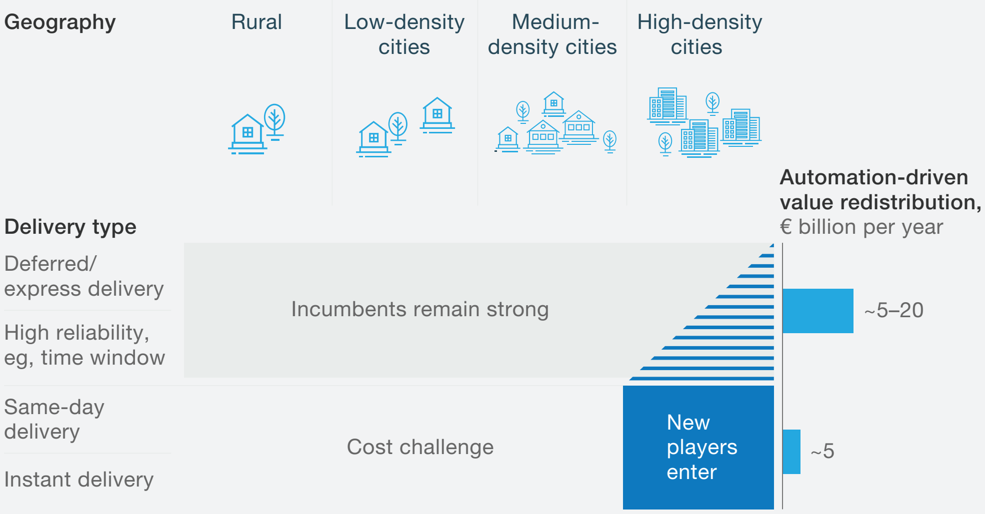
Technology will reshape value and competition in last-mile delivery

As described above, customers are demanding more from their delivery providers, and a highly competitive environment combined with customers' high cost sensitivity has pushed forward the development of technology that will help the industry deliver on these demands. Combined, these trends mandate immediate adoption of these new technologies by last-mile players. The growing importance of technology in the last-mile industry will **affect the overall ecosystem**, including its competitive dynamics and the distribution of value across industry players (Exhibit 2).

Exhibit 2

Incumbents will likely continue to dominate the industry core, where the bulk of value redistribution from automation will occur, but new entrants have the opportunity to emerge in the same-day and instant-delivery segments.

Competitive dynamics in different geographies and product segments



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There are three main implications for the ecosystem:

- **First, courier, express, and parcel (CEP) players are likely to remain strong in the industry core.** Despite the rather large technological leap that is required, incumbent CEP players are still well positioned to control the bulk of parcel volumes (75 to 80 percent of the 2025 volume) in deferred, in B2B, and—to a lesser extent—in **same-day delivery.** The capital-intensive nature of sorting and full-scale logistics networks, the almost-mandatory nationwide service offer, significant economies of scale, and the required access to the customer are immense barriers to entry for new players and will help traditional players hold on to dominance in the core. However, certain very large retailers may enter traditional last-mile delivery (that is, deferred delivery) in selected high-density cities to gain control of the customer touchpoint and to create synergies with their same-day networks.

- **New players can enter in new segments.** For other new entrants, however, emerging niches in last-mile delivery such as same-day and instant delivery are opportunities for which they are well positioned to move in and compete. First, while incumbents have dense delivery networks that bring a strong competitive (cost) advantage in the traditional business, the volumes in same-day and instant delivery are still low, making it easier for new players to enter and compete at comparable cost. On top of that, ADVs will dramatically drive down operations costs, making dense networks less essential and further opening the door to smaller, newer players.

- **In both the industry core and new segments, significant cost savings will trigger a multibillion-euro redistribution of value.** In developed economies, €20 billion to €25 billion per year in savings from cost-effective autonomous technology are up for grabs. The magnitude of the value redistribution is significant, exceeding the overall profit pool of CEP players in developed countries today by quite some margin. Moreover, the lion's share of value redistribution (€15 billion to €20 billion) in the last-mile ecosystem is expected to occur in today's core market rather than in the emerging same-day and instant markets. The value will likely be redistributed across CEP players, autonomous-vehicle manufacturers, IT operators, and customers. We believe that three control points will determine the shape of this shift. Specifically, the players that master delivery tour planning, routing, and management of autonomous fleets will be the ones that capture the largest chunk of the new value pool. Even though full deployment of fully autonomous fleets is not expected until well into the 2020s, rapid tech development means that its future winners will likely be determined in the next two to three years because the foundations for future success (for example, data collection, capability building, formation of partnerships) need to be laid by then.

Strong business partnerships can help CEP and commercial-vehicle (CV) players unlock the full automation value potential and ensure competitiveness

In the future, CV players are likely to play a more important role in last-mile delivery, since they not only are well positioned to operate the autonomous delivery fleets (fleet management) but can also leverage their routing expertise. CEP players are well positioned to control the core steps—capacity management, tour optimization and planning, and sorting—as they will continue to play from a position of strength in the core business. Physical control of the parcels also gives CEP players possession of and control over the associated data, which is a vital input for process excellence.

These shifts would bring CV and CEP players closer together. To capture the full efficiency potential, both sides would need to collaborate closely in the routing of autonomous vehicles and together tackle capabilities challenges, such as suggesting possible parking spots and instant rerouting based on traffic information. A close partnership also facilitates the integration and alignment of the routing software with the player's related IT backbone (for example, tour planning and optimization IT). Beyond the technology advances that benefit CEP and CV players collectively, strong business partnerships can result in competitive advantages to individual players depending on the roles they play in the last-mile ecosystem.

The main advantages to CEP players are better access to technology and, ultimately, a chance to obtain technology leadership as well as improved requirements management. CV players benefit from better core-market access, access to additional value pools, and data insights and IT-related lessons.

The benefits of collaboration can certainly accrue to CEP and CV partners in ways that serve the competitive interests of individual players, but there's more. In addition to helping ensure they don't lose ground to other players, collaboration has the potential to give CEP and CV players collective influence in two key ways:

- **Establishment of an ecosystem.** Highly successful collaborations can open the door for CEP and CV players to establish a last-mile delivery ecosystem. As "founders" of a new landscape, they could make their routing and delivery planning the industry standard and build a platform on which other ADV manufacturers run and different applications and services are built.

- **Creation of additional data-driven business models.** Jointly creating integrated routing and delivery-planning software can give both players access to an immense amount of data. **Insights derived from data** gathered from various sources—for example, from traffic, parking spots, or consumers themselves—can shape new joint business models.

For CV players, it seems advantageous to partner with one or more large CEP players who are leading in their home countries, because they possess the best data and typically the greatest innovative power. For CEP players, size matters, and smaller CEPs risk falling behind the innovation curve.

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Overall, the unprecedentedly fast technology development expected for the coming years is likely to put pressure on both CEP and CV players to act immediately to defend their industry positions and capture new value opportunities. Furthermore, in the future, successful strategies will need to be based on a set of specific capabilities and require leveraging a complex and resource-intensive technology infrastructure. Fulfilling these demands seems overly ambitious for any single CV or CEP player, and so we expect players to set up strong business partnerships in response to these challenges.

Download Fast forwarding last-mile delivery—implications for the ecosystem, the full report on which this article is based (PDF–size).

Bernd Heid is a senior partner in McKinsey's Cologne office; **Matthias Kässer** is a partner in the Munich office, where **Christoph Klink** is an associate partner and **Simon Tatomir** is a consultant; **Florian Neuhaus** is a partner in the Boston office; and **Jürgen Schröder** is a senior partner in the Düsseldorf office.

Media contact

Martin Hattrup-Silberberg
Senior Communication Specialist
Düsseldorf
+49(211) 136-4516
martin_hattrup-silberberg@mckinsey.com

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Charging ahead: Electric-vehicle infrastructure demand

Technology delivered: Implications for cost, customers, and competition in the last-mile ecosystem

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