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The trends transforming mobility's future

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

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

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

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

Mobility's autonomous future

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

by Kersten Heineke and Philipp Kampshoff

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

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

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

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

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

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

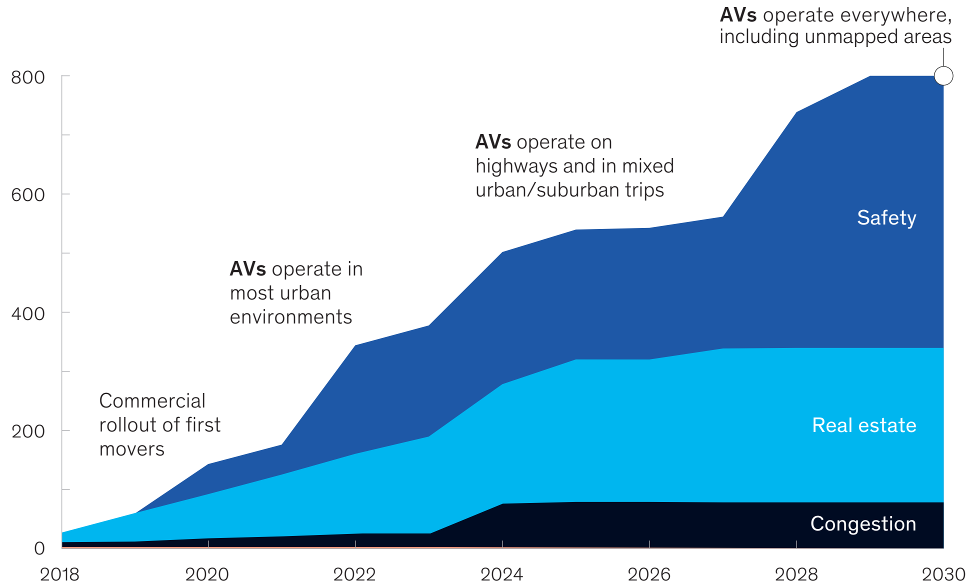
[1] The US Defense Advanced Research Projects Agency.

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

Exhibit

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

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



[1] Environmental benefits are proportionately small (<$4 billion) and barely visible in the chart.
Source: US Federal Highway Administration; McKinsey analysis

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

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

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

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

Connectivity: Turbocharging the new mobility ecosystem

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

by Michele Bertoncello, Gianluca Camplone, and Asad Husain

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

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

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

- L1 — **General hardware connectivity:** the driver is able to track basic vehicle usage and monitor technical status.
- L2 — **Individual connectivity:** the driver uses her personal profile to access digital services via external digital ecosystems and platforms.
- L3 — **Preference-based personalization:** all occupants enjoy personalized controls, their own infotainment content, and targeted contextual advertising.
- L4 — **Multisensorial live interaction:** all occupants interact live with the vehicle and receive proactive recommendations on services and functions.
- L5 — **Virtual chauffeur:** cognitive AI fulfills all occupants' explicit and unstated needs, predicting and performing complex, unprogrammed tasks.

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

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

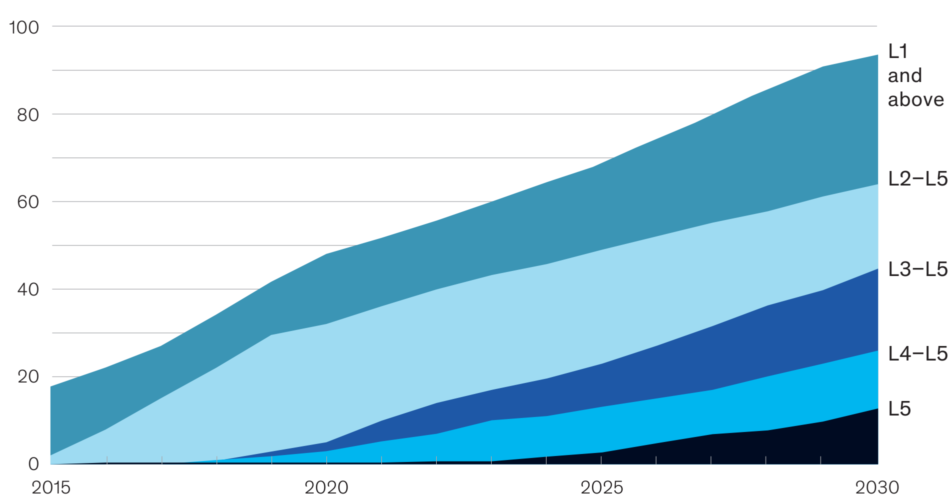
How this may play out for the insurance industry—a key link in the mobility value chain—is instructive (Exhibit 2). At level-1 connectivity, as insurers learn more about risk, drivers might receive a personal discount based on how and where

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

Exhibit 1

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

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



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

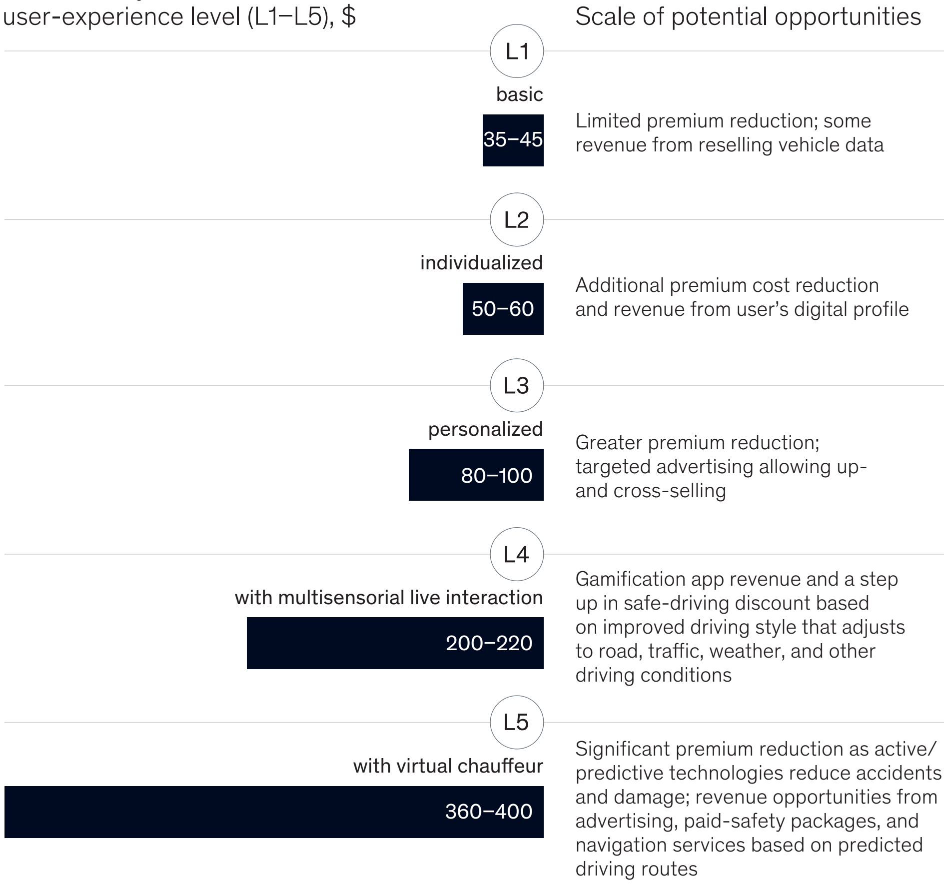
Level-5 sensor systems would incorporate sensors that could detect driver fatigue and suggest rest time—or even allow the car to take over some key driver functions, such as braking or steering to avoid collisions. Much of the value would arise from the diminished risk of insuring a driver, and savings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

Exhibit 2

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

Annual value[1] per vehicle of usage-based insurance, by connected-car user-experience level (L1–L5), $

Scale of potential opportunities



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

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

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

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

Bending the cost curve for electric vehicles

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

by Patrick Hertzke, Martin Linder, and Shivika Sahdev

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

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

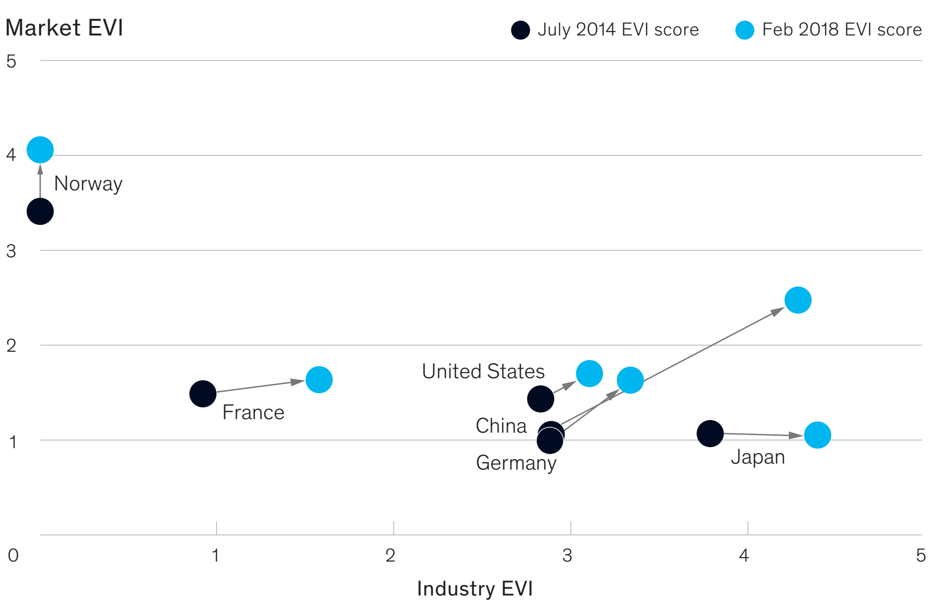
Vehicle Index (Exhibit 1), which measures both consumer demand and production capabilities across nations. EV sales have doubled annually in several markets with the help of plentiful subsidies and regulations that encourage adoption. Norway is an example of how fast the transition can happen: EVs soared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

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

Exhibit 1

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

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



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

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

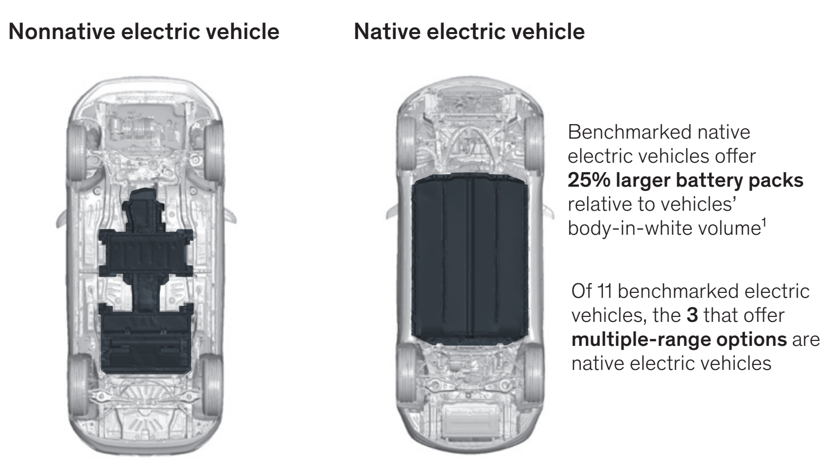
All players, meanwhile, benefit from continuing advances in manufacturing technology and component design (for example, integrated powertrain components that reduce the number and weight of power cables). And across the board, manufacturers are coming closer to hitting the cost benchmarks established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

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

Exhibit 2

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

Battery-pack architecture



[1] That is, measured at the stage when the car body's sheet-metal components have been welded together.

Source: A2Mac1; McKinsey Center for Future Mobility

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

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

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

Hydrogen cars or battery electric vehicles—why not both?

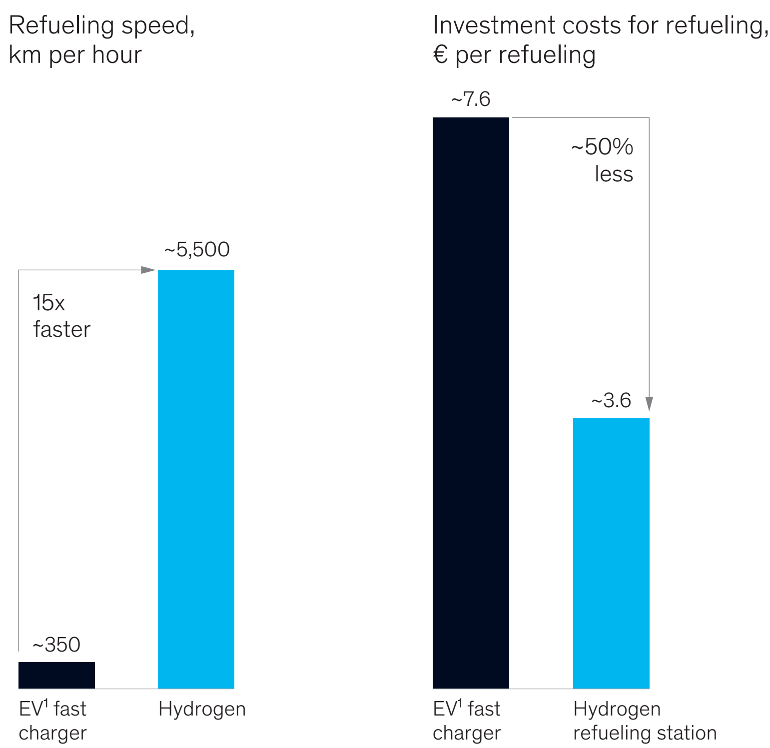
The future of carbon-free mobility may not be a winner-takes-all duel between electric batteries and hydrogen fuel cells.

by Bernd Heid, Martin Linder, and Markus Wilthaner

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

Exhibit

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



[1] Electric vehicle.

Source: Nationale Plattform Elektromobilität (NPE); Fastned; Forschungszentrum Jülich; McKinsey analysis

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

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

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

Ridesharing and the great urban shift

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

by Troy Baltic, Russell Hensley, and Jeff Salazar

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

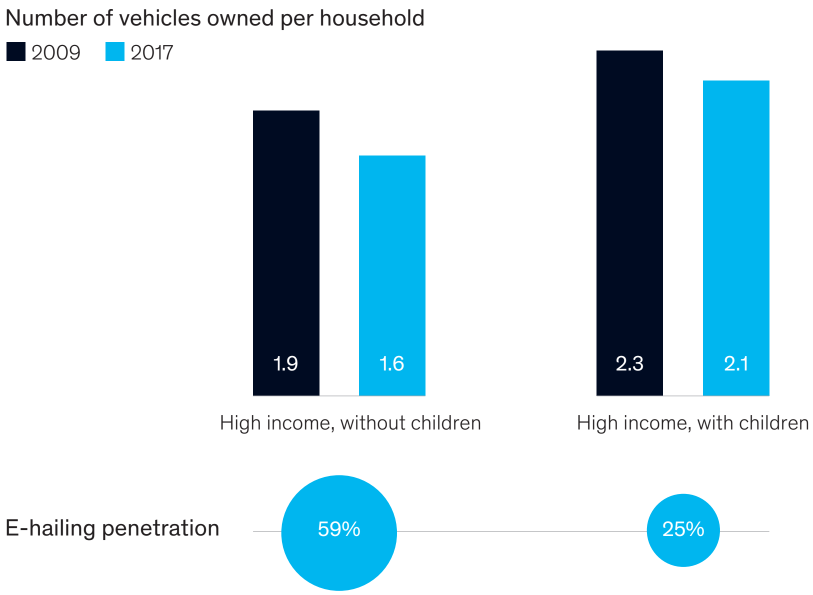
Even so, ridesharing is primed to accelerate. Globally, $55 billion has been invested in the industry in the past seven years. In the United States, this is a $30 billion market and growing. The country now has approximately ten metropolitan areas that generate $500 million or more in yearly ridesharing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

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

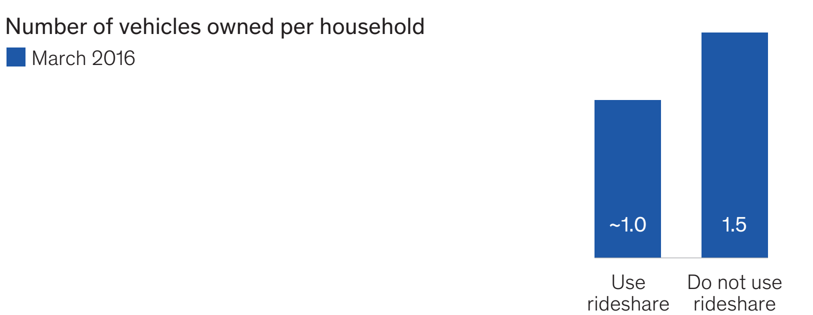
Exhibit

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

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



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



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

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

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

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

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

"Connectivity: Turbocharging the new mobility ecosystem"
Saral Chauhan

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

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

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

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