WHITE PAPER

JULY 2017

NEW MOBILITY: TODAY'S TECHNOLOGY AND POLICY LANDSCAPE

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ACKNOWLEDGMENTS

This work was conducted with the generous support of The 11th Hour Project of the Schmidt Family Foundation and the William and Flora Hewlett Foundation. The authors thank the experts, practitioners, and observers identified throughout the report who agreed to answer our many questions and share their understanding of this quickly evolving sector. Drew Kodjak, Nic Lutsey, and Joe Schultz provided critical reviews on an earlier version of the report. Any errors are the authors' own.

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I. INTRODUCTION

The phrase "new mobility" has come into widespread use to name the results of the intersection of new technologies with new and existing business models. The dawning age of new mobility has the potential to revolutionize the transportation of people and goods. The effects could include improved transportation system efficiency, cleaner air, and better quality of life. Or the results could be just the opposite: more traffic congestion, dirtier air, and erosion to quality of life. The ability of government regulators at all levels to plan for and shape a rapidly changing transportation system, rather than reacting to new developments after the fact, will largely determine the environmental and societal outcomes.

New technologies include vehicles that communicate electronically with each other and the traffic grid, fully or partially self-driving vehicles, electric vehicles, and vehicles with some combination of those elements. New transportation business models involve services that provide mobility on demand, or mobility as a service, or shared mobility. For the purposes of this paper, new mobility refers to the convergence of new technologies and business models.

Generally speaking, new mobility concepts are nothing new. Governments have long encouraged ridesharing with high-occupancy vehicle lanes (U.S. Department of Transportation [U.S. DOT], 2013a); for-hire ride services have existed for centuries (Piot, 2015); autonomous vehicles have been dreamed of for decades (The Victoria Advocate, 1957); and transportation experts have been considering the potential effects of automated and other intelligent vehicle and highway systems for years (Replogle, 1994). However, the rapid development and deployment of smartphones, real-time connectivity, and autonomous vehicle technology are now unlocking the potential for today's new mobility.

This scoping paper is a first step toward identifying policy approaches for ensuring that the development of new mobility supports and advances the goal of clean transportation. We survey the literature, policies, policymakers, key industry players, projects, and relevant experts. This paper is intended to be representative of major trends rather than comprehensive. We focus primarily on the U.S. market but include relevant international developments. Similarly, we examine the development of new mobility with respect to light-duty vehicles while also highlighting action in other arenas, such as heavy-duty vehicles and infrastructure.

The effects of new mobility will spread far beyond transportation, energy consumption, and emissions as considered in this paper. Further study is needed to better understand the broader impacts on labor, equity, insurance, and transportation costs, among others.

The results of the 2016 U.S. presidential election have created uncertainty in the direction of federal policy on a range of new mobility issues as well as the impact of federal government positions on state and local efforts. While the administration has yet to release public statements related to new mobility, it is clear that the president's environmental agenda is to reduce and eliminate regulations (U.S. Office of Management and Budget, 2017). Future ICCT work will focus on governance and political feasibility to further inform policy related to new mobility's environmental impacts.

II. DEFINITIONS AND BACKGROUND

The development of new mobility has spawned a new vocabulary. While some terms and phrases have been used for decades, such as "carsharing," others are new, such as "mobility as a service." Here is an overview of commonly used terms that appear throughout the new mobility literature, news articles, projects, and policies.

NEW MOBILITY TAXONOMY

Figure 1 shows the taxonomy of new mobility concepts, divided into the two categories of innovation: new technologies and new and existing business models. Another term that similarly captures the intersection of these two categories is "technology enabled transportation". Under each category are listed key terms and concepts and examples of each.

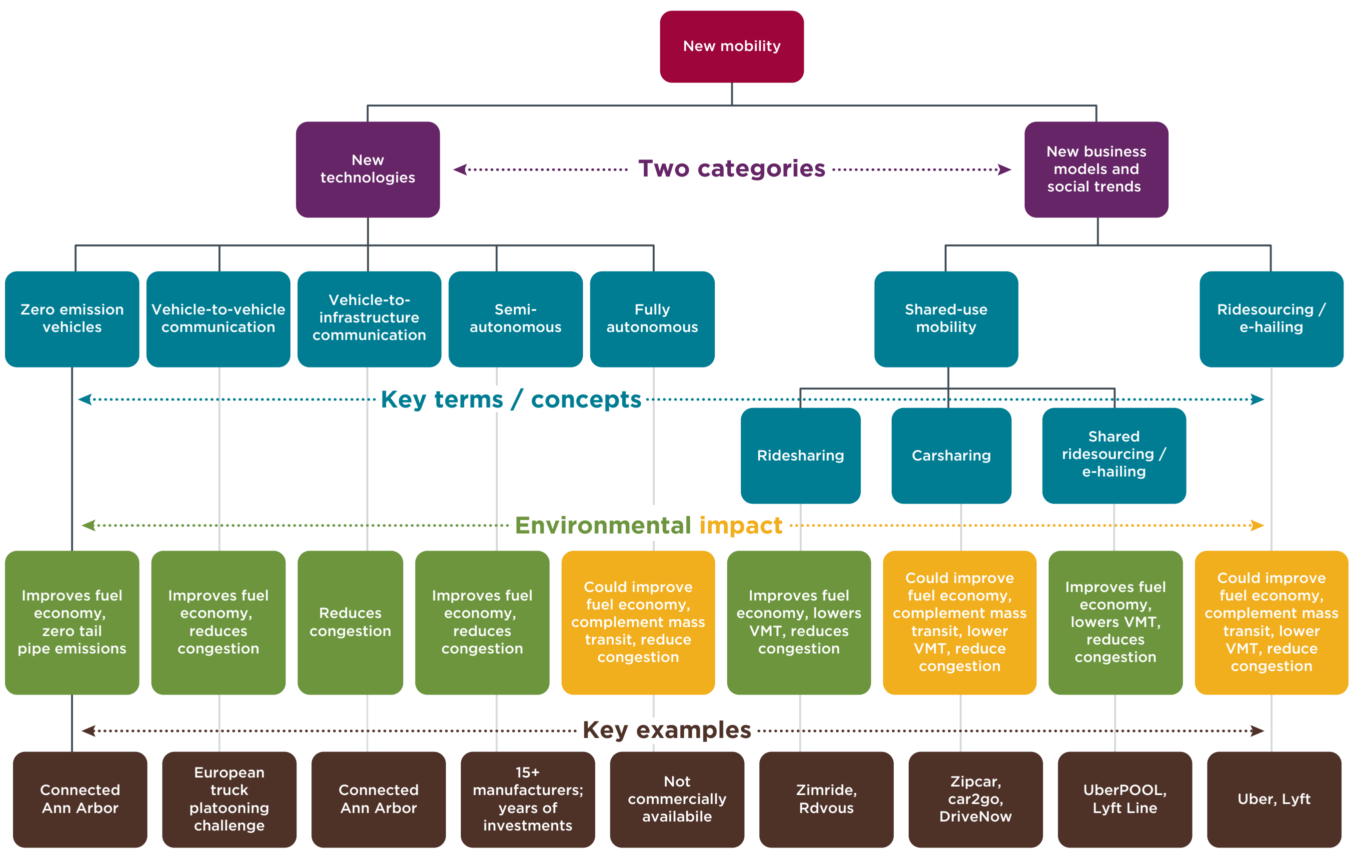


Figure 1. New mobility taxonomy

New technologies. As shown in the figure, new technologies include zero-emission vehicles (ZEVs), vehicle-to-vehicle communications (V2V), vehicle-to-infrastructure communications (V2I), semi-autonomous, and fully autonomous vehicles. Fully autonomous vehicles (referred to here as "autonomous vehicles") are also often referred to as "self-driving" vehicles. We use these terms interchangeably, although some stakeholders consider "self-driving vehicles" to be those without the option for human driving (i.e., no steering wheel, foot pedals) while "autonomous vehicles" may have controls for human driving (see S.W., 2015).

In 2013, the U.S. Department of Transportation defined five levels of vehicle automation (U.S. DOT, 2013b). SAE International in 2014 issued a six-level international classification system. Both classification methods have been cited frequently. In an effort to increase standardization and clarity, the DOT adopted the SAE International definitions in its 2016 Federal Automated Vehicles Policy (U.S. DOT, 2016a). The SAE International definitions are summarized in Table 1. For the purposes of this paper, we use the term "autonomous" when discussing the highest level of autonomy, Level 5, and "semi-autonomous" for Levels 2–4, and we say otherwise for specific levels of autonomy.

Table 1. Levels of autonomy (adopted from SAE International, 2014)

Level	Name	Description	Example	Commercially available?
0	No automation	Complete human control	Ford Model T	Yes
1	Driver assistance	Vehicle can assist either steering or acceleration/deceleration	Cruise control	Yes
2	Partial automation	Vehicle can assist in both steering and acceleration/ deceleration	Tesla (Autopilot), Audi (traffic jam assist), Mercedes-Benz (Intelligent Drive)	Yes
3	Conditional automation	All tasks can usually be handled by the system, human takeover sometimes required	NuTonomy, Delphi, Volvo, Ford, Google, others	No
4	High automation	All tasks can be handled by the system without human intervention, but only in limited environments (e.g., college campus or dedicated zones)	Not currently available	No
5	Full automation	Automated system can handle all roadway conditions and environments	Not currently available	No

New and existing business models and social trends. Also shown in Figure 1 are business models and social trends, including shared-use mobility such as ridesharing, shared ridesourcing and more traditional carsharing. Other commonly used terms include "mobility as a service" and "mobility on demand."

Ridesharing is the filling of otherwise empty seats in a vehicle and includes carpooling and vanpooling. Carsharing is typically a short-term rental service in which users reserve one of a fleet of vehicles placed throughout an urban area. Companies like Uber and Lyft are "ridesourcing" providers, though they are commonly mislabeled as "ridesharing" providers. These enterprises are often referred to as "transportation network companies," or TNCs. TNCs offer a private driver on demand with door-to-door service that is typically "e-hailed" via smartphone. Shared ridesourcing includes services like UberPOOL and other shared e-hail services in which multiple riders are paired with a driver at a lower cost. Resources such as those made available by the Shared-Use Mobility Center, a public interest group, provide additional information on shared mobility options (see Shared-Use Mobility Center, 2016a).

Environmental impact. Figure 1 includes an indication of each new mobility concept's potential environmental impact, depicted on the fourth row. Based on the best available research, we consider whether each concept might result in environmental benefits by promoting electric vehicles, improving fuel economy, reducing vehicle miles traveled (VMT), reducing congestion, and complementing mass transit. There may be additional impacts on transportation, such as mode shifting or vehicle ownership rates. Those elements with a green background represent developments that will result in some form of environmental benefit. Those with a yellow background do not have inherent environmental benefits and would require policy action to ensure positive environmental outcomes. For example, autonomous vehicles (yellow background) will greatly increase comfort, convenience, and tolerance of travel, which could lead to increased VMT, sprawl, traffic, and pollution.

Our evaluation of the environmental implications of the new mobility concepts in Figure 1 is an initial screening based on available literature. A more thorough analysis is required to assess the potential environmental impacts of each component of new mobility.

In addition to the examples shared above, many projects under development combine several technologies and business models listed in Figure 1. If supported by well-designed policies, some combinations have the potential to provide significant energy savings and emissions reductions. For example, many experts believe that a fleet of right-sized, shared, fully autonomous, electric-drive vehicles integrated into the transportation network could be a key to reaching transportation decarbonization goals (see Barcham, 2014; Brown, Gonder, & Repac, 2014; Greenblatt & Saxena, 2015; Wadud, MacKenzie, Leiby, 2016). This combination of shared, autonomous, and electric is discussed in greater detail in the “Environmental impacts” section below.

III. NEW MOBILITY LANDSCAPE

The new mobility landscape is rapidly evolving. The phrases "autonomous vehicles," "self-driving cars," "on-demand mobility," "mobility as a service," and "shared mobility" appeared in the media most days of 2016, driven by news from automakers, technology companies, industry partnerships, and government agencies.

Technological breakthroughs have sparked significant interest in the revolutionary potential of autonomous vehicles, especially from the private sector. Proliferation of smartphones and connectivity has elevated the possibilities of pairing the technologies to enable e-hailed autonomous mobility on demand, attracting many unexpected stakeholders and billions of dollars in new investment into this space. Morgan Stanley estimated that the autonomous vehicle–enabled, shared-mobility market will be worth $2.6 trillion by 2030 (as reported by Neiger, 2016). Similarly, McKinsey projected that automotive revenue pools from shared and connected vehicles could add up to $1.5 trillion by 2030 (McKinsey & Company, 2016). A previous report by Morgan Stanley estimated that the annual social and economic benefits from autonomous vehicles (e.g., from improved safety, reduced congestion, fuel savings, time savings, new business revenues) could amount to $1.3 trillion in the U.S. and $5.6 trillion globally (Ravi et al., 2013).

To understand the current landscape, we surveyed the literature, key industry players, government reports and policies, policymakers, projects, and media articles. We focused primarily on major news stories and announcements from April through October 2016 but included research literature, policies, and other developments that emerged over the past two decades.

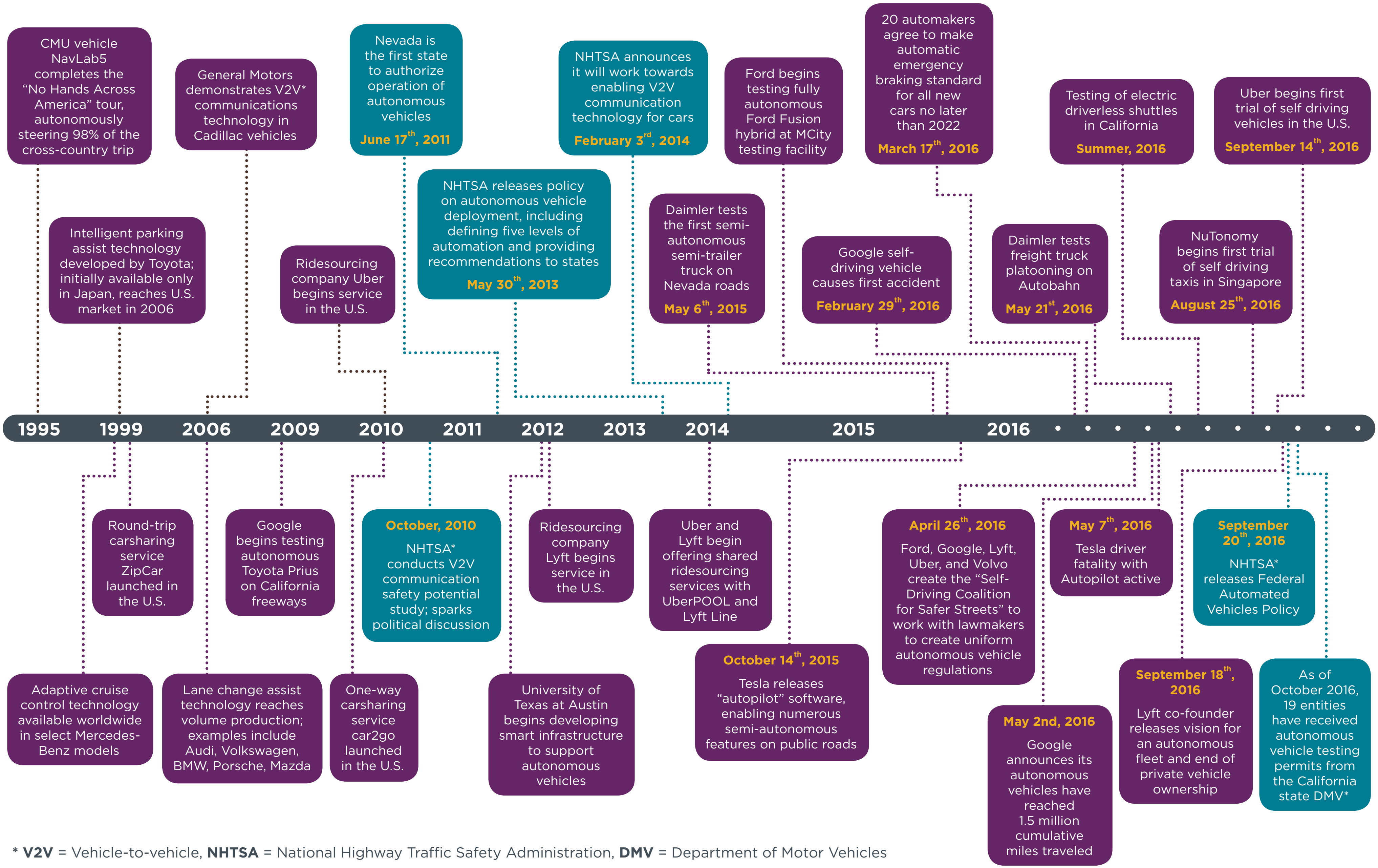
We found that far fewer than half of studies, projects, policies, and media articles analyzed or even discussed energy and emissions as related to new mobility. Most of the attention was on how to overcome deployment barriers and unlock the potential of new mobility for social benefits such as improved safety, reduced congestion, and expanded transportation options (e.g., see Bonnefon, Shariff, & Rahwan, 2016; Fagnant and Kockelman, 2016; Pan, Thornton, & Gerdes, 2016; Schellekens, 2015; Vine, Zolfaghari, & Polak, 2015). Many consumer-focused articles addressed how new mobility could change the ways we think about mobility, safety, congestion, commuting, expanded access, land use, parking, privacy, cybersecurity, insurance, and other issues (e.g., Brown, 2016; Carty, 2016; McKinsey & Company, 2015). The energy and emissions implications need more discussion.

Key players include automakers such as General Motors, Ford, BMW, and Tesla; technology giants such as Google, Apple, and Microsoft; and technology and software startups such as Zoox, NuTonomy, and Nauto. There are also private-sector mobility providers including Uber, Lyft, ZipCar, and car2go; government entities including the federal DOT, municipal transportation agencies, and metropolitan planning authorities; and universities including the Massachusetts Institute of Technology, the University of California at Berkeley, the University of Michigan, Carnegie Mellon University, Stanford University, and Nanyang Technological University. Other leading participants are independent researchers, foundations, and advocacy groups.

KEY PLAYERS, POLICIES, AND PARTNERSHIPS

In the following sections, we highlight the current landscape with a focus on the key players, partnerships, and policies that are shaping the new mobility landscape. We focus our attention on the development to date, partnerships, investments, announcements, and future targets. Our discussion of the new mobility landscape is intended to reflect major trends and is not intended to be comprehensive. To support the discussion, we display key new mobility milestones on a timeline in order to reflect the rapid pace of development. The milestones achieved to date are shown in Figure 2. Anticipated future projections and milestones that are based on announcements are shown in Figure 3. The milestones plotted in Figure 2 and Figure 3 include landmark achievements from vehicle manufacturers, technology companies, policymakers, and universities. Political milestones on the timeline are displayed in blue.

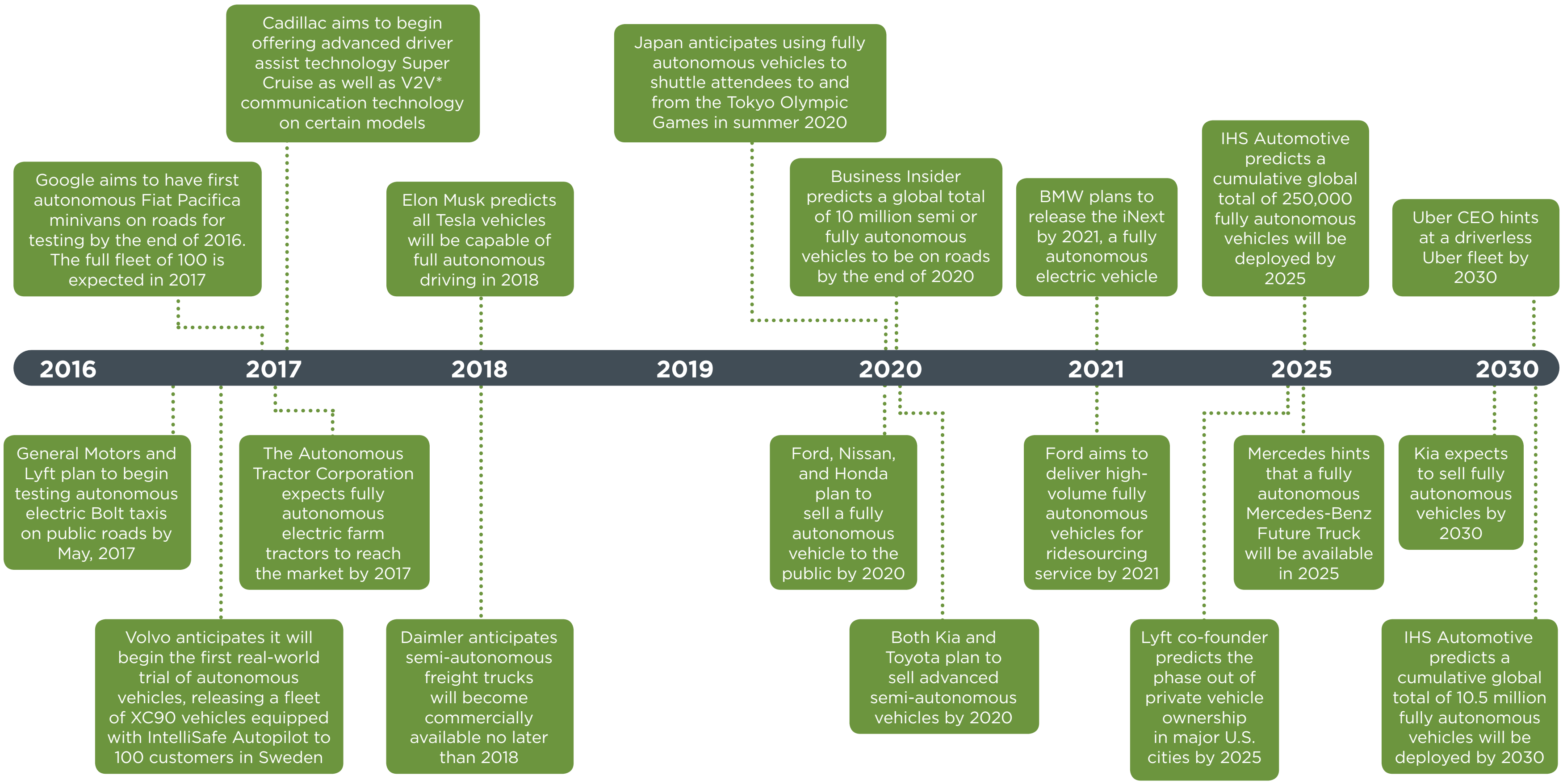
NEW MOBILITY TIMELINE (PAST THROUGH PRESENT)



* **V2V** = Vehicle-to-vehicle, **NHTSA** = National Highway Traffic Safety Administration, **DMV** = Department of Motor Vehicles

Figure 2. New mobility timeline, 1995–2016

NEW MOBILITY TIMELINE (FUTURE)



* **V2V** = Vehicle-to-vehicle

Figure 3. New mobility timeline, 2016–2030

Automobile manufacturers

Some of the biggest players and stakeholders in the development of new mobility are clearly vehicle makers. These companies have been making investments in autonomous vehicle technologies while also planning to broaden their portfolios as mobility providers. Many automakers already offer vehicles equipped with one or more semi-autonomous features (Level 2, see Table 1). The semi-autonomous technologies available in non-luxury models typically cost a few hundred to a few thousand dollars (e.g., Siler, 2015; Toyota, 2015).

While some manufacturers are investing more heavily than others in autonomous driving technology, all major manufacturers appear to be gradually heading toward some level of automation. For example, 20 manufacturers recently pledged to make automatic emergency braking—a semi-autonomous technology—standard on all new cars by 2022 (see Figure 2).

Other notable autonomous vehicle developments are also shown in Figure 2. Ford began testing autonomous vehicles with Level 3 capability at the University of Michigan MCity testing facility in 2015 and has since expanded testing to as many as 30 autonomous Ford Fusion Hybrid vehicles (see Ford, 2015a, 2016a). Also in 2015, Tesla released Autopilot, an advanced Level 2 technology that is available on all production vehicles (Tesla, 2016a). Tesla also announced that all Tesla vehicles are now equipped with the hardware to eventually enable full self-driving, presumably Level 5 (Tesla, 2016b). General Motors is testing autonomous Chevrolet Bolts (General Motors, 2016a). Volvo has announced a pilot project in Sweden that will provide 100 autonomous XC90 vehicles equipped with IntelliSafe Autopilot to customers as a trial (Volvo, 2016). Uber launched a self-driving test late in 2016 in Pittsburgh using Volvo XC90 and Ford Fusion vehicles (Bensinger and Nicas, 2016).

More than 10 major manufacturers have announced goals, formed partnerships, and made investments that reflect a shift in their historic business models from carmakers to mobility providers. Some OEMs have formed subsidiaries to develop and invest in mobility services:

» Ford created Ford Smart Mobility LLC, which has invested in more than two dozen experiments in vehicle connectivity, mobility, customer experience, big data, and autonomous vehicles. Ford has set a goal of deploying a high-volume fleet of shared autonomous vehicles by 2021 (Ford, 2016b).

» BMW set up BMW i Ventures, and the subsidiary has invested in more than a dozen mobility-service start-ups.

Other OEMs have chosen not to form mobility subsidiaries but instead have invested directly in start-ups and existing ventures.

» General Motors invested $1 billion to purchase autonomous vehicle start-up Cruise Automation and $500 million in Lyft to create on-demand autonomous vehicles.

» General Motors has launched its own carsharing service, Maven.

» General Motors and Lyft unveiled plans to provide an on-demand network of autonomous vehicles available by e-hail (General Motors, 2016b).

» Tesla outlined a vision of offering on-demand shared electric autonomous vehicles (Tesla, 2016c).

» Other examples include Volkswagen's $300 million investment in Gett, a popular European ridesourcing/e-hailing company, and Toyota's strategic partnership with Uber.

And so it goes, as automaker after automaker explores the strategic shift to mobility provider. A summary of announcements by automakers appears in Annex Table 3. Automakers are typically investing in multiple new mobility projects, indicating the importance they are placing on this emerging business model and showing that they are now hedging their bets on the future of private vehicle sales (Center for Automotive Research, 2016). Annex Table 4 highlights several comments from automaker representatives on the shift.

Technology companies

Many technology companies are similarly working to develop next-generation vehicle technologies and mobility services. Annex Table 5 shows some of the tech companies' investments related to new mobility. Tech companies in this space range from technology giants such as Google and Apple to start-ups such as DriveAI and Zoox.

Google has been testing self-driving cars on California roads for a number of years. Google's autonomous vehicles are most likely considered capable of Level 3, or conditional autonomy. The vehicles have logged more than 2 million miles as of late 2016 (Google, 2016).

While some of the companies in Annex Table 5 focus primarily on developing autonomous vehicle technologies, many are involved in the convergence of vehicle automation with on-demand mobility. NuTonomy for example is a start-up focused on autonomous urban driving. In August 2016, nuTonomy started testing an autonomous e-hailed electric taxi in Singapore. The company is expanding the trial phase and expects to quickly scale up the project through 2018, deploying an autonomous, on-demand, all-electric taxi fleet (nuTonomy, 2016). The ridesourcing company Uber started testing autonomous vehicles in Pittsburgh (Uber, 2016a). Uber has a strategic partnership with Carnegie Mellon University to accelerate development of mapping, vehicle safety, and autonomous technology (Uber, 2015a). The company continues to invest in on-demand mobility, teaming up with Carpooling.com to extend its service to longer trips.

Based on our research, it appears (see Annex Table 3 and Table 5) that the majority of investment is being made in developing fully autonomous technology, rather than ZEVs or shared-mobility services like carsharing, bikesharing, or ridesharing. As indicated in Figure 1, autonomous vehicles are unlikely to offer environmental benefits without policy action. While autonomous-vehicle technology continues to advance and reach the market, policymakers have a unique and significant window of opportunity for shaping its development and deployment toward a low-carbon and socially equitable transportation system.

Regulations and regulators

The new mobility regulatory landscape is fragmented. Nevada was the first state to establish definitions and rules for autonomous vehicles, as early as 2011 (Stanford, 2016). Policymakers in Florida and California in 2012 adopted definitions and declared autonomous-vehicle testing legal. To date, 10 states plus the District of Columbia have enacted some form of autonomous-vehicle legislation (National Conference of State

Legislatures, 2016). States are charting different regulatory paths. Michigan, for example, has permitted testing and has addressed liability. Florida has adopted autonomous-vehicle definitions, permits autonomous-vehicle testing on public roads, and allows any individual with a valid driver's license to operate an autonomous vehicle in autonomous mode. Early state political action typically includes establishing definitions, directing motor vehicle departments to adopt rules, determining the legality of autonomous vehicles, addressing liability, and calling for additional study of potential effects.

Industry, researchers, and the federal government have all cited the patchwork of state regulations as a barrier to the safe and successful advancement of autonomous vehicles (Kang, 2016; Lyons, 2015; Volvo, 2012). In a push encourage consistent regulation, Ford, Google, Lyft, Uber, and Volvo created the Self-Driving Coalition for Safer Streets in 2016 to work with lawmakers.

The U.S. Department of Transportation released a preliminary policy statement on autonomous vehicles in 2013 (U.S. DOT, 2013b). The document established definitions and levels of vehicle automation and provided recommendations to the states. In 2016, the DOT released the first Federal Automated Vehicles Policy (U.S. DOT, 2016a). The policy outlines an approach to accelerate the transition to autonomous vehicles, divided into four categories: performance guidance for autonomous vehicles, a model for state policy, the National Highway Traffic Safety Administration's (NHTSA) current regulatory tools, and new tools and authorities. In general, the policy suggests that in the near term the federal DOT will work primarily with industry to ensure safety.

It is clear from the document that the environmental implications of automated vehicles will not be a current focus. The DOT identified the environmental effects of automated vehicles as a gap in regulation, and wrote: "Gaps in current regulations should be identified and addressed by the states (with the assistance of NHTSA)" (U.S. DOT, 2016a). Given the priorities outlined by the current administration in its first hundred days, it is highly unlikely that the environmental impacts of autonomous vehicles will be a federal government priority (U.S. Office of Management and Budget, 2017). While the administration has yet to release public statements related to autonomous vehicles, it is clear that the administration is not focused on extending the reach of environmental protection programs (e.g., see Guskin, 2017).

In addition to NHTSA and the DOT, other federal agencies have a stake in new mobility. The Environmental Protection Agency regulates greenhouse gas emissions of light- and heavy-duty vehicles. Although the EPA has not publically announced how it will approach autonomous vehicles (or other aspects of new mobility), it falls within the agency's inherent jurisdiction to regulate the GHG emissions of autonomous vehicles. The EPA has a process for working in partnership with state regulators to develop and improve State Implementation Plans (SIPs) for regulating pollutants including GHGs under the Clean Air Act. Through these SIPs, the EPA could give credits for new mobility if projected reductions meet certain criteria. The EPA currently uses these criteria when evaluating energy efficiency and renewable energy measures (U.S. EPA, 2016), and similar criteria are used in carbon-offset markets (IETA, 2016). This is a reasonable and well-established process that would offer proof that new mobility developments result in real environmental benefits. For new mobility to count toward environmental targets, the emissions reductions need to be real, quantifiable, surplus, enforceable, and permanent. Although introduced in a federal context, these criteria are also broadly applicable to any evaluation of new mobility projects or policy. However, because the new administration's proposed budget for 2018 includes plans to largely defund the EPA and abandon GHG regulation (U.S. Office of Management and Budget, 2017), it is highly unlikely that this process would be considered throughout the 2017–2021 presidential term.

The Alliance of Automobile Manufacturers, a trade group, in testimony before Congress has advocated GHG and fuel economy credits for manufacturers that include semi-autonomous crash avoidance technologies in new vehicles on the basis that they will prevent collisions and thereby reduce congestion and improve fuel economy (see Alliance of Automobile Manufacturers, 2015; Spector, 2015). The allowance of any new credits for semi-autonomous technologies would inherently erode the environmental benefits of current fuel economy standards.

The DOT has played an active role in new mobility by establishing and funding pilot projects. For example, the department launched a connected vehicle deployment pilot project in 2015 to study the safety and potential of vehicle-to-vehicle and vehicle-to-infrastructure communications technology for reducing congestion (U.S. DOT, 2016b). The DOT recently sponsored the Smart City Challenge, offering $40 million (plus $10 million from Vulcan for electrification) of backing for the winning city's proposed new mobility vision. Columbus, Ohio, won the award with a proposal to improve transit equity, access, health, and safety while reducing energy consumption and emissions by deploying semi-autonomous, autonomous, and connected technologies, and leveraging emerging mobility options to complement transit and provide first and last mile connections.

New mobility developments in Columbus in the near term are likely to include installing and collecting data from Mobileye driver alert systems on Central Ohio Transit Authority buses to prove the technology's safety and congestion mitigation potential, developing and testing a Smart Corridor to improve mobility and provide access to jobs while evaluating its safety and efficiency potential, improving data availability and analytical capacity, updating and integrating system-wide transportation service information into smartphone applications, expanding electric vehicle adoption and use, and expanding the existing smart grid. Eventually, among other things, Columbus anticipates utilizing a fleet of self-driving electric vehicles to service fixed routes and provide first-last mile connections (City of Columbus, 2016). Columbus has designed its Smart City Challenge proposal to complement many of its existing initiatives, including reduction in single occupant vehicle driving, reduction in vehicle accidents, increased air quality, and increased access to jobs. The city has also established key metrics to track as a method of determining project success, including transit-accessible jobs, number of low-income individuals able to access new mobility services, transportation costs as a percentage of total expenditures, efficiency of movement, commute times, and others (City of Columbus, 2016).

The DOT's Advanced Transportation and Congestion Management Technologies Deployment Project authorizes $300 billion through 2020 to fund technologies that advance system performance, efficiency, safety, and infrastructure return on investment (U.S. DOT, 2016c). Qualifying projects must deliver environmental benefits, such as reduced congestion and improved efficiency, and expand deployment of V2V, V2I, autonomous vehicle, and other new mobility technologies. The San Francisco Municipal Transportation Agency, for example, was awarded $10.9 million in 2016 to enhance safety and promote shared mobility through utilizing dynamic pickup/drop-off curb space, regional carpool lanes, congestion pricing, smart connected traffic infrastructure, and automated shuttles, among other measures (U.S. DOT, 2016d).

The DOT also recently named the winners of its Mobility on Demand Sandbox Program (U.S. DOT, 2016e). The program challenged local transit agencies to propose innovative ways of integrating mobility on demand into public transportation. Almost $8 million was distributed among more than 10 agencies. Valley Rail Metro of Phoenix is receiving funds to create a smartphone platform to integrate mobile ticketing and multimodal transportation planning options, such as bikesharing, carsharing, e-hailing, and public transit. Primary motivations include improving transportation access and equity. The Los Angeles Metropolitan Transportation Authority won support to partner with Lyft and explore first- and last-mile solutions for certain transit hubs to expand access for lower-income citizens. And the Bay Area Rapid Transit system received funding to implement a carpool-to-transit software program with integrated priority-parking access and payments at transit locations. These pilot projects are intended to expand mobility access and integrate new mobility services into public transportation. Leveraging new mobility services to complement mass transit has the potential to offer environmental benefits through reduced single-occupant private-vehicle usage.

Our research did not turn up any federal policies related to mobility on demand, mobility as a service, shared mobility, or transportation network companies. In contrast, state and local governments have taken steps to regulate TNCs after these providers emerged and gained importance relatively unencumbered by the regulatory requirements that govern their direct competition, the taxi industry. As of September 2016, more than 30 states and 65 cities had adopted some level of regulation for TNCs (Taylor, 2016). These companies have a history of suspending service in areas they consider overregulated (see e.g., McPhate, 2016). Although state and municipal regulations vary significantly, the enacted measures typically cover issues such as establishing TNC legality and definitions, determining protocols for driver fingerprinting requirements, and implementing rules for driver background checks and screening. Based on our research, the current regulations do not take into account the potential environmental effects of TNCs or other mobility providers.

Taxis for some time have been subject to regulations to mitigate their environmental impact. San Francisco's 2008 Green Taxi Ordinance (26-08) (City and County of San Francisco, 2008) permitted vehicle lessors to increase gate fee surcharges (the rental fee charged to taxi drivers) for low-emission vehicles, defined as Super Ultra Low Emission Vehicles or better by the California Air Resources Board. The ordinance received support from both taxi vehicle lessors and drivers. Taxi lessors received additional compensation for investments in low-emission vehicles; taxi drivers saved on fuel expenses. The city achieved a penetration rate of more than 90% hybrid and compressed natural gas vehicles in the taxi fleet and reduced average per-mile taxi GHG emissions by 49% compared to 1990 levels (City and County of San Francisco, 2012).

New York City's Taxi and Limousine Commission in 2009 enacted a similar policy, the Hybrid Incentive Plan (New York City Taxi and Limousine Commission, 2009). The policy allowed taxi owners to raise lease fees to drivers of clean-air vehicles by $3 per shift. As in San Francisco, increasing the lease fees resulted in a much higher penetration of hybrid taxis. In 2006, the city had extended the retirement periods for clean-air and wheelchair-accessible cars, providing another investment incentive (New York City Taxi and Limousine Commission, 2015). Also indirectly mitigating the environmental impact of taxis, all taxi trips are subject to a 50-cent surcharge that goes to the Metropolitan Transportation Authority to support public transportation (New York City Taxi and Limousine Commission, 2016).

Regulatory frameworks are as fragmented for on-demand mobility providers as for autonomous vehicles. There is a clear need for a strong but flexible regulatory approach that can encourage innovation while protecting the public interest. As reflected in Figure 3, multiple companies are moving to deploy fleets of on-demand autonomous vehicles. Their vision is similar to the current TNC business model of on-demand e-hailing/ridesourcing, but without a human driver. Billions of dollars have been invested toward this goal (see Annex Table 3 and Table 5). Because TNCs typically have to, and often want to, seek operational approval, policymakers have a unique opportunity to establish rules limiting the environmental impacts of TNCs and others.

The regulatory and policy landscape at the federal level suggests that regulations are likely to be developed and tested initially at the local level. This is already happening to some extent as cities chart different paths to regulating mobility services and deploy various transportation technologies. However, as shown in Figure 1, new mobility is unlikely to result in environmental benefits without policy action. As mobility services become prevalent and autonomous vehicles reach the market, policymakers have an opportunity to shape this development towards a low-carbon and socially equitable outcome. As the environment is not a priority of the federal administration's agenda, state and local policymakers likely have the largest opportunity to shape new mobility towards the public good.

Public-private partnerships

Several governments are turning to the private sector to help solve transportation challenges. There are a number of public-private partnerships that include new mobility services. Here are a few examples.

In California, the Contra Costa Transportation Authority is testing two shared autonomous shuttles at the 5,000-acre GoMentum Station proving grounds in Concord (GoMentum Station, 2015). The all-electric shuttles, made by EasyMile, can be e-hailed from a smartphone (EasyMile, 2016). They transport as many as 12 people at a top speed of 25 kilometers per hour. The vehicles will first be used to shuttle workers on-demand at the 585-acre Bishop Ranch business park. Long term, the agency expects them to be used to complement mass transit and address gaps in first- and last-mile connections to major transit stations (Torres, 2016). GoMentum Station expects the project to reduce emissions and fossil-fuel consumption, but no quantitative estimates have been made.

Similarly, the Nevada Center for Advanced Mobility collaborated with the Nevada Governor's Office, the University of Nevada at Las Vegas, and Local Motors to deploy and test shared, electric, on-demand shuttles on the UNLV campus. The vehicles, referred to as Olli (Local Motors, 2016a, 2016b), are intended to demonstrate the safety, reliability, and effectiveness of autonomous-vehicle technology. The goal is to scale up Olli vehicle use to address first- and last-mile connectivity gaps to complement transit (Nevada Governor's Office of Economic Development, 2016). Local Motors said it expects that the on-demand, shared electric shuttle will reduce individual driving and carbon emissions, although no quantitative estimates have been made. The vehicles have been reported to sell for $299,000 (Morroquin, 2016).

Other examples of early collaborations include the City of Denver and B-Cycle bikesharing partnership in 2009 (City of Denver, 2009) and the City of Baltimore and ZipCar carsharing partnership in 2010 (Smith, 2010). Certain local governments appear to be increasingly interested in exploring the potential benefits of new mobility, including providing broader transit options, complementing and strengthening mass transit, providing first- and last-mile operations, or expanding the operating hours of transportation services (see Center for Automotive Research, 2016; City of Columbus, 2016; Natural Resources Defense Council, 2016; San Francisco Municipal Transportation Agency, 2016a).

The American Public Transportation Association reported on research showing that mobility services including TNCs can complement and fill gaps in public transit, mitigate first- and last-mile connection barriers, encourage higher transit ridership, reduce vehicle ownership and congestion, and save on total transportation costs (American Public Transportation Association, 2016). Linking and seamlessly integrating mobility services into transit applications can enhance the user experience and encourage multimodal travel, improving urban mobility (Shared-Use Mobility Center, 2016b). Some localities have also suggested that leveraging mobility services "is infinitely cheaper than the alternatives" (Frank Martz, Altamonte Springs City Manager), such as expanding roads and infrastructure or developing new public transit routes (Nicholson, 2016). Some cities have established partnerships with mobility providers for other reasons. Seattle, for example, subsidizes late-night Uber rides to reduce drunk driving and related crashes (City of Seattle, 2016).

Many local and regional transit agencies are exploring the potential transportation and mobility benefits of public-private partnerships. Here are a few examples.

» The Hillsborough Area Regional Transit Authority in Tampa, Florida, is partnering with TransDev to provide on-demand, first- and last-mile transit options to and from transit hubs. The shared minivans will cost users $3 and the agency $7 per trip (Hillsborough Area Regional Transit Authority, 2016).

» The Pinellas Suncoast Transit Authority is subsidizing Uber and taxi services to and from designated public transit stops in underserved areas (Pinellas Suncoast Transit Authority, 2016).

» Agencies in Dallas, Atlanta, Memphis, and Raleigh have integrated mobility services such as Uber, Lyft, and Zipcar into their mobile ticketing and trip-planning applications (Dallas Area Rapid Transit, 2015; TransLoc, 2016; Uber, 2015b).

» The San Francisco Bay Area's 511 trip planner service is expected to integrate mobility services such as Lyft, Carma, and Scoop into its platform (Center for Automotive Research, 2016).

» Uber has partnerships with 14 transit agencies as of early 2016 (Juliano, 2016).

As implied by the examples above, public–private partnerships can offer financial, social, and environmental benefits. Several local and regional governments are exploring how collaborating with private-sector mobility providers can fill transportation service gaps, lower costs, and increase public transportation ridership. If successful, these projects could deliver environmental and social benefits. At the same time, it is important to tread forward with prudence to understand the full impacts that these services have on mode shifting, transportation costs, access, congestion, and climate and air pollution.

ENVIRONMENTAL IMPACTS

Although policymakers and investors rarely discuss the potential energy consumption and environmental benefits of new mobility, researchers have begun examining those issues. Table 2 summarizes a sampling of the literature from national laboratories, research universities, and independent researchers. The work includes findings from real-world testing, modeling, consumer surveys, and reviews and expansion of previous works.

Table 2. Potential environmental impacts of new mobility

Study	New mobility category	Metric	Effect	Notes
Brown et al. (2014)	Fully autonomous, semi-autonomous	Platooning	–10% energy use	Analysis of the possible energy implications of autonomous vehicles, including an estimation of individual factors.
		Efficient driving	–15% energy use	
		Efficient routing	–5% energy use	
		Travel by underserved	+40% energy use	
		Efficient driving (additional)	–30% energy use	
		Faster travel	+30% energy use	
		More travel	+50% energy use	
		Light-weighting and size optimization	–50% energy use	
		Less time searching for parking	–4% energy use	
		Higher occupancy	–12% energy use	
		Electrification	–75% energy use	
		Net outcome	–95% to +173% energy use	
Wadud et al. (2016)	Fully autonomous, semi-autonomous	Platooning	–25% to –5% energy use	An analysis of the possible energy and environmental implications of autonomous vehicles estimated by mechanism. The authors evaluate four potential future scenarios of autonomous vehicle deployment and provide policy recommendations for an optimal outcome.
		Eco-driving	–20% to 0% energy use	
		Congestion mitigation	–5% to 0% energy use	
		De-emphasized performance	–25% to –5% energy use	
		Improved crash avoidance	–25% to –5% energy use	
		Vehicle right-sizing	–45% to –20% energy use	
		Higher highway speeds	+5% to +25% energy use	
		Increased features	0% to +10% energy use	
		Travel cost reduction	+5% to +60% energy use	
		New user groups	+5% to +15% energy use	
		Changed mobility services	-20% to 0% energy use	
		Net outcome	–45% to +105% energy use	
Greenblatt and Saxena (2015)	Fully autonomous, ridesourcing/e-hailing, shared ridesourcing/e-hailing	Shared, electric, right-sized, autonomous vehicles	–87% to –94% reduced GHG/mi	An analysis of the maximum potential energy consumption and GHG reduction from the optimal utilization of fully autonomous, shared, electric, right-sized taxis.
Fagnant (2014)	Fully autonomous, ridesourcing/e-hailing, shared ridesourcing/e-hailing	Vehicles removed	11 conventional vehicles per shared autonomous vehicle	A model of that considers the potential benefits of replacing current vehicle usage and travel with shared autonomous vehicles.
		Increased travel	11% more travel	
		Energy and emissions implications	–12% energy use; –5.6% GHG; –19% SO_2; –34% CO; –18% NO_x; –49% VOC; –6.5% PM_{10}	
Lammert and Gonder (2014)	Semi-autonomous	Fuel savings of platooning tractor trailers	Fuel savings of 6.4%	Summary results from the real-world testing of semi-autonomous tractor trailers in the U.S.

Study	New mobility category	Metric	Effect	Notes
Martin, Shaheen, and Lidicker (2010)	Round-trip carsharing	Fuel economy	Increase by 10 MPG from fleet turnover	Analysis of how carsharing influences user vehicle ownership rates based on consumer survey in North America.
		Vehicle ownership	Per household rates fell from 0.47 to 0.24	
		Vehicles removed	1 carshare vehicle removes 9–13 vehicles	
Martin and Shaheen (2011)	Round-trip carsharing	Vehicle miles traveled (VMT)	Reduced by 27%	Evaluation of GHG emission reduction impacts from round-trip carsharing in North America based on consumer survey.
		GHG emissions	Average household reduction of 0.58-0.84 tons of GHG/ year	
Namazu and Dowlatabadi (2015)	One-way carsharing	GHG emissions	Mode shifting reduced emissions 42%–54%	Study of the GHG emission implications of carsharing on various types of households and their characteristics in Vancouver, Canada.
			New fleet reduced emissions 19%–20%	
			Right sizing reduced emissions 31%–34%	
Martin and Shaheen (2016)	One-way carsharing	GHG emissions	Reduced by 4%–18%	Analysis conducted across five U.S. cities to study the impacts of car2go. Includes data from car2go as well as consumer survey and activity data.
		VMT	Reduced by 6%–16%	
		Vehicle ownership	Removed 7–11 vehicles per carshare vehicle	
Shaheen (expected in 2017)	Ridesourcing/e-hailing	Currently unavailable	Currently unavailable	Currently unavailable

Researchers have documented environmental benefits from particular elements of new mobility. Namazu and Dowlatabadi (2015) as well as Martin and Shaheen (2011, 2016) found that carsharing can reduce energy use and GHG emissions by encouraging mode shifting, reducing vehicle miles traveled (VMT), encouraging right-sizing, and delivering higher fuel economy from accelerated fleet turnover. While some carsharing members could use the service as a substitute for public transportation and increase total travel, the researchers find that carsharing programs will produce net environmental benefits. Researchers also find that ridesharing, or the filling of otherwise empty seats in a vehicle, is a robust strategy to reduce emissions, congestion, and fossil-fuel usage (see Chan and Shaheen, 2011). Bikesharing offers similar benefits, researchers report. Public bikesharing programs enhance urban mobility, complement transit, reduce automobile use and ownership, encourage transportation mode-shifting, and reduce emissions, according to Shaheen and Martin (2015). As reported by the Shared-Use Mobility Center, "The more people use shared modes, the more likely they are to use public transit, own fewer cars, and spend less on transportation overall" (Shared-Use Mobility Center, 2016b).

Ridesourcing companies Uber and Lyft claim that their services, especially their shared services UberPOOL and Lyft Line, help cities fight traffic congestion (Lyft, 2016; Uber, 2016b). However, very few studies exist that evaluate their impact. One study analyzing real world data from New York City's Taxi and Limousine Commission found that TNCs led to a 7% increase in VMT from 2013–2016, which can substantially increase congestion (Schaller Consulting, 2017). According to the San Francisco Municipal Transportation Agency, the increase in traffic congestion in the city is largely attributable to TNCs (California Public Utilities Commission, 2016). More research is needed to better understand the environmental and transportation impacts of ridesourcing.

Semi-autonomous vehicle technologies will result in some level of environmental benefit, the research shows. Features including platooning (groups of vehicles traveling close together to minimize aerodynamic drag), smooth acceleration/deceleration, eco-driving, and crash avoidance are all expected to improve vehicle fuel economy (e.g., see Brown et al., 2014; Lammert and Gonder, 2014; Wadud et al., 2016).

At the same time, the literature indicates that there are reasons to be highly skeptical that autonomous vehicles will deliver environmental benefits in the current policy landscape. As shown in Table 2, Brown and colleagues (2014) found that autonomous vehicles could lead to 50% increased energy use from additional travel. Similarly, Wadud and colleagues (2016) estimate up to 60% increased energy use due to additional travel. Because full automation relieves the "driver" of operating the vehicle, individuals may have greater tolerance for longer trips due to their ability to engage in tasks other than driving.

Furthermore, transportation emissions and VMT could increase as automation enables zero-occupant travel where vehicles can handle all tasks independently such as looking for parking, running errands, or driving back home after a commute. Other factors such as higher highway speeds and new user groups could also contribute to increasing energy use in transportation nearly threefold (see Brown et al., 2014; Wadud et al., 2016). As travel comfort and tolerance increases with vehicle automation, people may be willing to travel more frequently and for further distances, leading to sprawl, congestion, and pollution (International Association of Public Transport, 2017; Lerner, Pollard, Lovass, & Coequyt, 2016).

Wadud and colleagues (2016) suggest that while semi-autonomous vehicles (Levels 1–3) will generally reduce energy consumption because of platooning, eco-driving, and crash avoidance, full autonomy will enable dramatically increased travel demand and undermine efficiency improvements. For this reason, the authors suggest that "policymakers may wish to focus their energies less on accelerating Level [5] automation (which may come in due course) and more on measures that promote the application of automation toward socially desirable objectives" (Wadud et al., 2016). Brown et al. (2014) similarly project that increased travel will probably be the most significant factor contributing to the negative environmental impact of fully autonomous vehicles. Some experts (e.g., see Isaac, 2015) suggest that a tax or fee on VMT could help limit increases in travel, congestion, energy consumption, and air pollution.

Some investigators have argued that as fully autonomous vehicles become available, mobility providers such as TNCs will choose vehicles with greater fuel economy, including ZEVs, to minimize operating costs (see Tillemann and McCormick, 2016; Weiland, Rucks, & Walker, 2015). However, new mobility is unlikely to result automatically in ZEV adoption, based on our research. Certainly, compared with conventional vehicles, ZEVs have clear environmental benefits (Nealer, Reichmuth, & Anai, 2015) and lower operating and maintenance costs (Lutsey, 2015a). However, there are significant hurdles to their widespread adoption, including higher upfront costs, unavailability of charging infrastructure, and long charge times (NRC, 2015). Encouraging electric vehicle penetration among consumers has required the creation of a whole ecosystem of policies and actions at all levels of government (e.g., Lutsey, Searle, Chambliss, & Bandivadekar, 2015; Lutsey, Slowik, & Jin, 2016). It would take a similarly comprehensive, targeted effort to ensure penetration of ZEVs in shared and autonomous transportation.

There is growing evidence that a fleet of right-sized, shared, electric, fully autonomous vehicles integrated with mass transit will lead to an optimal environmental outcome (e.g., see Barcham, 2014; Brown et al., 2014; Greenblatt & Saxena, 2015; Greenblatt and Shaheen, 2015; International Association of Public Transport, 2017; Wadud et al., 2016). Electrification has the greatest potential for autonomous vehicles to offer energy and emissions reductions (e.g., see Brown et al., 2014; Alexander-Kearns, Peterson, & Cassady, 2016). Other indirect environmental benefits could stem from a fleet of shared autonomous vehicles. Some researchers argue that shared autonomous vehicles can meet mobility demand with a significantly downsized fleet, resulting in less congestion, reduced requirements for parking space, higher per-vehicle utilization rates, faster fleet turnover, and a newer fleet on average (e.g., Spieser et al., 2014).

In practice, shared vehicles could make up a large percentage of an autonomous vehicle fleet, as there are no technological barriers to shared mobility. While there are non-technological barriers such as consumer preferences, new business models such as Lyft Line and UberPOOL suggest that consumers are becoming comfortable with shared services (Huet, 2015). Population density may be another barrier; researchers predict shared mobility will emerge and thrive in dense urban environments and slowly expand to suburban areas and perhaps even rural areas (e.g., see Shaheen and Galczynski, 2014). Some scholars suggest that shared mobility networks of autonomous vehicles may be cheaper than private vehicle ownership, raising the potential for shared business models to emerge without policy action (e.g., see Brown et al., 2014; Greenblatt & Saxena, 2015; Pavone, 2015). The goals of transportation network companies such as Uber, which aims to make its service cheaper than owning a car, reflect this possibility (Shontell, 2015).

The pairing of electrification with autonomous vehicle technology may occur less naturally; barriers exist to widespread vehicle electrification (e.g., see NRC, 2015) and new mobility is unlikely to result in electric vehicle adoption by design. A recent ICCT report on global electric vehicle adoption targets found that annual global electric vehicle sales could account for as much as 15% of new vehicle sales in 2030, 35% in 2035, and 55% in 2040 (Lutsey, 2015b). Figure 4 plots these estimates against projections of autonomous vehicle penetration as estimated by major consulting firms.

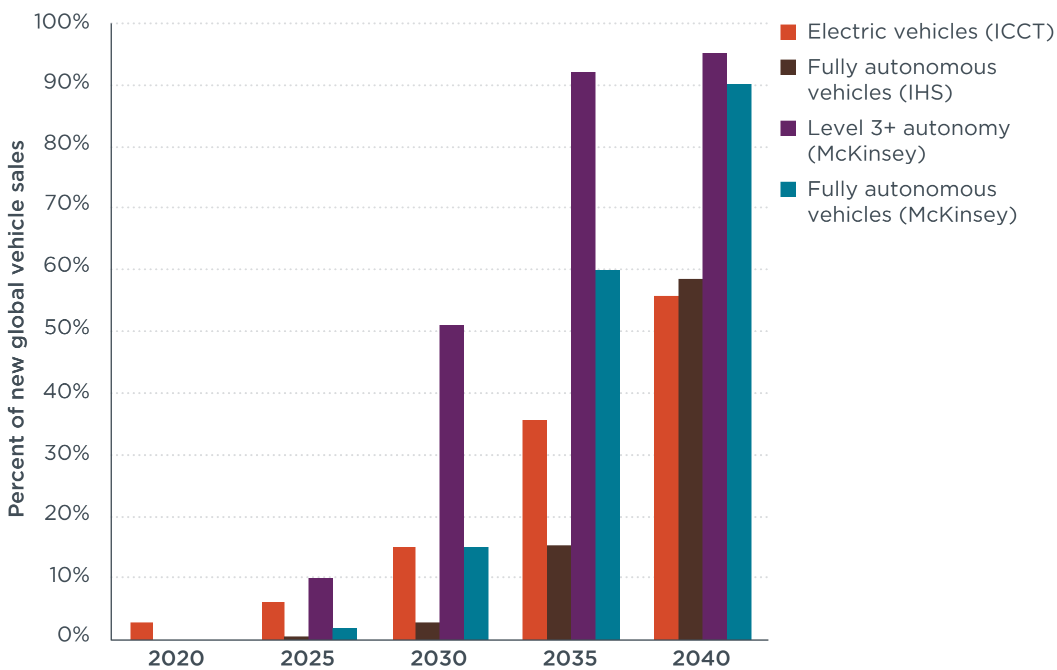


Figure 4. Projections of electric, semi-autonomous, and fully autonomous vehicles

As shown, estimates of future autonomous vehicle sales significantly exceed demand estimates for electric vehicles. McKinsey projects that vehicles with automation at Level 3 or higher may account for more than 50% of new auto sales worldwide by 2030 and more than 90% by 2035 (McKinsey & Company, 2016). IHS Automotive projects that global sales of fully autonomous vehicles, or Level 5, will be more gradual, reaching 15% of sales in 2035 (IHS Automotive, 2016).

As electrification is key to low-carbon transportation, we strongly recommended that governments continue to provide strong market signals for electric and other zero-emission vehicle technology. The ramping up of electric vehicle targets to accelerate their adoption and keep pace with production of autonomous vehicles could greatly help reduce the emissions and energy consumption of autonomous vehicles.

FEATURED PROJECTS AND INITIATIVES

Our review of the new mobility landscape turned up a number of projects and initiatives that take into account the potential environmental implications. Several of these incorporate one or more of the elements that are likely to result in environmental benefits, including sharing, electrification, complementing transit, higher occupancy, and mode shifting. Here is a look at some projects that are poised to promote a transportation system with less environmental impact. Initiators of these projects include governments, industry, research universities, NGOs, or some combination.

Shared, autonomous, electric

As described earlier, two separate trials of shared, electric, autonomous shuttles are underway in the U.S. They are the Contra Costa Transportation Authority's test in California and the project at UNLV.

If successful, these programs will deliver environmental benefits by providing low-carbon transportation to major mass-transit hubs, replacing personal driving. This has the potential to reduce fuel consumption, emissions, congestion, and VMT. The biggest environmental uncertainty involving autonomous vehicles is their potential to dramatically increase VMT. Limiting the shuttles to 25 kilometers per hour as in both trials will discourage the use of shuttles for trips of long distance, as will limiting the vehicles' areas of operation.

Autonomous, electric

In August 2016, nuTonomy started a trial of on-demand, autonomous electric taxis on public roads in Singapore. The all-electric Mitsubishi i-MiEV vehicles can be e-hailed from a smart phone and are available to select customers in the 450-acre One North business district (nuTonomy, 2016; Singapore Land Transport Authority, 2016b). Among others, the primary partners and implementers include nuTonomy, the Singapore Land Transport Authority, and the Singapore-MIT Alliance. Long term, the agency aims to use the on-demand taxis to complement mass transit and expand access to currently underserved remote areas (nuTonomy, 2016; Singapore Land Transport Authority, 2016b).

Leveraging autonomous, electric taxis to extend access and complement transit is likely to provide environmental benefits. Electrification has the greatest potential for autonomous vehicles to offer emissions and energy reductions. If the trial vehicles encourage a decline in personal driving and an overall mode shift toward public transit, environmental benefits would result. The project sponsors have not discussed plans to explore the potential for shared e-hailing/shared ridesourcing (e.g., UberPOOL, Lyft Line) to fill otherwise empty seats. Doing so would increase occupancy and could provide additional benefits by reducing the energy and carbon intensity per person-trip. Understanding the current baseline and the project's impacts on mode shifting, transit ridership, VMT, congestion, and the intensity of energy and emissions would help assess the results.

Shared, electric

The California Air Resources Board awarded Los Angeles $1.6 million to explore the potential for an electric vehicle carsharing program to enhance low-carbon mobility in disadvantaged communities (California State Senate, 2015). The project's first phase includes deployment of 100 carshare vehicles. Project sponsors expect to recruit 7,000 new electric vehicle users, prevent the private purchase of 1,000 combustion-engine vehicles, and reduce CO_2 emissions by 2,150 tons per year (City of Los Angeles, n.d.).

This project is expected to result in environmental and supplemental benefits. Electric vehicles have clear environmental benefits and carsharing programs offer benefits including lower vehicle ownership rates, mode shifting, right-sizing, reduced VMT, higher fuel economy, and reduced GHGs. Understanding the current baseline will allow for thorough evaluation of the program's impact.

Shared, transit-complementing

Research suggests that a transportation system offering an array of new mobility options that are integrated with public transit can reduce emissions. The Shared-Use Mobility Center reports that people are more likely to forgo vehicle ownership and use public transportation if they have access to multiple mobility options, such as carsharing, ridesharing, bikesharing, ridesourcing, shared ridesourcing, and transit. Mobility options have been found to complement transit, offering environmental benefits from lower emissions, reduced vehicle ownership and VMT, and congestion. The Shared-Use Mobility Center offers a free "Shared Mobility Toolkit" online. It includes a policy database of more than 700 shared-mobility policies and plans in the U.S., a mapping and opportunity analysis tool to help cities understand which areas have the greatest potential for shared mobility options, and a shared-mobility benefits calculator that models the potential benefits including reductions of emissions and VMT (Shared-Use Mobility Center, 2016c). These resources can be valuable to local and regional transportation planners.

A key enabler for leveraging shared mobility to complement existing public transportation is integrating services on a single platform or mobile application. One provider is TransitApp, available in 125 cities (TransitApp, 2016). TransitApp works with cities and transit agencies to provide a single, multimodal trip planning tool, including carsharing, bikesharing, ridesourcing, walking, biking, and local mass transit. Data collected from use of the application can help cities understand the effects of various shared mobility options on existing transportation. Leveraging a service like TransitApp can help local governments meet mobility and environmental goals by expanding mobility access and increasing the use of shared mobility.

Shared

Ola, a ridesourcing company in India, has an interesting campaign to encourage more users to take an "Ola Share," an example of shared ridesourcing similar to UberPOOL and Lyft Line. Partnering with the World Resources Institute, Ola's #doyourshare campaign encourages users to reduce congestion and emissions by taking a shared ride rather than catching a ride alone. In addition to advertising the cost savings, the campaign publicizes the benefits of shared rides in lowering GHG emissions. It also includes a competition among three cities to reduce carbon emissions by 400 tonnes (Ola, 2016). The competition includes billboards that track progress on emissions reduction. Ola reports that Ola Share saved 2 million liters of fuel, reduced CO_2 emissions by 4.8 million kilograms, and kept 3.7 million vehicles off roads since 2015 (Ola, 2016).

This campaign demonstrates one imaginative approach to encouraging shared mobility. Clearly Ola Share offers environmental benefits compared with single-use trips. However, the overall environmental implications of ridesourcing and shared ridesourcing are relatively unexplored. More work is expected in 2017 from researchers at the University of California, Berkeley (National Resources Defense Council, 2015). The #doyourshare campaign does not appear targeted at complementing public transportation, encouraging mode shifting, or promoting fuel economy or electric vehicles. Further study is needed to assess the environmental benefits.

IV. SUMMARY OBSERVATIONS

The landscape of new mobility is rapidly developing. Powerful stakeholders are investing in and planning for new mobility. They range from the federal government to local and regional governments and transportation agencies to vehicle makers, tech industry giants and start-ups, NGOs, and philanthropic organizations. The level of action, investment, and policy-making suggests that this is more than industry hype. New mobility is poised to revolutionize transportation.

New mobility could improve system-wide efficiency, air quality, and quality of life. Alternatively, new mobility could lead to mass congestion, hypersprawl, worsened air quality, and a deteriorated quality of life. Based on the research literature, there are many reasons to be skeptical that new mobility will deliver environmental benefits under the current policy landscape. If the implementation of autonomous mobility is successful, there will be massive impacts on mobility access, convenience, and cost that will increase travel activity.

Achieving environmentally beneficial outcomes will require the sharing of autonomous vehicles by multiple passengers and increased electrification. There is no assurance in current policies or market conditions of such an outcome. The level of political action by environmental and transportation regulators will largely determine the transportation efficiency and environmental implications of new mobility. Without policy action, new mobility is unlikely to result in lower-carbon transportation.

This scoping paper lays the groundwork for understanding today's technology and policy landscape for new mobility. Additional research is needed to identify policy approaches that can ensure the development of new mobility supports and advances the goal of a transportation system with far less environmental impact. This work would define the policy toolkit available to federal, state, and local regulators and lead to a fuller understanding of its applicability across jurisdictions. It would also eventually help quantify the benefits and costs associated with policy options to ensure that new mobility emerges as a low-carbon and socially equitable transportation system.

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ANNEX

Information on new mobility partnerships and investments for automobile manufacturing and technology company partnerships is summarized in Table 3 (for manufacturers) and Table 5 (for technology companies).

In Table 4 is a summary of quotations from automaker management reflecting the transition of vehicle manufacturers to mobility providers.

Table 3. Automobile manufacturer partnerships and investments in new mobility

Automaker	Project name	Description	Project type	Partners	Investment
General Motors	Maven	Car sharing service	Carsharing	N/A	Undisclosed
	Connected network for self-driving cars	GM and Lyft have launched a strategic alliance to create a U.S. network of on-demand autonomous vehicles.	Fully autonomous, ridesourcing / e-hailing	Lyft	$500 million, 9% stake
	Express Drive	Short-term car rental program exclusive to Lyft platform.	Ridesourcing/e-hailing	Lyft	Undisclosed
	OnStar	Began in 1996 and now offers emergency, security, navigation, vehicle connectivity, and vehicle management services.	Vehicle communications	GM, Electronic Data Systems, Hughes Electronics	Undisclosed
	Cruise Automation	Cruise Automation has developed a $10,000 aftermarket kit called RP-1 Highway Autopilot that can be installed on certain vehicles. GM and Cruise Automation are testing all electric Bolts in San Francisco.	Fully autonomous	Cruise Automation	$1 billion purchase
Volkswagen	Strategy 2025	Part of the plan includes tackling digitally connected and autonomous vehicle challenges.	Vehicle communications	N/A	Undisclosed
	V-Charge	Project developing smart car system allowing for self-driving valet services, including automated electric vehicle charging.	Fully autonomous	Swiss Federal Institute of Technology, Braunschweig Technical University, Robert Bosch GmbH, Parma University, and Oxford University	Undisclosed
	On-demand mobility provider partnership	VW invests in Gett, a ride sourcing company that is considered the European rival of Uber. VW has goals to generate significant sales revenue from new business models, like Gett, by 2025.	Ridesourcing/e-hailing	Gett	$300 million investment in Gett
Ford	Ford Smart Mobility LLC	Ford is investing in more than two dozen global mobility experiments with the goal of advancing in vehicle connectivity, mobility, autonomy, customer experience, and big data.	New mobility	N/A	Undisclosed
	FordPass	Platform that connects users to vehicles via an app with the goal of helping solve mobility challenges. Features include vehicle controls, smart parking reservations, e-payments, carsharing.	Carsharing	Pivotal Others include ParkWhiz, Parkopedia, Flightcar	$182.2 million
	Dynamic Shuttle	Pilot project offering on-demand ridesharing with goals of increasing ridership through smart routing.	Ridesharing	N/A	Undisclosed
	Peer-to-peer carsharing platform partnership	Through a Ford-Getaround partnership, customers are able to rent Ford vehicles to others.	Carsharing	Getaround	Undisclosed
Fiat Chrysler	100 self-driving minivans	Fiat Chrysler and Alphabet partnership to build a fleet of 100 self-driving minivans.	Fully autonomous	Alphabet/ Google	Undisclosed

Automaker	Project name	Description	Project type	Partners	Investment
Daimler	Car2Go	Largest global carsharing service.	Carsharing	N/A	Undisclosed
	Moovel	Mobility application to plan and compare various mobility options (carsharing, public transportation, on-demand mobility).	Mobility on demand	N/A	Undisclosed
BMW	i Ventures	BMW-formed venture capital company which invests in projects focusing on meeting mobility needs of urban populations. Has invested in more than a dozen mobility service start-ups.	New mobility	Numerous	Undisclosed
	ReachNow	Carsharing service currently limited to Seattle metro area. Available vehicles include the electric BMW i3.	Carsharing	RideCell (Software platform enabling mobility as a service, including carsharing, ridesharing, fixed-route, and dynamic transit services)	Undisclosed
	Ridesharing application investment	Investment in carpooling application aiming to increase shared commuting by using smart routing, automated matching, and lower costs.	Ridesharing	Scoop Technologies	Undisclosed
	Parking and car services investment	Strategic investment in Zirx, a company that facilitates vehicle ownership and parking by working with enterprises to provide on-demand valet services	N/A	Zirx	Undisclosed
	Live transit information service investment	Investment in Moovit, an application that provides trip planning options for public and private transportation.	N/A	Moovit	Undisclosed
Nissan	Intelligent Motoring Advisory Board	Independent group of experts convened by Nissan whose focus is on smart mobility and connected cities. Head of electric vehicles for Nissan in Europe leads the board.	New mobility	A board of 12 members (includes European Climate Foundation)	N/A
Volvo	Drive Me (Volvo)	Fleet of 100 autonomous XC90 vehicles to be tested by consumers in Sweden using IntelliSafe Autopilot features	Fully autonomous	Autoliv	Undisclosed
	Volvo-Microsoft partnership	Volvo uses Microsoft technology such as HoloLens and Band 2 to develop and implement next generation automotive technologies. Collaboration could eventually include autonomous and connected car technologies	Vehicle communications	Microsoft	Undisclosed
Toyota	Toyota Connected	Company to develop Internet connected services for vehicle owners and dealers. Services include connected vehicle networks that share information (weather, road conditions), information tailored to a driver's habits and preferences, and insurance coverage and rates based on individual driving patterns.	Vehicle communications	Microsoft	Microsoft 5% stake
	Ann Arbor Connected Cars	Real-world connected vehicle technology testing. Vehicles of participating Toyota team members and families to be equipped with devices to support V2V and V2I systems in Ann Arbor, MI. Up to 5,000 vehicles.	Vehicle communications	University of Michigan Transportation Research Institute (UMTRI)	Undisclosed
	Toyota-Uber strategic partnership	Memorandum of understanding to collaborate on new mobility services. Includes Toyota providing new leasing options for individuals to cover lease payments through earnings as Uber drivers.	Ridesourcing/e-hailing	Uber	Undisclosed
Jaguar Land Rover	InMotion	New technology business formed by Jaguar Land Rover works to build apps and on-demand services. Future services may include carsharing and vehicle ownership solutions.	Mobility on demand	N/A	Undisclosed
Porsche	Porsche Digital GmbH	Subsidiary aimed at connecting Porsche with mobility innovators. Focuses include connectivity, smart mobility, and autonomous vehicles.	New mobility	N/A	Undisclosed

Table 4. Key quotes from automaker representatives

Automaker	Quote	Source
Ford	"It's a very exciting time at Ford, because we are transitioning from an auto company to an auto and a mobility company. Mobility for us, at the very simplest level, is to allow people to live, play, and work where they want. How do we help enable them to get around to do that? And there's a lot of talk around technology companies disrupting the auto industry. Our approach is very simple: We're disrupting ourselves." Mark Fields, CEO	Blodget, 2016
Volkswagen	"Alongside our pioneering role in the automotive business, we aim to become a world leading mobility provider by 2025. Within the framework of our future Strategy 2025, the partnership with Gett marks the first milestone for the Volkswagen Group on the road to providing integrated mobility solutions that spotlight our customers and their mobility needs." Matthias Müller, chairman of the board of management of Volkswagen AG	Volkswagen, 2016
General Motors	"GM is at the forefront of redefining the future of personal mobility. With the launch of our car-sharing service through Maven, the strategic alliance with ride-sharing company Lyft, and building on our decades of leadership in vehicle connectivity through OnStar, we are uniquely positioned to provide the high level of personalized mobility services our customers expect today and in the future." Dan Ammann, president "We see the future of personal mobility as connected, seamless and autonomous." Dan Ammann, president	General Motors, 2016c General Motors, 2016b
Mercedes-Benz	"This digital transformation is in full swing at Mercedes-Benz. We are transitioning from car manufacturer to networked mobility provider, whereby the focus is always on the individual—as customer and employee. This is how we will continue to develop the company and thereby ensure our future competitiveness." Dr. Dieter Zetsche, chairman of the board of management of Daimler AG and head of Mercedes-Benz Cars	Mercedes-Benz, 2015
Nissan	"At Nissan, we're not content sitting back and watching as our cities become more complex, crowded and congested. Selling cars is no longer a moment-in-time transaction. Cars have a fundamental impact on the cities we live in and the lives we lead. With the advent of new technologies and drivetrain innovations, new mobility solutions can make our lives 'smarter' and better connected. This is why we're thrilled to launch the Nissan Intelligent Motoring Advisory Board; we hope others in the industry will join us on this journey." Gareth Dunsmore, head of electric vehicles for Nissan in Europe	Nissan, 2016
BMW	"We used to be the provider of premium cars and now we're the provider of premium mobility services as well as premium cars." Richard Steinberg, CEO of BMW DriveNow	Neiger, 2016
Toyota	"Ridesharing has huge potential in terms of shaping the future of mobility. Through this collaboration with Uber, we would like to explore new ways of delivering secure, convenient and attractive mobility services to customers." Shigeki Tomoyama, senior managing officer of Toyota Motor Co., president of Toyota Connected	Toyota, 2016

Table 5. Technology company partnerships and investments in new mobility

Technology company	Project name	Description	Project type	Partners	Investment
Apple	On-demand mobility provider partnership	Investment of $1 billion in Didi Kuaidi, the largest on-demand mobility company in China.	Ridesourcing/ e-hailing	Didi Kuaidi	$1 billion
	Titan / iCar	While speculative, a number of media articles report that Apple is heavily investing in shared, electric, autonomous vehicles.	Fully autonomous, electric, and shared use mobility	Unknown	According to Morgan Stanley, Apple has spent $5 billion on car / services R&D over the past three years, outspending major car manufacturers by 20:1 and Tesla by 10:1. Reportedly they have spent more on car / services R&D than the watch, iPad, and iPhone combined.
Uber	deCarta	Purchase in 2015 of startup that develops a mapping software platform.	Ridesourcing / e-hailing	deCarta	Undisclosed
	Uber Advanced Technologies Center	Partnership with Carnegie Mellon (including funding from Uber) to open a research center that will work on mapping, vehicle safety, and autonomous vehicle technology.	Fully autonomous	Carnegie Mellon University	Undisclosed
	Saudi Arabia Public Investment Fund	Fund invests $3.5 billion to help Uber expand service in the Middle East.	Ridesourcing / e-hailing	Saudi Arabia Public Investment Fund	$3.5 billion
	Carpooling partnership	Integrating Carpooling ridesharing app's program interface, expanding Uber's market to allow for mid to long distance services.	Ridesourcing / e-hailing	Carpooling (app)	Undisclosed
Google	Uber	Google investment in 2013.	Ridesourcing / e-hailing	Uber	$258 million
	Waze Rider	Carpooling app in pilot phase in SF, significantly cheaper than Uber/Lyft at 54 cents/mile	Ridesharing	Waze (owned by Google since 2013)	Undisclosed
	Self-driving car project	Google has been developing autonomous vehicle technology since 2009 and is testing vehicles in California, Texas, Washington, and Arizona, logging more than 2 million miles of autonomous driving as of Fall 2016.	Fully autonomous	N/A	Undisclosed
Nvidia	Automotive Technology Solutions	Nvidia is developing a number of hardware and software platforms to support autonomous driving, allowing vehicles to "see, think, and learn." Many vehicle manufacturers are using Nvidia products.	Semi-autonomous, fully autonomous	More than a dozen automotive partners including Audi, Tesla, Mercedes, Volvo, Honda, and BMW	Undisclosed
Microsoft	Connected car collaboration	A partnership between Microsoft and Harman will combine Microsoft's Office 365 and Harman's connected car systems to introduce mobile productivity services, cloud platforms, telematics, and vehicle connectivity. The partnership and software are expected to improve safety.	Vehicle connectivity	Harman	Undisclosed
DriveAI	DriveAI	A nonprofit startup conducting artificial intelligence R&D for autonomous vehicles. DriveAI is developing a prototype and providing data to others who are working to develop vehicle processing techniques and evaluate sensor equipment.	Fully autonomous	Funded by Munich Reinsurance	$12 million

Technology company	Project name	Description	Project type	Partners	Investment
Zoox	Zoox	Zoox itself is closely held. However, although speculative, a number of reports suggest that Zoox is developing fully autonomous taxis capable of e-hailing. Zoox co-founder envisions the Zoox autonomous taxi on public roads by 2020. Zoox has received a testing permit from the CA state DMV.	Fully autonomous, ridesourcing / e-hailing	Unknown	Estimated $1 billion valuation; currently seeking $252 million in funding
nuTonomy	nuTonomy	Startup focused on autonomous vehicle urban driving. The company started testing all-electric autonomous taxis in Singapore and expects to operate a commercial electric autonomous taxi service in 2018.	Fully autonomous, ridesourcing / e-hailing	Fontinalis Partners; Highland Capital Partners LLC; Singapore's economic development department; Ford Motor Co. Chairman Bill Ford	$3.6 million from Fontinalis Partners in January 2016 $16 million additional funding acquired more recently
Nauto	Nauto	Testing technology in 23 cities worldwide, including in taxi and private bus fleets. The company uses a connected camera network, driver alerts, and artificial intelligence to reduce false liability claims, alert drivers of potential dangers, and improve road safety. The system constantly collects data on driving behavior to eventually support the requirements for full automation.	Semi-autonomous, fully autonomous,	Playground Global; Draper Nexus; Index Ventures	$12 million