Emerging Mobility Technologies and Trends

And Their Role in Creating
"Mobility-As-A-System"
For the 21st Century and Beyond

ESN®
ENERGY SYSTEMS NETWORK

Building an Energy Ecosystem®

ABOUT THE AUTHOR

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Previously, Matt provided strategic consulting services to C-level executives in the fields of connected and automated vehicles and infrastructure, shared mobility, smart cities, big data, advanced mobility, and clean energy technologies. While at CAVita and his own firm, Peak Strategy Partners LLC, Matt worked with the nation's largest transportation research agency as its autonomous vehicle specialist, the world's largest aggregator of solar fuels partners and knowledge to commercialize innovative technologies, and has also assisted numerous laboratories and startups commercialize their automotive and energy technologies.

Matt previously launched and led Prize Capital's and Tri-State G&T's efforts to discover, invest in, and commercialize advanced energy technologies, and created what became the NRG COSIA Carbon XPRIZE, a $20 million (USD) competition to spur technological innovation at power plants. He was also the first employee of a venture-funded battery technology startup focused on commercializing a new type of lithium battery for electric vehicles and other markets, and led public policy, renewable fuel, and other collaborative efforts to develop and deploy advanced transportation technologies at CALSTART and the Natural Resources Defense Council (NRDC).

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ABOUT ENERGY SYSTEMS NETWORK

ENERGY SYSTEMS NETWORK

Energy Systems Network ("ESN"), a branded initiative of the Central Indiana Corporate Partnership ("CICP"), is a non-profit industry consortium of companies and institutions focused on the development of the advanced energy technology sector. ESN is building an energy ecosystem that integrates all aspects of the energy landscape: energy generation, distribution, the built environment, and transportation.

ESN leverages its network of global thought leaders to develop integrated energy solutions to increase quality of life for today and tomorrow. Its collective focus is to: reduce costs, emissions and waste; influence policy; and advance technological innovation.

ESN uses a three-pronged approach to provide services for its partner organizations and clients:

- Multi-company Projects: Multi-company collaborations that accelerate new technology commercialization through commercial-scale pilot projects;
- Consulting Services: Business services ranging from market studies to project development and management; and
- Workshops, Strategic Planning and Research: Provide facilitation and lead strategic planning and research efforts.

To date, ESN has launched a series of commercialization projects focused on dramatically reducing emissions/fuel consumption of heavy trucks (Hoosier Heavy Hybrid Partnership); allowing for an all-electric commute powered by a smart utility grid (Project Plug-IN); supplying our military bases with reliable homegrown energy (MicroGreen); and creating a single point of access for battery research, development, testing and commercialization (Battery Innovation Center).

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GLOSSARY OF TERMS

AAMVA	American Association of Motor Vehicle Administrators
ADS	Automated Driving System
ASCT	Adaptive Signal Control Technologies
AV	Automated Vehicle • Automated Vehicle: A vehicle that has one or several of a very wide range of automated driving features and replaces certain aspects of driver perception and control. • Autonomous Vehicle: An automated vehicle that relies entirely on its own onboard sensors for situation awareness in the roadway, and therefore for exercising vehicle control functions.
CAV	Connected and Automated Vehicle
CV	Connected Vehicle
DSRC	Dedicated Short Range Communication
EV	Electric (or electrified) vehicle
FHWA	Federal Highway Administration
HAV	Highly automated vehicle, of SAE Level 3 or above
HEV	Hybrid-electric vehicle
Lidar	Light Detection and Ranging
MaaS	Mobility as a Service
NPRM	Notice of Proposed Rulemaking
OBD	On-board diagnostics
OBU	On-board unit

PHEV	Plug-in hybrid electric vehicle
Platoon	Comprising two or more freight trucks enabled for V2V communication as well as automated longitudinal (and perhaps lateral) control functions.
RSU	Road-side Unit
SM	Shared Mobility
V2I	Vehicle-to-Infrastructure aspect of CV
V2V	Vehicle-to-Vehicle aspect of CV
V2X	Includes V2V and V2I, and vehicle communication with road users such as motorcyclists, cyclists and pedestrians.

EXECUTIVE SUMMARY

For the past 100 years, much of society in the United States and many other parts of the world has been organized around the personal automobile. In many ways, it has come to define what, where, and how we live. Yet change is afoot. In fact, some have predicted that there will be “more change in the next ten years than in the last fifty.” This could very well be so, given the onset and commercial advancement of core automotive and related trends.

Batteries, once primitive and expensive, now use energy-dense and increasingly cheaper lithium ion that enables more affordable, longer distance electric vehicles. This newfound affordability and viability has spurred cumulative global electric vehicle (EV) sales to total more than 3 million as of February 2017, a number that could climb to as high as 70 million by 2025 as automakers are expected to invest at least $90 billion to electrify their lineups.

Connected and automated vehicles (CAVs), once the domain of science fiction, are quickly becoming commercially viable. Initial use cases are oriented around safety messages and preemptive actions – such as collision avoidance – while various companies are piloting advanced use cases around broadly communicative, highly automated vehicles. Issues need to be resolved in order for CAVs’ full potential to be realized. These issues include connected vehicle regime standardization (i.e., “DSRC” vs. “5G”), automation components’ capabilities and affordability, and CAV deployment scenarios that reduce rather than increase congestion and pollution. Nonetheless, with some projecting the CAV market will be worth $7 trillion in 2050 and with major technology developers and automakers deeply invested in the technologies, CAVs’ arrival seems more a matter of "when" and "how," rather than "if."

The same technologies that enable the smartphone have combined with the “shared economy,” in which strangers are comfortable renting private property and services to each other to establish “shared mobility.” Shared mobility integrates an array of transport modes and services – including but not limited to buses, microtransit, taxis, rail and metro, shared and pooled cars and rides, scooters, bicycles, and others – into a single portal (e.g., smartphone app) that is accessible on demand as needed, and charges customers for mobility-as-a-service (“MaaS”) rather than for the acquisition of assets. The popularity of ridesourcing services such as Uber and Lyft spurred shared mobility, which some project could replace over 2.3 billion urban private car journeys annually in 2023 (compared with just 17.6 million globally in 2018), while more recent efforts have focused on the development of comprehensive services and apps that enable full multimodal journey planning and ticketing.

While each of these three trends engenders innovation and may likely result in radical change over the next decade, greater change – the “disruptive innovation” – may be realized in the seamless combination and integration of each of these three trends while applying them not only to passenger automobiles, but to a wide array of vehicles and modes as well. Multiple modes of electrified, connected, (at least partially) automated, shared vehicles can act as a system, with public transit serving as the backbone of that system upon which the broader architecture is layered.

A challenge with such an approach is that public transit ridership has declined significantly, particularly in recent years. Between 1945 and 1969, the number of U.S. transit passengers dropped from 23 billion to 8 billion. Today, increasingly fewer commuters across the country are using public transit. Transit ridership fell in 31 of 35 major metropolitan areas between 2016 and 2017. Overall, 76.4 percent of Americans drive alone to work every day; just 5.2 percent take public transit.

Modern modes and models are emerging that can assist transit's revival. Electric transit buses provide not only more pleasant rides, but can also reduce maintenance and operating costs due to their relatively few drivetrain components, greater efficiency, and use of a cheaper fuel – all of which can leave more money in transit agencies' pockets to use to increase service and frequency. Additionally, some of the same technologies that enable shared mobility are enabling new transit bus services, such as dynamic routing, the provision of real-time information, and service-based pricing models.

Yet for the ridership revival to take hold, transit has to overcome the "first/last mile challenge," which refers to the hurdle imposed by pedestrian access to transit stations at distances greater than one-half mile, and the associated decline in ridership. The solution to the first/last mile challenge isn't simple, and the application of any single challenge-solving mode in isolation of the others can compromise affordability and accessibility, and impose issues pertaining to intersectionality and overall mobility.

Instead, the solution to the first/last mile challenge can be found in the establishment of a "mobility menu" of domains, modes, and usage models that, when integrated with transit, can form a complete urban mobility system. Designating domains based on real-world usage patterns is essential in order to match appropriate modes and usage models and to establish a practical system. Of primary importance is recognizing that the overwhelming number of trips are short distances: in 2017, over 85 percent of all trips were 15 miles or less. Only 4.9 percent were 31 miles or more.

A further segmentation of trip data reveals three primary travel domains. The "Local Domain" is defined by trips up to five miles in length, which comprise 59.5 percent of all trips, and is served by "micromobility" modes such as shared scooters, bikes, and automated shuttles. The "Midrange Domain" is defined by trips between five and 15 miles long, which comprise 25.7 percent of all trips, and is served by models such as microtransit, ridesourcing, and carpooling. The "Long-range Domain" is defined by trips beyond 15 miles long, which comprise 14.8 percent of trips, and is served by models such as carsharing and car subscriptions.

Within each of these domains, data on user adoption rates and usage patterns are demonstrating the feasibility and popularity of various modes for specific use cases. This feasibility and popularity is enabled by a variety of adjacent technologies and market drivers. Included among these are "big data" computations that enable advanced modeling and analytics, freight and commercial markets, intelligent transportation systems (ITS), land use and congestion, prize competitions, public policy and regulations, safety, smart cities, and venture capital, among others.

Altogether, the application of modes within the framework of domains and the backbone of transit yields the very real possibility that "mobility-as-a-*system*" (MaaSys) may emerge that affords much, if not all (or more), of the movement provided by personal car ownership yet without many (or all) of its downsides. Fulfilling such potential will require full and complete systemic integration of modes and domains, as well as their optimized, dynamic coordination. Various companies are already advancing such efforts, mainly in the form of smartphone applications that bring all modes and technologies to bear to present options, coordinate routing and timing, and simplify payments for users. Beyond these efforts, potential enablers and market drivers currently advancing the system may include the advancement of aerial drones and flying cars/taxis, automated micromobility, blockchain, "land traffic control" systems, ultra-fast electric vehicle charging, and vehicle-to-grid (V2G) deployments.

In the future, it may be that society no longer associates mobility with personal automobiles, but rather develops an association more akin to the modern telecommunications industry. Just as consumers can walk into a telecommunication provider's retail store and be afforded one of many different smartphone handsets, minutes of talk-time, and gigabytes of data by subscribing to a package that best meets their needs and desires, future travelers might enter mobility hubs that afford the use – rather than ownership – of a wide variety of shared modes by subscribing to a package based upon travel frequency, timeframes, domains, and mileage.

Emerging mobility technologies are elevating the potential for the creation of such a system of services that enable full urban mobility to a new high. Should such a system fully materialize and scale, and should it do so in a timeframe consistent with emerging mobility technologies' current rates of adoption, the change to society as a whole will make the predicted changes to any single industry, such as that of the automobile over the next ten years, pale in comparison.

INTRODUCTION

The development and use of mobility technologies and systems revolutionized society. No longer did people need to live in the immediate vicinity of jobs, families, and recreational areas in order to access them. Instead, they could leverage technologies to conveniently travel to these and other destinations while living in more affordable or desirable areas.

In the early days, mobility was enabled by horses, which in time gave way to streetcars, trolleys, and personal automobiles. For the most part, this system worked. Roads were built out, vehicles became increasingly affordable, and a culture of transnational freedom emerged that was embodied by the romantic ideal of personally owned automobiles traveling anywhere at anytime on wide-open highways.

Yet over time, cultural norms, societal investments, and public policies focused this system on the personal automobile, to the exclusion of others, and grew it to the breaking point. Congestion, expense, inefficiency, and mortality were more or less institutionalized. In 2014, urban commuters collectively wasted 6.9 billion hours and 3.1 billion gallons of fuel due to traffic delays. Excess fuel and lost productivity cost them $160 billion in 2014, up from $114 billion in 2000, and $42 billion in 1982.[1] Drivers are averaging 335 hours in the car each year,[2] their search for parking alone costs them $73 billion per year[3], and motor vehicle fatalities totaled over 37,000 in 2017 alone.[4]

The urgent need to alleviate these and other problems brought about by the current mobility paradigm is prompting its rapid evolution. This evolution, which some are saying will yield "more change in the next 10 years than in the last 50," is driven by the advance of technologies that enable electrified, connected and automated vehicles of various shapes, sizes, and functionalities. When combined with new travel modes and business models – first and foremost among them being shared mobility, which orients users around the procurement of services rather than the acquisition of assets – these technologies have the potential to (and in some cases are already delivering) the flexibility and versatility offered by personally owned and driven automobiles, yet at lower personal and societal costs.

THE AUTOMOBILE, ROADWAYS, AND 20TH CENTURY MOBILITY

For the past 100 years, much of society in the United States and many other parts of the world has been organized around the personal automobile. In many ways, it has come to define what, where, and how we live. In its earliest days it was transformative, reshaping lives, laws, and the land as people embraced the "horseless carriage" and its descendants.

Ironically, it was the popularity of bicycles – and, specifically, the innovators behind them – that first sparked the revolution in transportation in the 20th century and led to the need for paved roads and the interstate highway system.[5] In 1893 in Springfield, Mass., bicycle mechanics Charles and Frank Duryea built the first gasoline-powered "motor wagon" to be operated in the United States. They formed the first company to manufacture and sell gasoline-powered vehicles, although they sold very few. The same year, the Office of Road Inquiry (ORI) within the

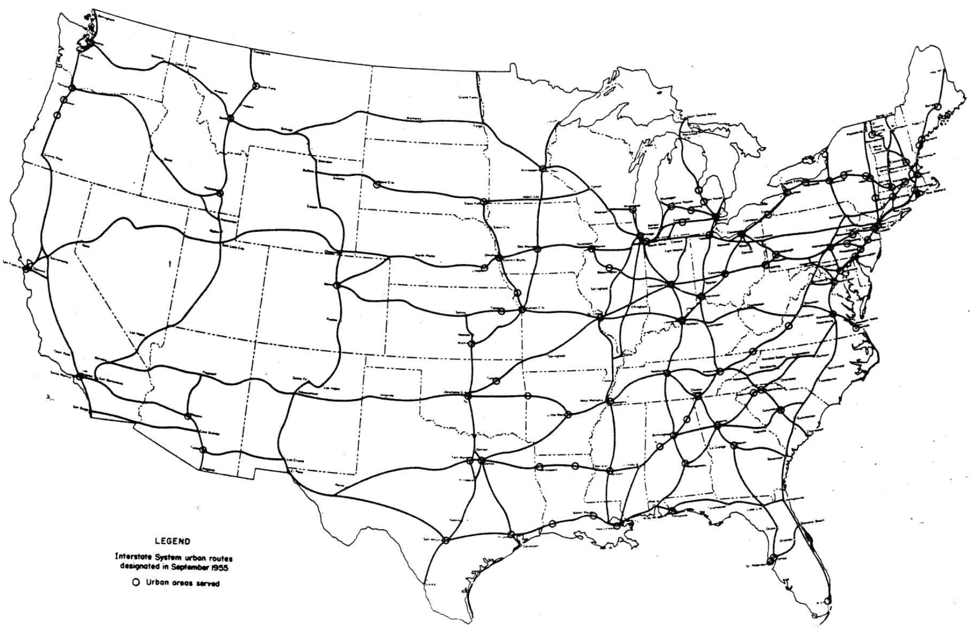
Department of Agriculture was established to promote new rural road development, which at that time were made mostly of dirt.[6]

The push to make and pave roads received a shot of adrenaline in 1908 when Henry Ford began mass-producing and selling the Model T. His competitors followed shortly thereafter and built cars for the broader public. The increasing numbers of Americans behind the wheel began lobbying for paved roads with the slogan, "Get the farmers out of the mud!" As a result, the Federal-Aid Road Act of 1916 created the Federal-Aid Highway Program, which funded state highway agencies' abilities to make road improvements.[7]

After the end of World War I, the Federal Highway Act of 1921 transformed the ORI into the Bureau of Public Roads and provided funding for state highway agencies to construct paved two-lane interstate systems. These road projects benefited from Depression-era job creation programs during the 1930s, as well as military needs and associated spending to support the transport of troops and materials during World War II.

Yet it wasn't until President Dwight D. Eisenhower signed the Federal-Aid Highway Act of 1956 that the modern interstate system was truly born. The bill authorized and provided $26 billion (approximately $241 billion in 2018 dollars) for the construction of a 41,000-mile "National System of Interstate and Defense Highways" that would, according to Eisenhower, eliminate unsafe roads, inefficient routes, traffic jams and all of the other things that got in the way of "speedy, safe transcontinental travel." A 1955 Department of Commerce "yellow book" outlined the vision for the Interstate Highway System, including a national map of routes (see Figure 1).[8] All told, the Interstate Highway System is approximately 48,000 miles long.[9]

Figure 1: Planned "National System of Interstate Highways" (1955)



Source: Public Roads Administration, Federal Works Agency

When the Interstate Highway Act was first passed, most Americans supported it. At its beginning, the interstate system offered unprecedented access, freedom, and mobility. Soon, however, the unpleasant consequences of rapid, large-scale roadway construction began to show. Most unpleasant of all was the damage the roads inflicted on the city neighborhoods in their path. They displaced people from their homes, sliced communities in half, and led to abandonment and decay.[10]

In fact, highways were *intentionally* divisive. During the New Deal activities of the early 1930s, the federal government sought to use new spending efforts to help alleviate a housing shortage. Yet to secure this new funding, compromises were made with segregationist legislators that led to the codification of segregation in housing policies. In 1934, the Federal Housing Administration (FHA) was established and undertook actions to further segregation by refusing to insure mortgages in and near African American neighborhoods. It also published its Underwriting Manual, which spelled out its segregationist principles and recommendations. In stating that "incompatible racial groups should not be permitted to live in the same communities," the Underwriting Manual recommended using highways to separate African American from white neighborhoods.[11] This recommendation led to a long-standing – and wildly successful – federal regulatory approach that divided communities, fostered racial divisions, and helped create ghettos and pockets of poverty that have endured through the present day.

Beyond racism, key forces that pushed for the buildout of the Interstate Highway System included a mix of self-interested industry groups, design choices made by people far away, and a lack of municipal foresight.[12] The net result of the interstate's buildout is that it helped to cement the century's framework for mobility solely in terms of roadways and vehicles. Across the country, cities scrapped plans for rail and other fixed transit systems in favor of roadways. For instance, while Los Angeles had the country's best public streetcar system around the 1920s, a combination of the automobile's popularity; urban gridlock that caused streetcars to miss their schedules; artificially low fares;[13] and actions by a consortium of auto, oil, tire, and truck companies[14] prompted not just the shutdown of the system by 1962, but the near complete removal of its infrastructure.[15] Instead urban, and especially suburban, areas nationwide were built around roadways and thus became highly dependent on personal automobiles.

Over time, additional consequences of roadway dependence emerged. The idyllic picture that Eisenhower painted at the system's beginning has now become one that contributes to a broader car-based ecosystem that sees over 37,000 roadway fatalities annually,[16] more than 3 billion gallons of wasted fuel, nearly 7 billion extra hours (42 hours per rush-hour commuter), and $160 billion spent ($960 per commuter) annually due to traffic congestion.[17]

Additionally, increasing financial resources were allocated to provide for car-based mobility that dwarfs the Interstate Highway Act's original allocation. Such a statement doesn't just take into account direct expenditures, such as the $165 billion spent in 2014 on highways, roads, bridges and tunnels,[18] but also the supporting infrastructure, such as the $5,000 to $50,000 spent to construct each one of the 744 million to more than 2 billion parking spaces in the U.S., more than $100 billion a year in what amounts to subsidies for "free" parking,[19] and between $4 billion and $20 billion spent each year to maintain this infrastructure.[20]

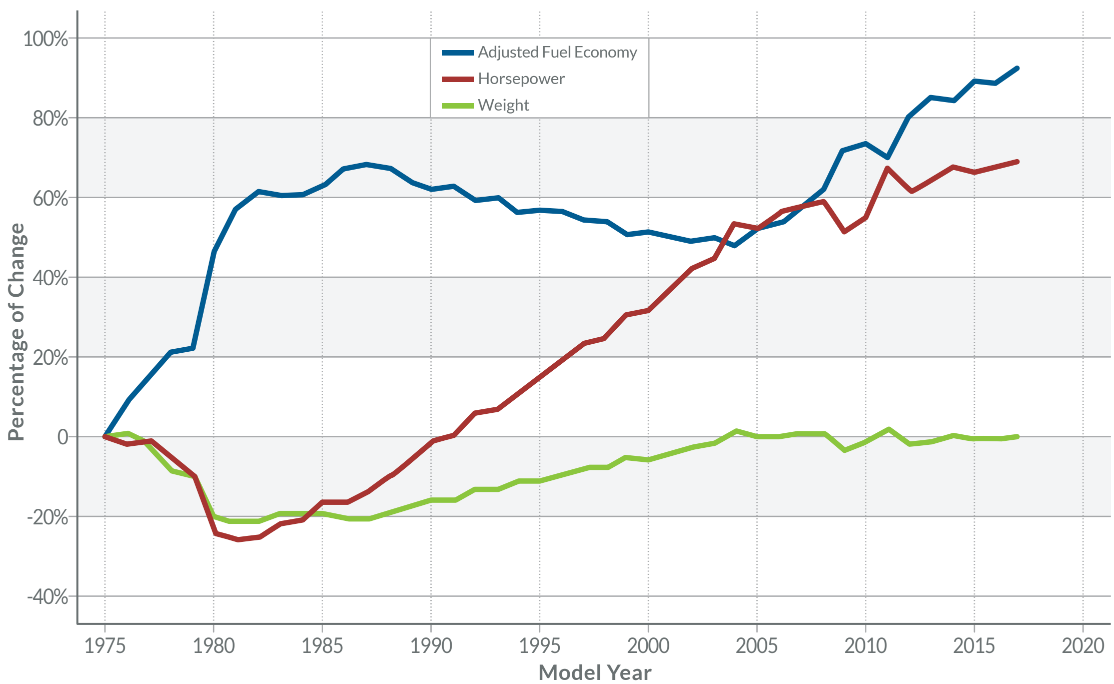
The modern amount spent on building and maintaining reflects the fact that the mobility paradigm in the United States hasn't changed much in the past hundred years. This isn't to say that technology hasn't advanced. On the contrary, vehicular technology is radically more advanced than it was just a few decades ago, not to mention at its origins. Figure 2 illustrates this advancement by showing how automakers have nearly doubled average fuel economy over the past 30 years while maintaining vehicular weight, and that this advancement of fuel economy has come along with – rather than at a cost to – similarly increased horsepower.

Yet the fact remains that, just like their counterparts at the beginning of the 20th century, automobiles today are for the most part powered by internal combustion engines that burn gasoline, are operated entirely by humans who own the vehicle and are the vehicle's only occupant, and serve as the operator's dominant mode of travel.

'MORE CHANGE IN THE NEXT 10 YEARS THAN IN THE LAST 50'

Recently, and particularly over the past decade, transportation technologies have advanced to the point where companies and society are able to consider and embrace forms of mobility at a scale previously unimaginable in the U.S. These technological advancements are occurring at such a rapid pace that auto industry executives, such as General Motors Chairman and CEO

Figure 2: Percent Changes in Fleet Average Fuel Economy, Horsepower, and Weight Over Time



Source: U.S. Department of Energy

At its core, the advancement of mobility technologies is occurring in three separate categories:

1. Electrification
2. Connectivity and automation
3. Shared mobility

Mary Barra, are predicting "…the auto industry will change more in the next five to 10 years than it has in the last 50."[21] Already, more than 50 percent of orders received by Tier 1 automotive supplier Valeo in 2018 were for products that didn't exist five years ago.[22]

Yet prospective change applies to factors and issues beyond the auto industry itself, a reality that isn't included in predictions such as the former. In fact, the advancement and large scale adoption of emerging mobility technologies and systems can help drive broader societal changes that make the changes to the auto industry pale in comparison. This might even include the alleviation of the societal shortcomings imposed by the large-scale roadway and interstate system buildout that were discussed in the previous section, for as the size and cost of modes decrease, widespread mobility increases and the need for large-scale roadways decreases.

Many are projecting that these transformations will yield what are in many cases significant economic benefits. As important, many of these benefits won't necessarily be localized to a particular industry, but instead can be broadly societal. For instance, the World Economic Forum projects that the digital transformation of the auto industry can deliver $670 billion of value to automotive players and a further $3.1 trillion of overall societal benefits through 2025 by reducing the number of crashes, the impact of carbon emissions and the cost of car ownership, including maintenance, fuel and insurance.[23]

At its core, the advancement of mobility technologies is occurring in three separate categories:

1. Electrification
2. Connectivity and automation
3. Shared mobility

The disruption taking place in each of these three categories is collectively creating concurrent and converging trends that, once fully scaled, might prompt changes in the 21st century that dwarf those prompted by the automobile in the 20th century.

ELECTRIFIED VEHICLES

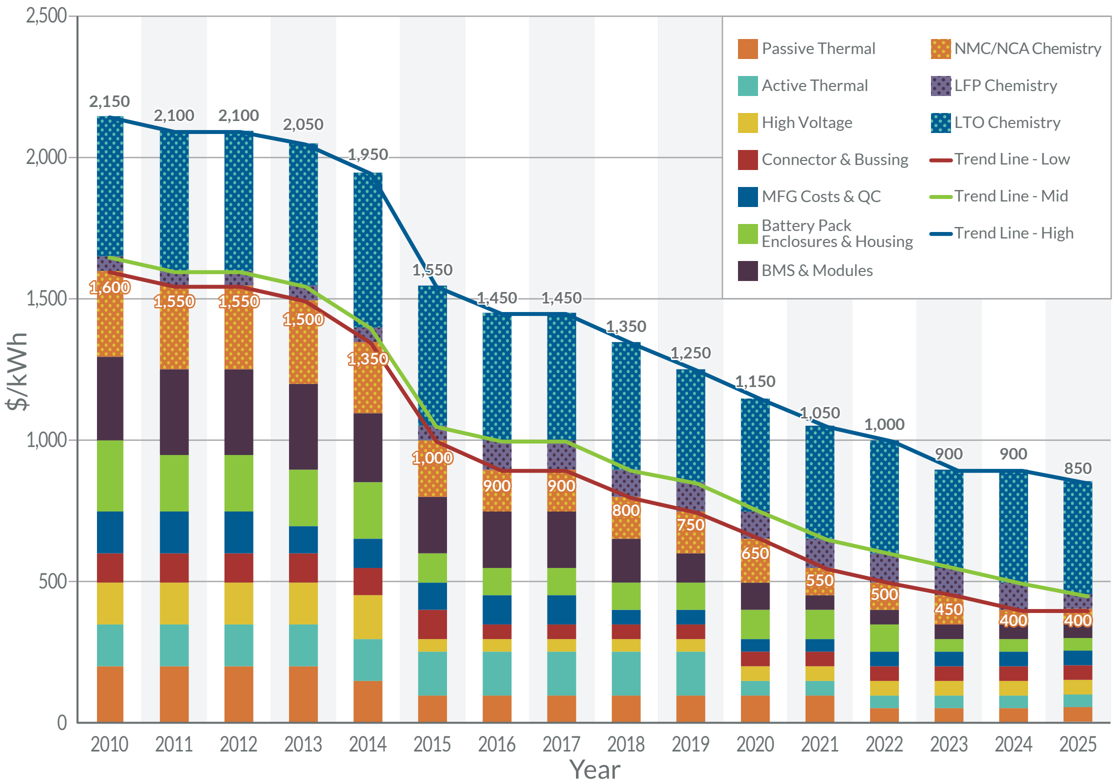
The term "electrified vehicles" refers to a range of technologies that use electricity to propel a vehicle:[24]

- ***Hybrid Electric Vehicles (HEVs)*** obtain all net propulsion energy from petroleum but use an electrical system to improve fuel efficiency.
- ***Plug-in Hybrid Electric Vehicles (PHEVs)*** store energy from the electric power grid and can drive partly using electricity and partly using petroleum. "Blended PHEVs" use a mix of gasoline and electricity when the battery is charged and then switch entirely to gasoline when the battery is depleted, while "Extended Range Electric Vehicles" (EREVs) are PHEVs that use only electricity when the battery is charged and switch to gasoline when the battery is discharged.

- ***Battery Electric Vehicles (BEVs)*** have larger battery packs to store more energy from the electric power grid for longer range. They have no backup gasoline engine. BEVs are also referred to by some as “pure-electric vehicles” or “all-electric vehicles” (AEVs).
- ***Fuel Cell Electric Vehicles (FCEV)*** refuel with hydrogen, methanol, or a carrier of one or the other and use a fuel cell to produce electricity to propel the vehicle. FCEVs are also referred to as fuel cell vehicles or FCVs.

While the automotive industry has been at the forefront of energy storage technologies for over a century (i.e., 1912 Cadillac with electric starter and battery),[25] and while the 1990s saw the first real attempts by OEMs to market and sell BEVs in the U.S., it was the last fifteen years that saw the bulk of public acceptance and market growth.[26] The Honda Insight and Toyota Prius were the first HEVs introduced to U.S. consumers in the late 1990s. By 2012, the Prius had outsold all other new cars in California, the country’s largest vehicle market.[27] Other HEVs followed, providing large

Figure 3: ESN Price Forecast for Full Battery Systems, 2010-2025



Assumptions and Disclaimers:

1. Individual component costs (i.e., thermal, BMS, connector and bussing, etc.) are not precise estimates, but reflect an approximate percentage of the total system cost.
2. Pricing of raw materials for NCM and NCA chemistries is fairly similar, so their pricing is combined in this report.

Source: ESN Energy Storage Roadmap Report, 2017 subsets of motorists with their first experiences driving electrified vehicles.

One of the major roadblocks to BEV development and market acceptance was limited vehicle range due to the use of lead acid or nickel metal hydride (NiMH) batteries in early BEVs and HEVs. Higher density, affordable battery technologies that could offer sufficient vehicular range weren't commercially available. That changed with the commercial introduction of lithium-ion (Li-ion) batteries less than 30 years ago, their widespread market adoption in personal electronics markets and (more recently) vehicular markets, and their incremental yet continual technological advancement – particularly over the past decade.

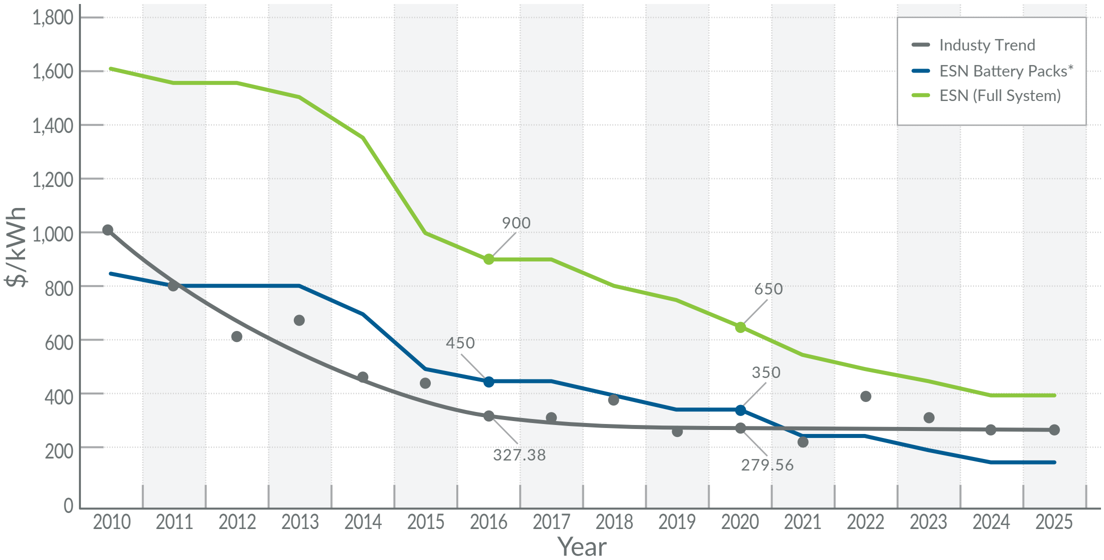
With the advent of Li-ion technology, and the increased electrification of the automobile (from 400 Watts in 1912 to over 100 kW today), the automotive industry collectively has invested over $10 billion in the safety, performance, durability, and warranty targets of Li-ion technology. These factors prompted the price of lithium-ion battery packs for transportation applications to decline. A September 2017 analysis by ESN of energy storage technologies, economics and pricing chronicled the rapid decline in full (primarily automotive) battery system prices and forecasted continued annual declines far into the future, as illustrated in Figure 3.[28]

Comparing the ESN trend line to the average trend line from eight other independent research and market studies reveals a much higher cost for a true energy storage system then what is commonly reported in most market studies. However, most market studies only consider a battery pack to include the lowest cost chemistries and a subset of the true balance-of-system components. Furthermore, battery pack pricing and estimates in the automotive market often only include cells, while other industries include modules and battery management systems (BMS), but rarely include enclosure costs and other balance-of-system components. Therefore, ESN developed a second trend line that represents more of an "apples-to-apples" comparison, which is much closer to the average trend line of the eight industry reports, as shown in Figure 4.[29]

As battery pack prices come down, vehicle demand goes up, for battery price is inversely correlated with electric vehicle affordability and consumer demand. Cumulative sales of EVs, including battery electric vehicles and plug-in hybrid electric vehicles, reached 1.2 million worldwide in 2015, surpassed 2 million vehicles in 2016, and crossed over 3 million as of February 2017.[30] Accordingly, automakers are expected to invest at least $90 billion over the coming years to electrify their lineups,[31] and Bloomberg projects that nearly eight out of every 10 batteries sold will be in an electric vehicle by 2030.[32]

To meet this added and projected demand, battery manufacturing capacity is increasing. As of February 2018, global battery manufacturing capacity reached about 110 gigawatt hours (GWh) a year, mostly for consumer electronics, electric vehicles and electricity storage. Recently, China has announced plans to add more than 150 GWh of production by 2021 or 2022, tripling its current capacity. Such an increase would dwarf Tesla's "gigafactory" in Nevada, which is often cited as an extreme case of increased capacity, but whose projected additions amount to 35 GWh by 2020.[33] Benchmark Mineral Intelligence

Figure 4: Comparison of Industry and ESN Battery Pack Price Forecasts, 2010-2025



Assumptions and Disclaimers:

1. The Industry trend line represents an approximation of pricing trends averaged across all previously mentioned market studies.
2. "ESN Battery Packs" pricing includes approximate pricing (based on approximate percentage of total system cost) for cells (NMC/NCA chemistry), BMS and modules, battery pack enclosures and housing only.
3. "ESN Full System" trend line represents all system costs as represented in Figure 5.

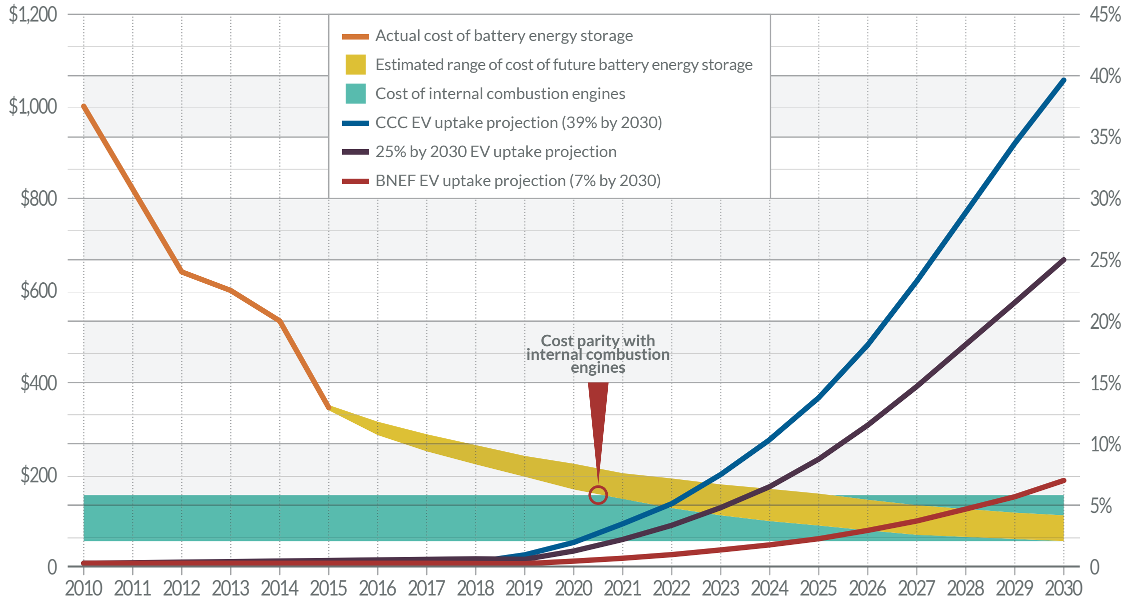
Source: ESN Energy Storage Roadmap Report, 2017

forecasts a 399 percent increase in Li-ion battery production capacity by 2028, which is enough to surpass 1 TWh in total capacity.[34]

While this growth is meaningful, electric vehicles still only represent less than 1 percent of vehicles in use globally.[35] The continual reduction in battery prices will be one of the primary drivers in prompting this number to grow, given that analyses peg BEVs and PHEVs as respectively costing almost $9,000 and $5,700 more to build than conventional cars,[36] with the battery accounting for 40 percent of the cost of building a BEV.[37] As battery prices come down, electrified vehicles can become as affordable as those powered by internal combustion engines (ICEs) and/or increase their battery capacities to increase vehicle range and, in turn, consumer demand. Figure 5 illustrates how the price of vehicular battery storage systems are rapidly approaching price parity with ICEs and that, once this happens, the sales volume of EVs are projected to grow exponentially.

In addition to battery costs and performance, some also cite infrastructure as a barrier to electric vehicle uptake. There are a relatively low number of charging stations for electric vehicles as compared to gas stations for conventional cars – 20,000 vs. 125,000, respectively.[38] To build out what it deems to be sufficient capacity, McKinsey predicts that major economies (i.e., those of China, Europe, India, and the U.S.) will need to invest $55 billion in charging infrastructure by 2031 to support what it

Figure 5: EV Battery Tech and ICE Commercial Parity vs. EV Uptake Projections



Source: www.rolton.com/EV

predicts will be the 140 million electric vehicles that will be on the road by then.[39] Goldman Sachs estimates that $6 trillion – or about 7.5 to 8 percent of the world's gross domestic product – is theoretically needed to fully build out electric vehicle infrastructure.[40] However, these comparisons and calculations could be misleading, for battery and ICE technologies' respective refueling models are different.

There are three major categories of chargers, based on the maximum amount of power the charger provides to the battery from the grid:[41]

- ***Level 1:*** Provides charging through a 120V AC plug and does not require installation of additional charging equipment. It can deliver two to five miles of range per hour of charging, is most often used in homes, and sometimes at workplaces.
- ***Level 2:*** Provides charging through a 240V (for residential) or 208V (for commercial) plug. It may require installation of additional charging equipment, but could also be tapped by plugging into washer/dryer power outlets common in U.S. homes' garages using the power cords that come with most electric vehicles. It can deliver 10 to 20 miles of range per hour of charging, and is frequently used in homes, workplaces, and in public locations.
- ***Level 3:*** Provides DC fast charging through 480V (or more) AC input and requires highly specialized, high-powered equipment as well as special equipment in the vehicle itself. It can deliver 60 to 80 miles of range (or more) in 20 minutes (or less) of charging, and is used most often in public charging stations, especially along heavy traffic

corridors. Current Level 3 standards include CHAdeMO, which is favored by Asian automakers; Combined Charging System (CCS), which is favored by U.S. and European OEMs; and Tesla's Supercharger.

Out of these three charging categories, the recharging scenario implied by Level 3 is the only one that comes close to resembling the one embodied by refueling a conventional car. The others – Levels 1 and 2 – afford drivers the ability to charge at home overnight or during other vehicular downtimes, thus enabling them to hit the road and, in the most common scenarios, drive throughout the day without needing to recharge. Therefore, it may not be that the number of public charging stations for electric vehicles needs to meet or exceed the number of gas stations for conventional cars.

Regardless of where they're charged, integration of EVs should play a sizeable role in electric system planning, given the projected load demands. Research from the California Energy Commission estimates that EVs could prompt peak demand to rise by 1 gigawatt (GW) by 2025.[42] Another analysis puts electricity use from light duty vehicle transport in the 570–1,140 terawatt hours (TWh) range, or between 13 and 26 percent, respectively, of total U.S. electricity demand in 2050.[43] According to the National Renewable Energy Laboratory (NREL), an electric vehicle market share of up to 3 percent (about 7.5 million EVs) would not significantly impact aggregate residential power demand. But for some utilities, any increase in projected load would be welcome news; given sustained periods of flat or even negative grid growth, new demand from EVs could offset these historic declines. That said, even having a couple of electric vehicles in the same neighborhood could make delivering that power a challenge. Distribution transformers may need to be sized up and replaced more frequently, and peak demand will be an issue in some areas, NREL's report concluded. Managing that demand will be essential, and is one of the key capabilities EVs will bring to utilities.[44]

Such planning is important, given that the transition to an electrified fleet seems well underway. Ford Motor Company has committed to spend $11 billion on product development that includes a Mustang-inspired crossover EV due in 2020, with plans to have 40 hybrids and EVs on the market by 2022. General Motors (GM) plans for more than 20 EVs globally by 2023, and Nissan plans to launch eight new EVs by early 2023 and to electrify most of Infiniti's lineup starting in 2021. Altogether, automakers have announced plans to bring more than 60 electric and plug-in hybrid models to market through 2020, and 100 through 2022.[45] Worldwide, established and startup automakers are spending $255 billion to develop more than 200 new electric models that are expected to hit the market by 2022.[46]

With such plans in place, it could be that plug-in electric vehicles sales account for as much as 20 percent of the U.S. market in 2030[47] and comprise 26 percent of the light-duty vehicle stock in 2040.[48] Another analysis indicates a good chance that the electric car stock will range between 9 million and 20 million by 2020, and between 40 million and 70 million by 2025.[49] Electric vehicles will account for 28 percent of global light-duty vehicle sales sometime shortly after 2025, according to Bloomberg New Energy Finance (BNEF),[50] and Bank of America analysts forecast they will account for 34 percent of global vehicle sales by 2030.[51]

CONNECTED AND AUTOMATED VEHICLES

While connected vehicles (CVs) and automated vehicles (AVs) are often discussed separately, their projected convergence over the coming decade – as highly-automated vehicles (HAVs) will depend on connectivity for full functionality – leads us to cover connected and automated vehicles (CAVs) as one unifying platform comprised of two distinct components and functionalities.

CAVs have received a fair amount of attention in recent years, perhaps due to their departure from the norms of automobile operation, the way in which thoughts of pilotless cars roaming the streets stoke the imagination, and the underlying materialization of what was once science fiction they represent. As important is the frenetic level of activity undertaken by various parts of society to explore and advance the technology. While not that long ago, reference to self-driving cars would often engender a response referencing Google's research and development activities, Table 1 notes the sheer volume of companies, vehicle manufacturers, deployments, universities, and investors that are actively working with CAVs.

Table 1: Quantities of Select CAV Interests

CAV Interests	Quantities
Companies	722
Vehicle Manufacturers	114
Regional Efforts, Proving Grounds, and Demonstrations	210
Universities and Institutes	168
Investors	336

Source: Peak Strategy Partners, LLC

Connected Vehicles

Virtually every aspect of society is becoming connected via the Internet, Bluetooth, and/or other protocols. From the ubiquity of the smartphone – which affords fast and ever-present Internet connectivity within one's own pocket – to home appliances, entertainment systems, security systems, exercise equipment, jewelry, and virtually every other component that can be equipped with the sort of small and cheap sensors and transceivers that have become common over the past 10 years, the trend towards connectivity is well established and increasing. With connectivity comes a plethora of features and services that consumers are demanding.

In this regard, vehicles are no different. CVs are those that are enabled for standardized communication between vehicles or with the roadside, to enable driver assistance applications for the purposes of safety, traffic efficiency, reduced fuel consumption or reduced emissions. Wireless vehicular communications include:

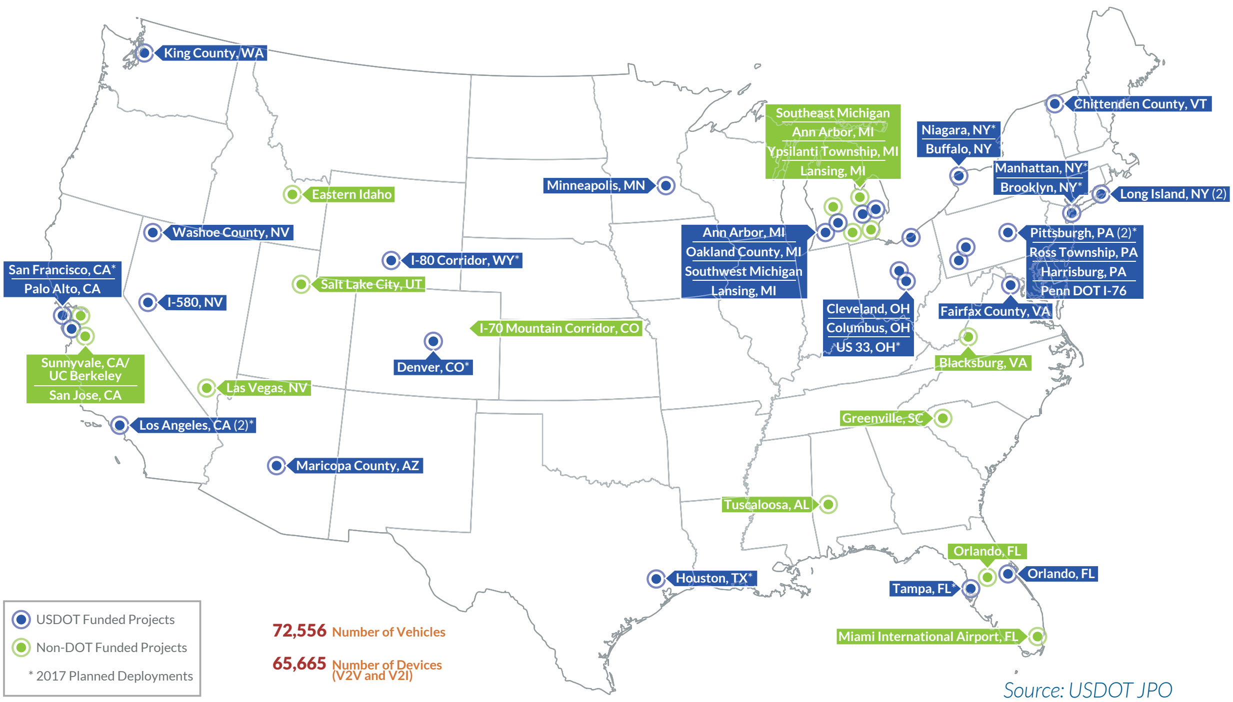
- ***Vehicle-to-Vehicle (V2V)***, which reflects an ability to wirelessly exchange information between vehicles about each one's speed and position in order to avoid crashes, ease traffic congestion, and improve the environment, among other objectives;[52]
- ***Vehicle-to-Infrastructure (V2I)***, which wirelessly captures vehicle-generated traffic data and provides information such as advisories from the infrastructure to the vehicle that inform the driver of safety, mobility, or environment-related conditions, among others;[53]

- ***Vehicle-to-Everything (V2X)***, which connects all road devices (motor vehicle, non-motor-vehicle, bicycle, pedestrian, etc.) and shares real-time information (speed, accelerate, route, etc.) among them for automatic piloting and intelligent traffic control.[54]

The move towards vehicular connectivity began over a decade ago with a focus on the development and advancement of the 5.9 gigahertz (GHz) dedicated short-range communication (DSRC) wireless regime. Comprised of on-board units (OBUs) that reside within the vehicle and transmit and receive a basic safety message (BSM), as well as roadside units (RSUs) that are mounted primarily on intersection infrastructure to receive and transmit BSMs and signal phase and timing (SPAT) data, DSRC establishes a simple yet effective safety system that enables vehicles to "see" each other even when their human drivers can't – and potentially address up to 80 percent of serious crashes.[55] Scenarios where DSRC can prove especially effective include when vehicles are making blind left turns at intersections and assistance with avoiding red light violation accidents.

DSRC has significant real-world experience, with perhaps the most prominent pilot project being the Ann Arbor Connected Vehicle Test Environment (formerly Safety Pilot). The University of Michigan (U-M) has operated this pilot since 2012 with the world's largest contingent of DSRC-connected cars, trucks and buses.[56] Yet as Figure 6 illustrates, DSRC pilot deployments are located throughout the country, and involve over 70,000 total vehicles (as of 2017):

Figure 6: Connected Vehicle (DSRC) Deployments Across The U.S. (2017)



Source: USDOT JPO

The challenge with DSRC is that it poses a typical chicken-and-egg scenario, in that the effectiveness of equipping any one vehicle with an OBU depends on the widespread inclusion of OBUs and RSUs within other vehicles and intersections, respectively. While individual OBUs and RSUs aren't inordinately expensive on their own, the aggregate cost to any single manufacturer or municipality of equipping entire fleets and intersections with equipment can be significant. This, along with the fact that benefits won't be realized unless a sufficient number of others follow suit, serves to dissuade early adopters.

Some automakers have taken initiative by announcing plans to advance DSRC. Toyota Motor Corporation, with nearly 2.5 million vehicle sales per year, is the third-largest seller of vehicles in the U.S. and has announced plans to include DSRC OBUs in vehicles sold in the U.S. starting in 2021 with the goal of inclusion across most of its lineup by the mid-2020s.[57] The company already has more than 100,000 DSRC-equipped cars are on the road in Japan.[58] Volkswagen is working with Siemens to deploy DSRC in Volkswagen Group vehicles in Europe starting in 2019. GM started deploying DSRC-enabled vehicles in the U.S. with its 2017 Cadillac CTS sedans, and will build upon this by equipping high-volume Cadillac crossover vehicles with DSRC by 2023 and the entire Cadillac portfolio following after that.[59] In October 2018, Honda partnered with the city of Marysville, Ohio to demonstrate and deploy a "Smart Intersection" whereby four cameras mounted above the traffic lights capture bird's-eye-view video of surrounding vehicles and pedestrian traffic. Honda's image processing software then creates a 360-degree image of the intersection that classifies vehicles and other moving objects and broadcasts pertinent information to 200 DSRC-equipped vehicles.[60] It remains to be seen whether individual OEMs' efforts such as these are sufficient to prompt broad-based DSRC OBU and RSU deployments among other OEMs and regions.

Meanwhile, alternate connected vehicle regimes have advanced and are gaining prominence. These alternate regimes, which include cellular V2X (C-V2X) and the fifth generation of cellular mobile communications (5G), have an advantage over DSRC in that their advancement is furthered by multiple markets rather than exclusively by automotive safety and management. The ubiquity of cellular networks offering 4G (LTE/WiMax) came about as a result of consumers' growing demand for bandwidth to better enable smartphone features such as high-definition video streaming, with the serendipitous byproduct being the establishment of a platform and infrastructure that has the potential to fully achieve the V2X requirements of and efficiently pave the way to connected and automated driving.[61]

The same will be true, at least in part, for 5G, which has the potential to enable consumers of entertainment to reduce the amount of time it takes to download a high-definition video from ten minutes via the current 4G LTE network to under a second.[62] 5G is comprised of a suite of new technologies, including include millimeter waves, small cells, massive MIMO, full duplex, and beamforming.

5G is advancing not only because of smartphone users' needs to download larger files faster, but also because of the forthcoming commercialization of a broad array of connected electronics, as previously discussed.

5G standard as defined by the International Telecommunication Union[63]

>10 GB/s peak data rates for the enhanced mobile broadband (eMBB)

>1M devices/km^2 for massive machine-type communications (MMTC)

<1 ms latency for ultra-reliable low-latency communication (URLLC)

Counted among those drivers are automotive uses that don't pertain to safety or management. For instance, in future scenarios whereby highly-automated vehicles (HAVs) chauffer passengers who have newfound idle time as their requirement to control the vehicles decreases, in-vehicle streaming entertainment will become increasingly prominent and diverse. With its ability to deliver data with less than a millisecond of delay (compared to about 70 ms on today's 4G networks) and bring peak download speeds of 20 GB/s (compared to 1 GB/s on 4G) to users, 5G has the potential to enable every vehicle to become a rolling entertainment venue, while also satisfying its broader V2X needs. Researchers have already demonstrated the ability to use a 5G frequency to send data at speeds of up to 2.867 GB/s to a connected vehicle, which is almost 40 times faster than speeds achieved with fixed line broadband.[64]

AT&T began introducing 5G in 12 U.S. cities in 2018. In August 2018, it announced that it would equip a community in Texas with 5G to enable pilot programs with the ultimate goal of creating a synchronized urban transportation network. Verizon has similar commercialization efforts under way, focused on providing home broadband via 5G. Both companies caution that these initial deployments won't include V2X communication applications, and that the network speeds consumers experience will differ from what is theoretically possible, given that the first iterations of 5G to reach consumers likely won't be "true 5G" but instead be more of an expansion of 4G LTE.[65]

With such a market-driven advantage and existing commercial pursuits, it's easy to conclude that 5G will be the "winner" in the race to connect cars. Yet the challenges to commercializing 5G are formidable, including fully defining what 5G comprises, establishing connections to billions of Internet of Things (IoT) devices, distributing information over millimeter-wave bands, and overcoming geographical disparities in Internet access that leaves a substantial portion of the world unconnected.

Clarity on the federal government's 5G policies is also nascent. The Commerce Department is developing a long-term comprehensive national spectrum strategy that is expected by July 2019 to prepare for the introduction of next-generation 5G wireless networks. While the goal is to ensure there is enough spectrum to handle the growing amount of Internet and wireless traffic and that future faster 5G networks have adequate spectrum, it's unclear to what degree this strategy will advance (or hinder) 5G beyond existing commercial pursuits.[66]

Perhaps 5G's biggest challenges are location and cost. While 4G towers can deliver service for up to 10 miles, true 5G waves can only deliver service up to 1,000 feet. 5G waves also can have difficulty penetrating walls and windows, and could even be hindered by leaves on trees. While carriers say the solution to those problems is more cell towers, overcoming these wavelength challenges would require thousands of new towers, which can be a very expensive proposition.[67] The wireless communications industry forecasts that building nationwide 5G networks will require 300,000 new cell sites to be erected by 2020. That is about double the approximately 150,000 cell towers in existence today, a number that took over 35 years to reach.[68] The timing of such a large investment could be daunting considering that some, including the "ComSenTer" academic research effort,[69] are already considering and preparing for 6G networks.

Thus, while the tendency is to position DSRC and 5G as competing platforms, of which one market winner will emerge, it could be that the fully-realized future of connected vehicles sees the two technologies working together, with DSRC offering essential safety features – for which some have argued it's best suited[70] – and 5G offering connectivity for entertainment and services, as well as a degree of redundancy. In fact, one model indicates that an approach that synthesizes DSRC with C-V2X (and by implication 5G, once it's available) achieves all V2X use cases today, is simpler, and more affordable.[71]

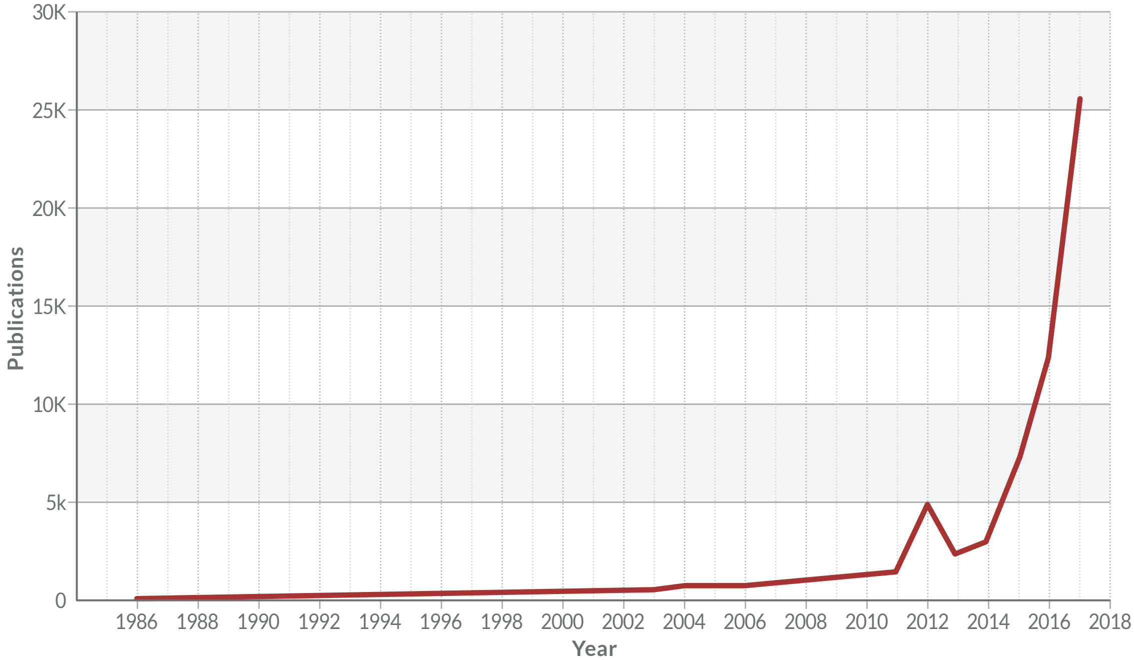
Automated Vehicles

Connectivity matters not just in that it can save lives and stream services today, but also in that it can pave the way for higher levels of automated vehicles in the future. Vehicle automation is enabled by a combination of software and hardware. Software tends to be oriented around developing two categories of artificial intelligence (AI) for vehicular control: machine learning and deep learning. Machine learning occurs when machine algorithms use statistics to find patterns in large datasets. Deep learning, which is a subset of machine learning that has received increased interest in recent years (see Figure 7), occurs when artificial neural networks – algorithms inspired by the human brain's structure and function – learn from (and in essence, write) their own programming based on large amounts of data.[72] Another primary category of software development involves localization, which determines a vehicle's location based upon high-definition mapping, precision GPS, and other strategies.

Automated vehicle hardware, on the other hand, is primarily comprised of an array of sensors. Connectivity – whether it's DSRC, C-V2X, or 5G – could be viewed as one such example that enables vehicles to "see" around corners and otherwise coordinate in ways that line-of-sight sensors cannot. Other examples of automated vehicle sensors include:

Ultrasonic: Ultrasonic sensors determine locations of objects by sending out sound waves, then collecting and processing their reverberations after they impact nearby objects. Ultrasonic are perhaps the most refined and commercial of the various sensors related to automation, given their longstanding use in numerous industries and current widespread application in conventional automobiles to enable features such as parking assist. They are also perhaps the least crucial to the AV sensor suite, for their short (i.e., ~2 meter) range means they're only used at low speeds.

Figure 7: Recent Rise in Deep Learning Research



Source: Dimensions

Radar: Radio Detection And Ranging, or radar, uses radio waves to detect and localize objects. In wide use for decades in diverse industries and applications ranging from meteorology to air traffic control, radar sensors have become common in vehicle applications in recent years. Their prices have decreased and vehicular features that rely on radar such as Automatic Emergency Braking (AEB) and blind spot detection have increased. A combination of short-range radar (SRR) and mid/long-range radar (MRR/LRR) sensors are placed throughout a vehicle's perimeter to gather unfiltered information about surrounding objects of various distances, all of which is fed to the vehicle's central computer for processing and integration into its decision-making.

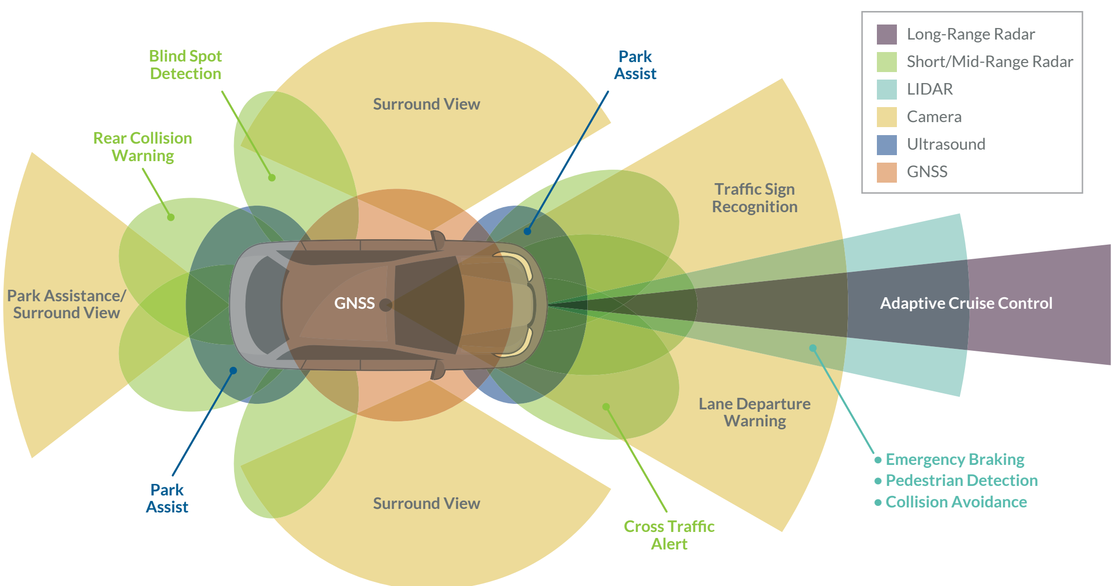
Optical: Cameras can be a very efficient and cost effective tool for helping automated vehicles classify and interpret their surroundings. They're widely available and significantly cheaper than other types of sensors, such as radar and lidar. Cameras' challenges and shortcomings include dealing with bad weather and the algorithmically complex computing required to process their data, thus potentially driving up systematic costs elsewhere.

Lidar: Light Detection And Ranging, or lidar, is comprised of a laser transmitter and a highly sensitive receiver. Lidar systems transmit beams of lights and then measure the returning signals when the light reflects off of an object to establish precise and detailed geospatial information about a vehicle's surroundings. Lidar is similar to radar, but can have a higher resolution, since the wavelength of light is about 100,000 times smaller than radio wavelengths, and thereby can establish detailed three-dimensional representations. Such representations are no doubt valuable to automated vehicles' efforts to understand their surroundings, but have sizeable drawbacks, first and foremost being cost. While initial vehicular mechanical lidar systems could cost around $75,000 or more, BNEF projects that demand from Waymo, Uber, General Motors and Mercedes-Benz is expected to lower the cost.[73] In recent years, newer solid-state sensors have emerged that are targeting price points of a couple hundred dollars. Still, given that most automated vehicle developers employ multiple lidars per vehicle, developers are continually working to lower costs. Additional current efforts include improving lidar's range, poor weather performance, velocity data, and ability to be physically integrated so as not to impair vehicles' aesthetics.

Global Navigation Satellite System (GNSS): GNSS is a general term describing any satellite constellation that provides positioning, navigation, and timing (PNT) services on a global or regional basis. Automated vehicles use GNSS to enable localization, or awareness of its current location within the broader landscape. While the Global Positioning System (GPS) is the most prevalent GNSS, other nations are fielding, or have fielded, their own systems to provide complementary, independent PNT capability.[74] GPS is a U.S.-owned utility that provides users with PNT services. This system consists of three segments: the space segment, the control segment, and the user segment. The U.S. Air Force develops, maintains, and operates the space and control segments.[75]

As efforts to overcome automated vehicles' shortcomings advance, a new batch of sensors might emerge to help with the effort. Time-of-Flight (ToF) cameras, which are also referred to as Flash Lidar or Time-of-Flight Lidar, use the known speed of light to calculate distances and dimensions, akin to functions performed by lidar

Figure 8: Typical Automated Vehicle Sensor Placement and Functionality



but at a lower cost. Ground-penetrating radar (GPR) bolted underneath a vehicle's chassis can help create a high definition, navigable map by scanning 126 times per second up to 10 feet underground, looking at geologic and man-made features like soil density, the location of pipes, cavities, roots, rocks and other larger and more stable features that are unlikely to change over time.[76]

"Sensor fusion" refers to vehicles' capabilities to aggregate, process, and synthesize information collected from all of the vehicle's sensors – whether they are the same type or different – into one coherent understanding of its surroundings. It's also an approach by which vehicles can leverage what redundancies exist to further validate their understanding of their surroundings and ensure that safe and accurate courses of action are made. Sensor fusion is a hot topic in automation, driving much of the work in both software and hardware development. Various sensors' roles in enabling different levels of automation are depicted in Figure 8. It shows how sensors' placement and capabilities can enhance and compensate for relative capabilities and shortcomings.

As sensor data is fused within a vehicle's central processing unit (CPU) and software determines the appropriate course of a vehicle's action, automation is enabled. The degree to which a vehicle is automated is measured by standards first established by the Society of Automotive Engineers (SAE) and later adopted into the National Highway Traffic Safety Administration (NHTSA) Federal Automated Vehicles Policy (FAVP) for safe testing and deployment of automated vehicles.[77] This standard identifies six driving automation levels:[78]

- ***Level 0 – No Automation:*** The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems;
- ***Level 1 – Driver Assistance:*** The driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task;
- ***Level 2 – Partial Automation:*** The driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment, and with the expectation that the human driver performs all remaining aspects of the dynamic driving task;
- ***Level 3 – Conditional Automation:*** The driving mode-specific performance by an Automated Driving System (ADS) of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene;
- ***Level 4 – High Automation:*** The driving mode-specific performance by an ADS of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene;
- ***Level 5 – Full Automation:*** The full-time performance by an ADS of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver.

Table 2: SAE Levels of Vehicular Automation and Functionality

SAE Level	Name	Examples	Vehicle Control	Monitoring	Fall Back Control	Vehicle Capability
0	No Automation	N/A	Human Driver	Human Driver	Human Driver	N/A
1	Driver Assistance	Adaptive Cruise Control / Lane Keeping & Parking Assist	Human Driver & Vehicle	Human Driver	Human Driver	Some Driving Modes
2	Partial Automation	Traffic Jam Assist	Vehicle	Human Driver	Human Driver	Some Driving Modes
3	Conditional Automation	Full Stop & Go Highway Driving, Self Parking	Vehicle	Vehicle	Human Driver	Some Driving Modes
4	High Automation	Automated Driving	Vehicle	Vehicle	Vehicle	Some Driving Modes
5	Full Automation	Driverless Vehicle Operation	Vehicle	Vehicle	Vehicle	All Driving Modes

Source: Society of Automotive Engineers

The functionality of automated vehicles conveyed by their levels of automation can imply user models and scenarios for ownership and use. The functions of advanced driver assist systems (ADAS), which include features such as lane keeping assist (LKA) and adaptive cruise control, fall within the lower (i.e., L 1-3) levels of automation, are compatible with the current automotive paradigm for ownership and use, and are commercially available. Because humans are still in control during most scenarios at these levels of automation, less intensive and thus expensive sensors and other components (e.g., lower-range lidar) can be used to enable these features. It is thus likely that these lower levels of automation will be primarily associated with business models oriented around the purchase of vehicles. Alternately, the functions performed at the higher levels of automation (i.e., L 4-5), whereby humans can cede control some or all of the time, require more intensive and thus expensive sensors and processing to ensure that the vehicle can safely navigate whatever scenario may arise. While later portions of this publication outline additional drivers of shared mobility and ownership models, it may be that the price point of the necessary L 4-5 components alone drives models of shared ownership, whereby the high initial costs can be amortized by a pool of users over time.

That said, the levels of automation contribute little to understanding an automated vehicle's broader contextual functionality, which most importantly pertains to safety. Early indications are that the levels of automation are falling short of facilitating a broader understanding and acceptance of vehicles' inherent technologies and performances. The AAA Foundation for Traffic Safety concluded that most drivers don't understand the limitations of the lower levels of automation – namely ADAS – particularly blind spot monitoring, forward-collision warning, and automatic emergency braking.[79] Combined with the fact that the Insurance Institute for Highway Safety (IIHS) declared that various ADAS technologies could be unreliable and require human intervention, an outcome confirmed by the AAA,[80] the misunderstanding of ADAS technologies could prove fatal.[81]

For the higher levels of automation, a fundamental problem exists in the ways that progress is measured. Typically, companies – and some states, like California – collect and report metrics such as disengagements, accidents, and miles accrued, all of which are problematic. The number of times an automated system is disengaged can either indicate that it is exposed to too few instructive scenarios (if not disengaged enough) or that it is not learning enough (if disengaged too frequently). Regarding accidents, the overwhelming majority to date have been caused by human-pilot vehicles that share the roadways rather than the AV systems themselves. Finally, miles accrued indicate nothing about how valuable those miles were in teaching the AV system to handle a given scenario.

Safety is always within some domain, for there will always be some domain in which any level of vehicular automation is unsafe. The federal government encourages automated vehicles' respective manufacturers to denote and, for the most part, self-certify their particular Operational Design Domain (ODD). The information included as part of the ODD includes the specific conditions under which a given ADS or feature is intended to function, including roadway types, geographic areas, speed ranges, environmental conditions (e.g., weather, daytime/nighttime, etc.), and other domain constraints.[82]

Thus, when it comes to the safe operation of a vehicle, ODD certification is paramount. It should focus on the mobility that is trying to be achieved; the application, placement, and fusion of sensors to enable a vehicle to perform as required within a prescribed domain; and subsequently the level of functionality within that domain. Additional factors include how AVs perform on roadways with other (automated and non-automated) vehicles[83] and the qualification and certification of the compute platforms underpinning automated driving to ensure they're able to handle the range of harsh environments that come with road travel.

Taking these and other factors into account, the International Transport Forum (ITF) at the Organization for Economic Co-operation and Development (OECD), an intergovernmental organization with 59 member countries that acts as a think tank for transport policy and ministers, suggests measures for road authorities to take to help ensure that roads become safer as automated vehicles deploy:[84]

Ensuring Safety with Autonomous Vehicles
• Avoid safety performance being used to market competing automated vehicles;
• Carefully assess the safety impacts of systems that share driving tasks between humans and machines;
• Report on safety-relevant data collected from automated vehicles;
• Apply Vision Zero thinking to automated driving to eliminate road fatalities;
• Develop and use a staged testing regime for automated vehicles;
• Establish comprehensive cybersecurity principles for automated driving;
• Ensure the functional isolation of safety-critical systems and that connectivity does not compromise cybersecurity or safety; and
• Provide clear and targeted knowledge about the vehicles' capabilities.

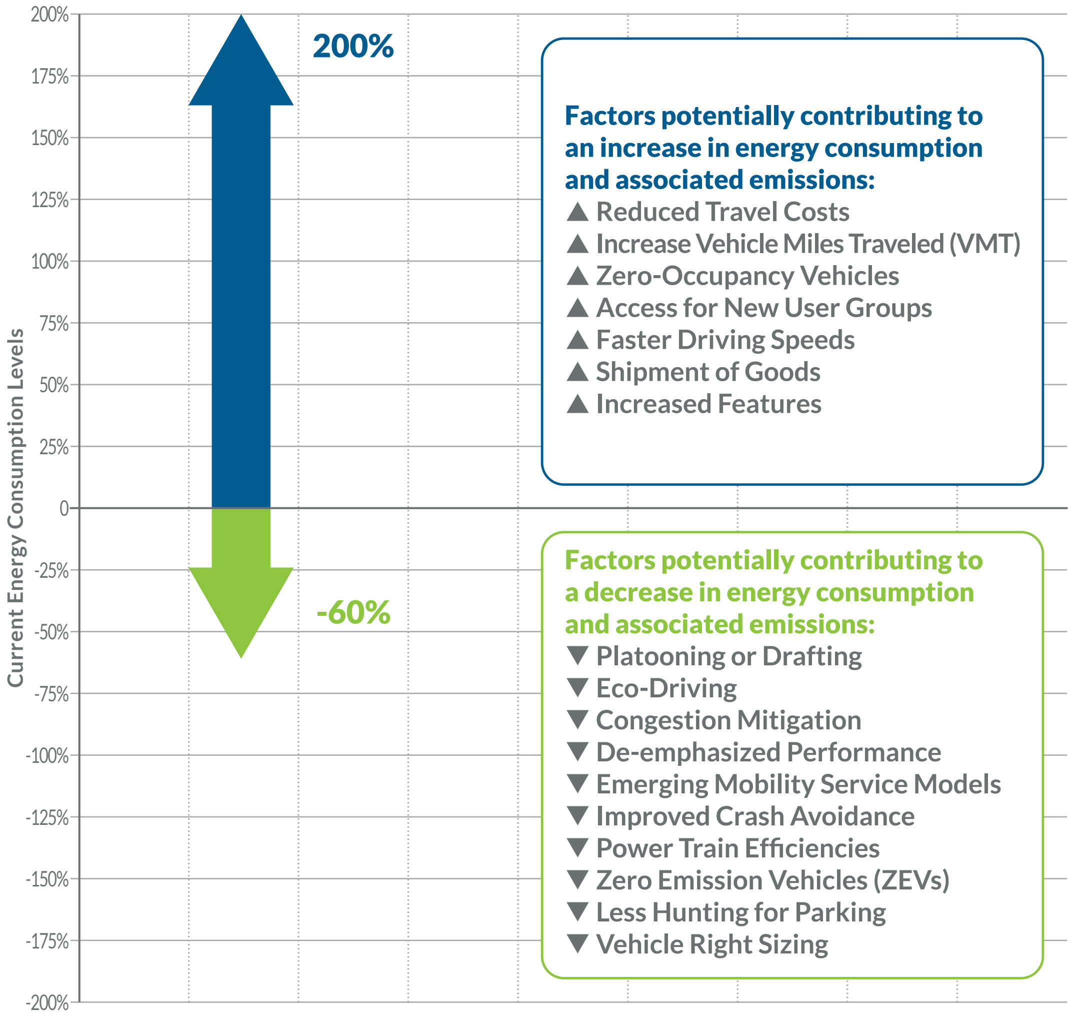
Beyond safety, an automated vehicle's environmental footprint is of paramount importance when considering its evaluation, application, and mass-market commercialization. With their array of sensors, intense computing power, and consistent wireless data transmission, automated vehicles' consumption of electricity could be significant. One automotive supplier projects AVs will require 200 to 350 W to process incoming and in-vehicle data generated from on-board sensor arrays, from other vehicles, the infrastructure, and the cloud.[85] This significant amount of electrical power would actually be much greater – between 1.5 and 4 kW, which almost equates the power consumption for propulsion when driving urban streets[86] – if a projected 90 percent reduction in energy consumption from dedicated processors fails to materialize. Electrical needs and efficiency considerations are prompting manufacturers to focus on advancing automated technologies primarily in plug-in vehicles, whether hybridized or propelled solely by electricity. While electrification solves the problem of power supply, automated electric vehicles' grid electricity consumption and carbon footprint could be impaired.

Aside from the vehicle itself, uncertainties regarding the final format, business models, and usage of CAVs mean that there are uncertainties regarding their impact on energy consumption and greenhouse gas (GHG) emissions. For instance, the Technical University of Vienna in Austria concluded that, should AVs be privately owned rather than shared, they would increase vehicle miles traveled (VMT) by between 15 percent and 59 percent, and would also increase suburban sprawl.[87] Conversely, researchers from the University of Delaware, University of Virginia, and Boston University found that algorithms for automated vehicles could help coordinate traffic patterns, resulting in conserved momentum and saved fuel. They also found that self-driving cars would be more likely to avoid rear-end crashes when slowing down by finding the optimal acceleration and deceleration rates.[88] Other research indicates that a single automated vehicle mixed in with 20 human-driven vehicles can help eliminate traffic congestion.[89]

The U.S. Department of Energy (DOE) National Laboratories took a broad look at how CAVs can affect future energy use and other environmental factors. It examined four possible mobility futures that could exist in 2050 and the positive and negative impacts of these futures on energy consumption and the broader economy. Based on variables such as improved crash avoidance, eco-driving, increased features, travel cost reductions, and others, the DOE concluded that the widespread deployment and use of CAVs could increase system-wide energy consumption by 200 percent or decrease it by 60 percent, as represented in Figure 9.[90]

Similarly, U-M performed a life cycle assessment (LCA) of Level 4 CAV sensing and computing subsystems integrated into internal combustion engine vehicle (ICEV) and battery

Figure 9: Prospective Energy Impacts of Connectivity and Automation



Source: U.S. Department of Energy

electric vehicle (BEV) platforms. The results, presented in Figure 10, indicate that CAV subsystems could increase vehicle primary energy use and GHG emissions by 3–20 percent due to increases in power consumption, weight, drag, and data transmission. However, when potential operational effects of CAVs are included (e.g., eco-driving, platooning, and intersection connectivity), the net result is up to a 9 percent reduction in energy and GHG emissions in the base case.[91]

Stevens Institute of Technology found that the collective potential of "smart car" technologies comprised of three categories – warning systems, control systems, and information systems – can save 27 to 119 gallons of fuel each year, representing 6 to 23 percent of the U.S. average fuel consumption, and yielding annual savings of $6.2 billion.[92]

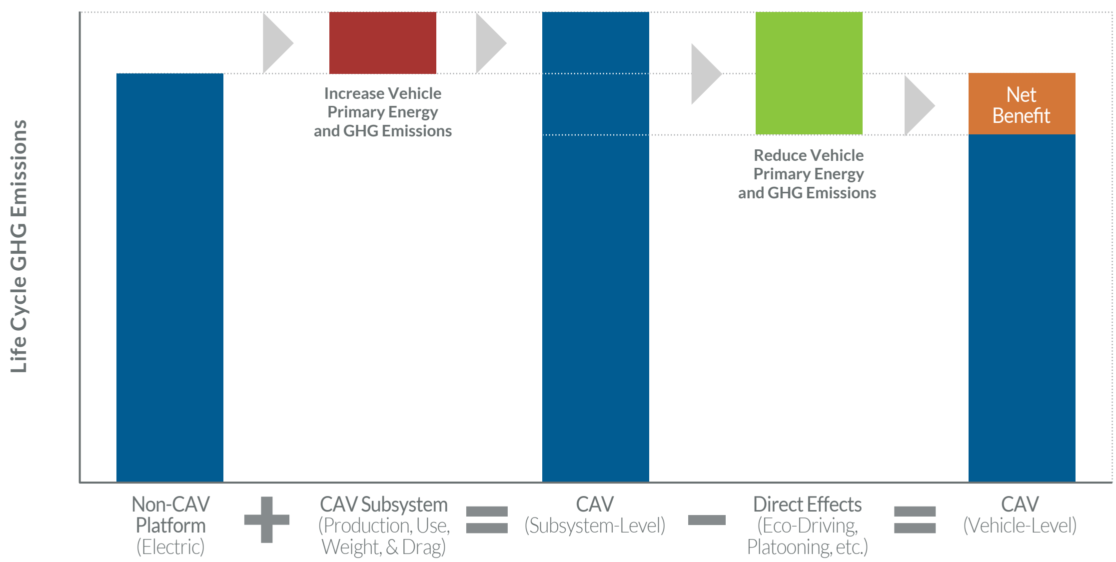
Analyses such as these indicate that decisions made today regarding technologies, business models, regulations, and other factors affecting CAVs can dramatically influence their environmental footprint.

SHARED MOBILITY

Shared Mobility (SM) integrates an array of transport modes and services – including but not limited to buses, taxis, rail and metro, shared and pooled cars and rides, scooters, bicycles, and others – into a single portal (e.g., smart phone app) that is accessible on demand as needed, and charges customers for mobility-as-a-service (MaaS) rather than for the acquisition of assets. SAE International organizes shared mobility's taxonomy into six categories:[93]

- Travel modes (e.g., carsharing and bikesharing)
- Mobility applications (e.g., mobility tracker apps)
- Service models (e.g., peer-to-peer service model)

Figure 10: Projected CAV Net Energy and Environmental Performance



Source: University of Michigan

- Operational models (e.g., station-based roundtrip)
- Business models (e.g., business-to-business roundtrip)
- Deprecated terms (e.g., ridesharing)

The potential for shared mobility has been brought about by the relatively recent societal embrace of the "shared economy," which is premised on the peer-to-peer provision of assets or services. Home sharing and ridesourcing platforms, including Airbnb in 2008 and soon thereafter Uber in 2009, fostered the embrace of the shared economy, as well as its potential to commercially scale, 10 years ago. The success of these platforms

SAE key definitions for primary components of the shared mobility ecosystem:[94]
Bikesharing provides users with on-demand access to bicycles at a variety of pick-up and drop-off locations for one-way (point-to-point) or roundtrip travel. Bikesharing fleets are commonly deployed in a network within a metropolitan region, city, neighborhood, employment center, and/or university campus.
Carsharing offers members access to vehicles by joining an organization that provides and maintains a fleet of cars and/or light trucks. These vehicles may be located within neighborhoods, public transit stations, employment centers, universities, etc. The carsharing organization typically provides insurance, fuel, parking, and maintenance. Members who join a carsharing organization typically pay a fee each time they use a vehicle.
Microtransit is a privately or publicly operated, technology-enabled transit service that typically uses multi-passenger/pooled shuttles or vans to provide on-demand or fixed-schedule services with either dynamic or fixed routing.
Ridesharing (also known as carpooling and vanpooling) is defined as the formal or informal sharing of rides between drivers and passengers with similar origin-destination pairings. Ridesharing includes vanpooling, which consists of seven to 15 passengers who share the cost of a van and operating expenses, and may share driving responsibility.
Ridesourcing services are prearranged and on-demand transportation services for compensation in which drivers and passengers connect via digital applications. Digital applications are typically used for booking, electronic payment, and ratings.
Scooter sharing allows individuals access to scooters by joining an organization that maintains a fleet of scooters at various locations. Scooter sharing models can include a variety of motorized and non-motorized scooter types. The scooter service provider typically provides fuel, maintenance, and may include parking as part of the service. Users typically pay a fee each time they use a scooter. Trips can be roundtrip or one way.

firmly disproved the longstanding notion that Americans prefer not to share their private property (i.e., cars and homes) with those they don't know, nor to access others' private property for safety, service, and other reasons.

Technological advancements are a second factor elevating the potential for shared mobility. Around the same time that home sharing and ridesourcing made their first appearances, the first smartphones arrived. Apple's iPhone hit the market in 2007, followed shortly thereafter by Google's first phone – the G1 – in 2008. Today, 10 years after their arrival, 77 percent of Americans own a smartphone, essentially putting a supercomputer in 250 million Americans' pockets.[95] Smartphones enable shared mobility by performing tasks fundamental to the collection and movement of people and vehicles, such as running third-party developers' applications to locate and match travelers, vehicles, and drivers. But they also enable shared mobility functions by leveraging other technological advancements, namely the miniaturization and dramatic cost reductions of sensors. As such, smartphones can establish geo-spatial positioning within seconds using GNSS, orient themselves with accelerometer and gyroscopic sensors, and collect and share photographic data via small optical (i.e., camera) sensors.

With people comfortable using other peoples' property and lending out their own, and empowered with a convenient platform by which to source and price rides, shared mobility is soaring. Today, approximately 40 million people use app-enabled carpooling services, and the usage of ridesourcing apps has grown to over 70 million users.[96] In major metropolitan areas, 21 percent of adults have installed and used ridesourcing apps, and an additional 9 percent of adults have used ridesourcing with friends.[97] Overall, nearly 10 percent of all Americans use ridesourcing in any given month. [98]

Given the large – and growing – user base, many have hypothesized that shared mobility has the potential to reduce the need to own vehicles, make travel more efficient, and altogether reduce congestion. Usage and awareness of ridesourcing is widespread, with 88 percent of respondents to an August

Global Shared Mobility

2018	2023	2030
17.6M	>2.3B	$1.0T+
urban private car journeys replaced by shared mobility	urban private car journeys replaced by shared mobility annually	global MaaS revenues

2018 survey aware of this mobility option regardless of where they live.[99] Furthermore, 39 percent of respondents indicated that while access to mobility is necessary, owning a vehicle is not, a 4 percentage-point increase over 2015 results.[100] That number jumps to 57 percent for urban consumers, a 13-point increase since 2015. This means increasingly more consumers are prioritizing technology solutions that provide convenient and cost-effective mobility over traditional vehicle ownership, which can cost upwards of $8,469 per year.[101] As such, shared mobility could replace over 2.3 billion urban private car journeys annually in 2023, compared with just 17.6 million globally in 2018,[102] and global MaaS revenues could exceed $1 trillion by 2030.[103]

Carsharing has experienced slower, pocketed growth with awareness at 54 percent. Lack of widespread adoption is due in part to carsharing being significantly less accessible than other alternative transportation methods. In urban areas where carsharing is most prominent, only 44 percent of consumers find it accessible versus the 85 percent of consumers that find ridesourcing accessible. The carsharing space also is fragmented with many players, giving consumers a lot of different options and leaving no clear leaders in usage. Ridesourcing is less crowded, with Uber (30 percent) and Lyft (18 percent) as the clear front-runners in terms of usage among respondents.[104]

While these modes and others are discussed in greater depth in the chapter on the *Midrange Domain*, what's important to note is the significant financial, social, and other benefits potentially afforded by sharing.

TECHNOLOGIES + TRAVEL MODES + BUSINESS MODELS = 21ST CENTURY MOBILITY

Electrification, connection and automation, and shared mobility each engender radical leaps in and/or applications of technology. Vehicle platforms and propulsion systems are diversifying, and new business models are emerging to facilitate access, affordability, and mobility.

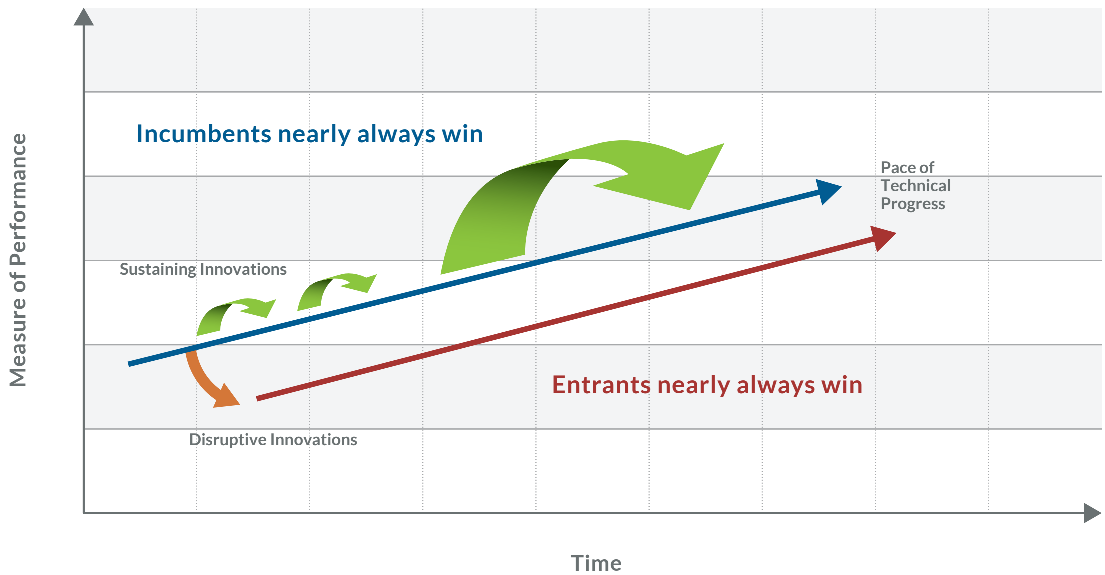
> *The core objective for 21st century mobility is to maintain – or exceed – the mobility afforded by the personal automobile while negating its drawbacks, including congestion, cost, pollution, and collisions.*

Yet each of these game-changing trends have challenges and shortcomings that on their own can impair their advancement. Electric vehicles costs are coming down, but are still higher than those of conventionally fueled vehicles and/or have limited ranges. The recharging infrastructure that many envision is needed in order for electric vehicles to fully displace those powered by gasoline would require a sizeable investment if oriented around current mobility paradigms. Connected vehicles don't yet have a standard platform, which is impairing widespread rollout. Highly automated vehicles are expensive to build, would thus be prohibitively expensive for consumers to purchase, are still a long way off from higher levels of automation that would enable their operation wherever a customer might be, and might grow energy consumption exponentially. Finally, shared mobility is in several cases worsening traffic congestion, particularly in urban regions, and in worst-case scenarios is increasing fatalities.

Furthermore, while these three trends are often referred to as disruptive, in the broader mobility paradigm they are far from it. The prediction about there being more change in the next 10 years than in the previous 50 tends to be in reference to the automobile industry, and thus engenders a 20th century mobility mindset. As applied to automobiles, each trend is more of a sustaining innovation than a disruptive one.

Instead, the real change – the radical disruption that has the potential to solve the shortcomings of each of the dominant trends – is the seamless combination and integration of each of these three trends while applying them not only to passenger automobiles, but to a wide array of vehicles and modes as well. Of particular importance is the application of these technologies to those vehicles at the bottom of the market that are less sophisticated, expensive, and complicated (e.g., scooters).[105] These vehicles – often introduced by smaller companies with fewer resources than the incumbents – have the most potential for classical "disruptive innovation,"[106] as illustrated in Figure 11.

Figure 11: The Classical Model of Disruptive Innovation Shows that Simpler Technologies Overlooked by Incumbents Win Over Time



Source: Clayton Christensen

The potential for systemic disruption is realized from the aggregation of each mode's disruptive potential. For instance, the technologies that are driving the trends towards electrification, connection and automation, and shared mobility can be applied not only to automobiles but also to multiple other travel modes – ranging from large-scale, multi-person, heavy vehicles to single-passenger, unenclosed, micro-vehicles – and can be utilized by travelers via numerous business models based on what's most appropriate and affordable given the need and function. Over time, each mode chips away at the market segment for which it is most appropriate to serve.

This combination of technologies, modes, and business models is what forms the framework for mobility in the 21st century, and the aggregated disruptive potential presents the pathway to establish it. The core objective for 21st century mobility is to maintain – or exceed – the mobility afforded by the personal automobile while negating its drawbacks, including congestion, cost, pollution, and collisions. This effort entails not simply displacing current automobiles with variations, such as those that are electrified or automated, but rather establishing the viability of multiple modes of efficient, electrified, and fully occupied vehicles that act as a system. Such a system needs a central, unifying "backbone" upon which the broader architecture can be layered.

PUBLIC TRANSIT: THE BACKBONE OF 21ST CENTURY MOBILITY

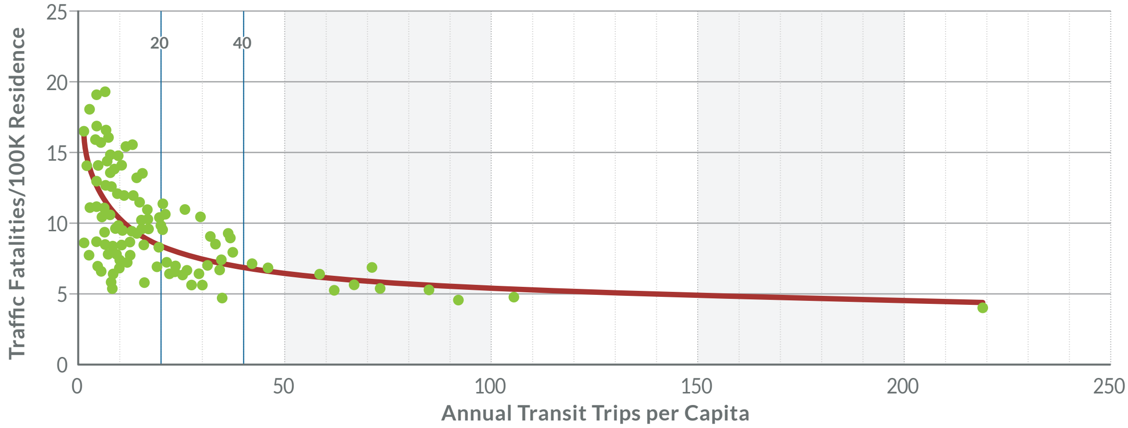
Before the 1920s, most urban residents commuted to work using public transportation. Today, eight in 10 Americans drive to work; just 5 percent take public transit. This decline is problematic for a number of reasons, many of which extend far beyond mobility. For instance, The London School of Economics determined that access to public transit played a critical role in helping transit-oriented submarkets retain their value throughout the recession circa 2008 and to recover value at a faster rate than homes without convenient access. Specifically, houses less than a mile from stations in Atlanta, Baltimore or Portland all kept their values to a greater degree than those located farther away from stations. This outcome is likely due to lower transport-related costs, better local economic conditions, and greater access to employment opportunities.[107] The American Public Transportation Association (APTA) came to the same conclusion, finding that residential property values performed 41.6 percent better on average if they were located near public transportation with high-frequency service during the most recent recession.[108]

APTA and the Vision Zero Network (a collaborative campaign helping communities eliminate all traffic fatalities and severe injuries while increasing universal mobility) found that places where people take more trips on public transit per capita have a smaller proportion of road fatalities. Specifically, large metro areas with higher levels of public transportation (more than 40 annual transit trips per capita) have lower traffic fatality rates than cities with fewer than 20 transit trips per capita.[109] Previously, APTA found that public transportation is 10 times safer per mile than traveling by car in terms of traffic casualty rate.[110] Altogether, and as indicated in Figure 12, APTA estimates that with Americans taking over 1,300 trips per year, an increase from 20 to 40 annual transit trips per capita could reduce traffic fatalities by anywhere from 10 to 40 percent.[111]

Researchers have increasingly documented the health benefits of public transportation in recent years. Studies show clear linkages between public transportation use and lower levels of air pollution, improved safety, and higher physical activity levels. On average use of public transportation instead of private vehicles produces 95 percent less carbon monoxide, 92 percent fewer volatile organic compounds, and 45 percent less carbon dioxide per passenger mile. Additionally, persons in communities that have access to regular public transportation service have increased physical activity levels.[112]

Public transit can be a wise investment, and can help spark economic growth. The Union Internationale des Transports Publics (UITP), the world's largest association of public transportation agencies, points out that "investment in public transport sparks a chain reaction in economic activity up to three or four times the initial investment," and that "while large-scale public transport investment projects are undoubtedly expensive, they are actually

Figure 12: Metro Areas with More Public Transit Use Have Lower Traffic Fatality Rates (2016)



Source: American Public Transit Association

significantly less expensive than the direct cost of congestion, which can seriously harm the cities' competitiveness, affecting travel time reliability and business productivity."[113] Additionally, Chicago's Metropolitan Planning Commission (MPC) found that businesses are choosing to locate near transit for several reasons. First, businesses are co-locating with public transit to access labor pools, and transit-accessible neighborhoods outperform the regional job growth average, altogether helping to attract and retain jobs in the area. Additionally, locating near transit offers businesses greater resiliency.[114]

Finally, public transit is simply the most efficient way to move people. The majority of private vehicles move one person per hour. In dense cites, fixed route transit buses can move more than 80 people per hour. Thus, if we're seeking to establish a framework for mobility that first and foremost moves people (i.e., "throughput") – but also prioritizes societally desirable functions such as improved safety, housing values, green space, clean air, equity, etc. – transit should be a major component.

Yet, unfortunately, the presence of transit is shrinking, not growing. Modern modes and models can help revive transit, but not without the use of emerging mobility technologies and establishment of all-encompassing systems.

DECLINING RIDERSHIP

Before the 1920s, most urban residents commuted to work using public transportation. Then, between 1945 and 1969, the number of U.S. transit passengers dropped from 23 billion to 8 billion. Today, increasingly fewer commuters across the country are using public transit. Transit ridership fell in 31 of 35 major metropolitan areas between 2016 and 2017, including in the seven cities that serve the majority of riders: New York, Chicago, Los Angeles, Washington D.C., San Francisco, Boston, and Philadelphia. Los Angeles-area transit agencies have seen dramatic bus ridership declines since the mid-2000s, with overall bus ridership falling about 30 percent over the course of a decade.

Overall, 76.4 percent of Americans drive alone to work every day; just 5.2 percent take public

Table 3: Transit Ridership, 2017 vs. 2016

Mode of Transportation	Commuters in 2016	Commuters in 2017	Percent Change
Bus or Trolley Bus	3.73 million	3.64 million	-2.34% ▼
Streetcar or Trolley Car	92,014	91,956	-0.06%▼
Ferryboat	58,914	57,768	-1.94% ▼
Subway or Elevated Train	2.88 million	2.95 million	+2.27% ▲
Railroad	882,668	895,998	+1.51%▲

Source: U.S. Census Bureau

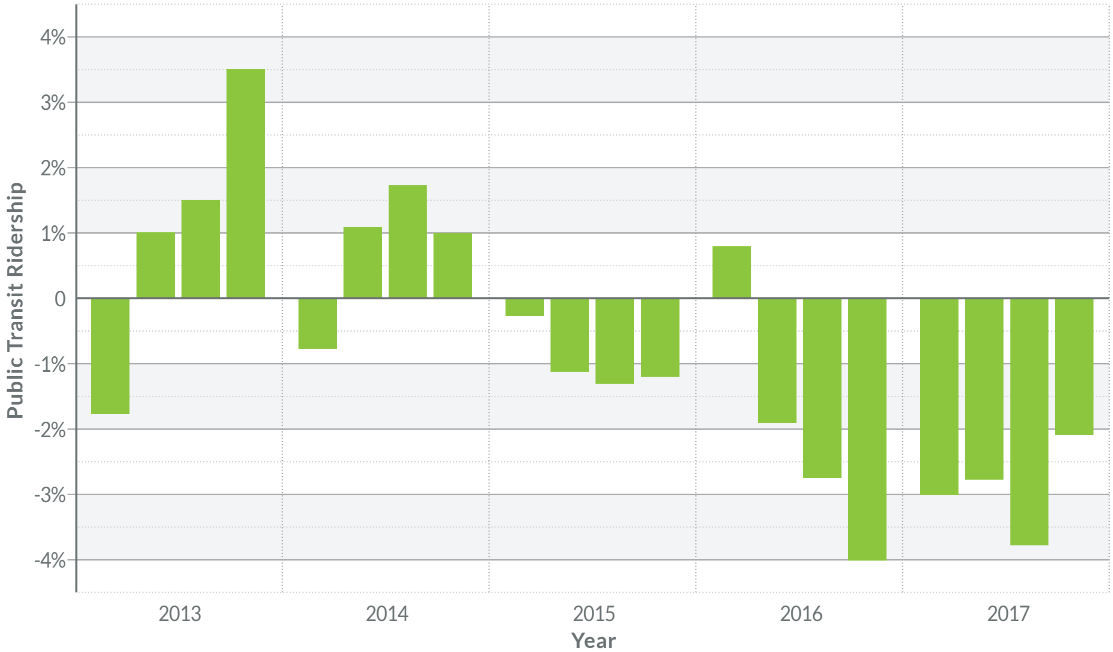
transit.[115] In 2017, 7.6 million people took public transportation, which is 12,000 fewer than the previous year,[116] and overall was the lowest year of transit ridership since 2005. All major transit modes experienced decreases, with the exception of subways and railroads, and bus ridership alone fell 5 percent.[117] Table 3 presents total transit ridership numbers per mode in 2016 and 2017, and the percent change between the two years.

Figure 13 illustrates how public transit ridership has been dropping every quarter since 2017.

The steep decrease in transit usage isn't a recent phenomenon, but rather one that extends back several decades. The United States once had a world-class public transportation system, with 115.8 annual per capita transit trips in 1950.[118] Yet by 1970, that number had decreased to 36.1, where it has roughly remained since, even as population has grown.

Challenges to transit first emerged with the onset and increasing popularity of the private automobile. Today, lower transit ridership is substantively due to increased car ownership, particularly among low-income and immigrant populations, as their incomes rebound in the improved economy and car ownership becomes more affordable. Fueling this trend is the increased ease of obtaining a car through factors such as subprime auto loans and low fuel prices.[119] The Congressional Research Service, a public policy research arm of the U.S. Congress, blames the ridership decline on low gasoline prices, increased cars, and the rise of ridesourcing.[120]

Figure 13: Public Transit Ridership Volumes by Quarter, 2013–2017



Source: American Public Transit Association

To this last point, while ridesourcing is a factor attracting travelers away from transit, it's not the instigator nor the primary source of lower ridership, given that per capita transit ridership began falling before the widespread availability of services such as Uber and Lyft. In fact, the University of Toronto concluded that while Uber reduces transit ridership in smaller Metropolitan Statistical Areas (MSAs), it increases ridership in larger cities.[121] So altogether, the picture is mixed.

Instead, while ridership numbers were destined to decrease in the face of modal competition from the automobile, such a dramatic decrease in ridership was by no means preordained. Rather, it was the progressive decrease in transit service brought about by agencies' budget cuts that, over time, made transit a less viable alternative to cars.

The frequency of service along existing lines, as opposed to aggregate transit lines and geographical service areas, is the most influential factor that persuades commuters that transit is a viable car-free alternative form of travel. Research shows that frequencies of 15 minutes or better are required to entice commuters to take transit rather than to drive.[122] Yet as transit agencies are forced to reduce their operating costs as riders switch to automobiles, transit line service intervals of 30 minutes or more are common, which means fewer transit riders. Fewer riders leads to less revenue for transit agencies, which prompts a further decrease in service. This in turn implants the notion that transit is of questionable value to the broader public, which leads to opposition to regional efforts to provide transit funding by other means.[123] It also fosters the notion that transit is a government aid program to help poor people who lack cars rather than a viable service, which becomes self-fulfilling as pressure is imposed on transit operators to keep fares artificially low. Altogether, these various components fuel a downward ridership spiral, as illustrated in Figure 14.

Figure 14: Self-Reinforcing Factors That Reduce Transit Ridership

MODERN MODES AND MODELS TO REVIVE RIDERSHIP

The potential exists to revive transit and establish consistently higher levels of ridership that are on par with the rest of the world. This is indicated by exceptions to the trend in decreasing transit ridership: New Orleans ridership stayed flat while others decreased, and Seattle, Phoenix and Houston either expanded transit coverage and increased service or underwent ambitious network overhauls.

Impressively, in 2015 Houston reversed the trend of steep losses that included losing a fifth of its ridership over a little more than a decade while fostering significant weekend ridership gains. It did so by transforming its bus system from a traditional hub-and-spoke design focused on downtown to a grid that apportioned equal service to other parts of the city,[124] eliminating stops and increasing frequency. In Seattle, transit increased from 29 percent to 47 percent of trips between 2000 and 2016 – improving bus ridership by 17 percent between 2015 and 2017 alone – by funding nearly 300,000 annual hours of bus service, improving weekday all-day service to 10 minutes or better, and undertaking initiatives to increase bus reliability.[125] The city also implemented low-cost measures such as making transfers from light rail to bus easier, implementing bus lanes, optimizing routes so they travel through the most congested places, and implementing queue jumps that allow buses to start before other cars at stoplights.[126] Accordingly, 64 percent of Seattle households were within a 10-minute walk of 10-minute all-day transit service in 2017, up from 25 percent in 2015.[127]

Polls in major metropolitan areas consistently show that if transit service were adequate, commuters would prefer not to drive. For instance, a poll of college and university students indicated that 90 percent would consider using public transit instead of driving if it were reliable, affordable, convenient, and safe.[128] Broader support for a viable public transit system is reflected in a poll that indicated that 70 percent of U.S. residents would support an increase in federal funding for public transportation systems.[129] Such examples and polls indicate that transit has an underlying level of support that can help its revival. The emergence of modes and models that afford better transit experiences, reduce operational costs, and altogether provide better service can further assist this effort. These modes and models include electric transit buses, dynamic routing, and service-based pricing models.

ELECTRIC TRANSIT BUSES

In the previous example of Seattle, it's worth noting that the city is also a leading adopter of electric transit buses, operating a fleet of 1,400 hybrid, electric trolley, and battery-electric models.[130] Electric buses can be transit enablers in at least two ways. First, they help ensure reliability, which aside from frequency is perhaps the most important component of a successful transit system. This is due to the simpler technical nature of electric as opposed to internal combustion propulsion. While internal combustion engines can have hundreds of moving parts, electric drivetrains have only a few, thereby reducing the chance that parts may fail, which would prevent the bus from completing its assigned service. This – along with the fact that electric buses are four times more fuel-efficient than natural gas buses – also reduces operating costs, as there are fewer parts to break, fluids to change, and vitals to track, thereby reducing spare parts consumption by 80 percent per mile.[131]

Figure 15: Battery Electric Transit Bus Drivetrain Components

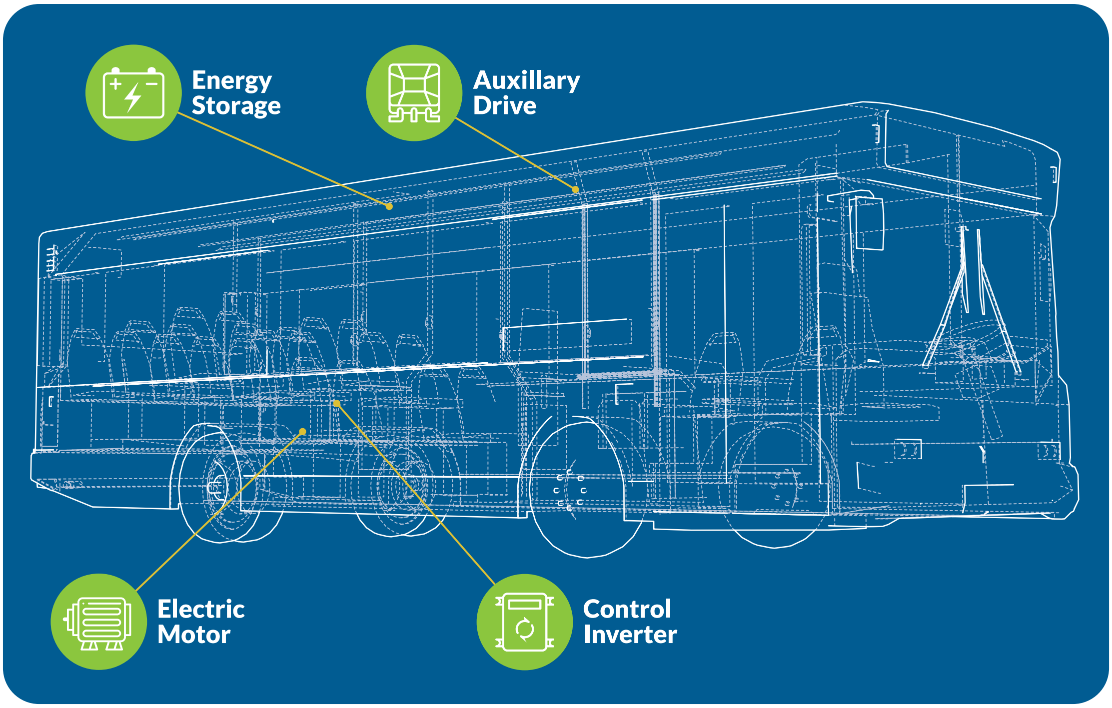
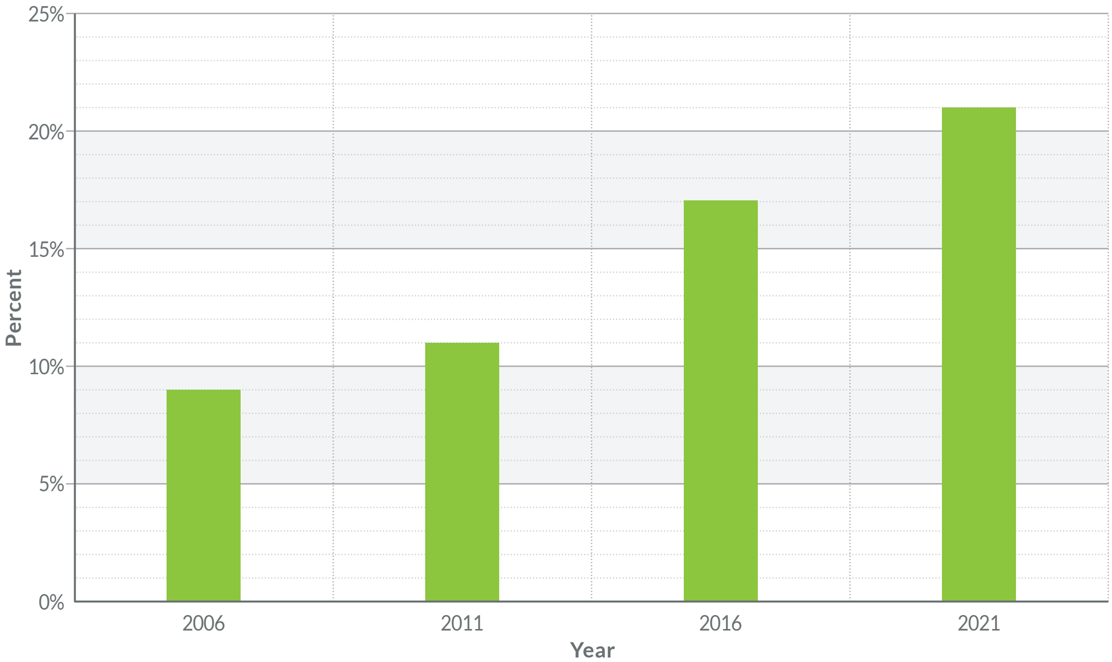


Figure 15 depicts a typical modern battery electric transit bus, with its comparatively few drivetrain components.

With less money allocated to operational costs, transit agencies can allocate more towards increasing the frequency of service and thus help revive ridership. Furthermore, electric models also offer a smoother and quieter experience, which makes them popular with riders. As opposed to internal combustion engines, which can vibrate a bus' chassis and create cabin noise from exhaust pipes, fans and belts, battery propulsion systems are vibration-free and, for the most part, silent.

The popularity of electric buses, their reduced maintenance costs that can enable more frequent service, and the technological maturity of battery electric propulsion systems that can enable more than 200 miles of driving range while eliminating point-source air pollution are prompting their adoption. About 40 percent of U.S. transit agencies either have electric buses in operation or have awarded purchase contracts. In total, approximately 1,200 electric buses are in operation nationwide.[132] Globally, Bloomberg New Energy Finance (BNEF) projects that 84 percent of new bus sales will be electric by 2030, thereby outpacing electric light-duty vehicles, as their scale and much higher utilization allow them to reach pricing parity with internal combustion vehicles in 2019.[133] BNEF also projects that 80 percent of the global municipal bus fleet will be electric by 2040.[134] Figure 16 illustrates the past, present, and projected demand for hybrid and fully electric buses.

Figure 16: Hybrid and Fully Electric Buses as a Percent of Total Bus Unit Demand, 2006-2021



Source: The Freedonia Group

DYNAMIC ROUTING

Modern propulsion systems aren't the only technology that can play a role in reviving transit ridership. The technologies – and even the business models – that enable connectivity, automation, and shared mobility can also contribute to the goal of providing reliable, consistent, and frequent service that attracts more people.

For instance, the same geolocation, tracking, and computing technologies that facilitate ridesourcing can help transit agencies track their vehicles, provide timely arrival and departure information to prospective riders, integrate with other modes for comprehensive journey planning, and even optimize their routes to better match with riders' needs. To this last point, static and dynamic route optimizations can better align collection and drop-off locations with riders' needs. Coupled with on-demand technologies that synchronize rider pickup/drop-off locations and timeframes, public transit can become more efficient.

This doesn't necessarily mean that dynamic routing and passenger boarding are appropriate – or even feasible – for all transit routes. Routes with frequent service and consistently high ridership would be poor candidates and would likely increase rather than reduce costs and inefficiencies, given that route capacity is already saturated. Instead, on-demand, flexible services have the most potential to improve routes with infrequent service and/or low ridership. Examples of routes with these characteristics are those that operate at night and those with lower densities, such as rural areas with 5-10 people per square mile, and suburban areas with 1,000-2,000 people per square mile.[135]

Tangential benefits from dynamic routing could come in the form of assisting with bus stop siting. Most cities in Western Europe and East Asia have one stop every quarter to one-third mile, which is more than twice as far as is common in the United States.[136] Bus stops in the U.S. are spaced comparatively close to each other because longer distances would be seen as harming seniors and disabled riders.[137] Dynamic routing alleviates this issue, for direction can be provided to buses to stop only when and where there are passengers and to more mobile passengers to congregate at centralized locations, thereby reducing the number of stops made along routes. The longer distances between stops leads to increased ridership, for the buses can average faster speeds, and arrive more often and reliably. The Washington, D.C. Metro's models show that a 10 percent increase in speed raises bus ridership by between 4 and 10 percent.[138]

Dynamic routing can also combine with other typical ridesourcing features to enable transit providers to price mobility around the value of the services provided, rather than simply operating under a one-size-fits-all approach. For instance, transit systems in cities like London and Toronto have higher fares that they use to fund more frequent service, among other things.[139] Transit agencies in the U.S. could use dynamic routing as a tool to increase ridership levels by holding prices constant, or they could justify the imposition of higher fares to different riders based on their needs, willingness-to-pay, and tiers of service offered. The increased funding could then be used to further enhance services that altogether enable the system to better compete with cars.

Static and dynamic route optimizations can better align collection and drop-off locations with riders' needs. Coupled with on-demand technologies that synchronize rider pickup/drop-off locations and timeframes, public transit can become more efficient.

SERVICE-BASED PRICING MODELS

Service-based pricing models offer benefits not just for transit providers, but for manufacturers as well. While several of the benefits of electric transit buses were previously covered at length, one major hurdle they face is the incremental cost above traditional diesel buses. At a typical price after incentives of $700,000, electric buses generally cost about 30 percent more than the $550,000 typically paid for natural gas and 50 percent more than the $450,000 typically paid for conventional diesel-powered buses.[140]

While the lower cost of fuel and reduced maintenance costs more than offset the higher upfront costs over the life of the vehicles, transit agencies still face an initial barrier to overcome in terms of upfront provision of capital for the acquisition. When faced with a similar barrier, the solar power industry innovated with financial models that enabled homeowners to install and use solar panels without having to pay tens of thousands of dollars of upfront capital costs. Instead, they opted to commit to long-term offtake agreements priced at a level below their current monthly electricity bill, yet high enough to amortize the capital and financing costs. Such an innovation catalyzed the solar power industry, helping it grow to 58.3 GW of total installed capacity – enough to power 11 million American homes – by mid-2018.[141]

Similarly, Chinese battery electric bus manufacturer BYD Motors and Generate Capital – a specialty finance company that builds, owns, operates, and finances infrastructure assets involving energy, water, agriculture and basic materials – have pioneered a leasing program to help reduce upfront costs. Under the program, Generate Capital invested $200 million to buy and lease buses that are built and marketed by BYD. Customers can lease an entire bus or buy only the chassis and lease the batteries on a monthly payment.[142] Generate Capital's model includes not just financing, but also monetization of the onboard batteries' residual value – i.e., the point at which the batteries are no longer able to meet the needs of the vehicle but have some other market value, such as baseload energy balancing. Another electric bus manufacturer offering service-based models is Proterra, who works with customers to help identify grant, loan, and financing programs such as municipal capital and battery leases.[143]

Beyond the reduction of upfront capital costs, potential exists for manufacturers and/or financiers to structure vehicle and infrastructure deployments around the provision of service and mobility rather than assets. Such a contractual structure has the added benefit of facilitating other shared mobility features like fleet maintenance, training and provision of drivers, and dynamic routing as service providers would be incentivized to provide riders with mobility, not simply routes and stops.

Beyond the reduction of upfront capital costs, potential exists for manufacturers and/or financiers to structure vehicle and infrastructure deployments around the provision of service and mobility rather than assets.

SNAPSHOT

Transit agencies, including Belleville Transit in Ontario, Canada, are experimenting with projects that highlight prospective use cases for on-demand, dynamically-routed bus transit.

Belleville Swaps Fixed Routes for On-Demand, Bus-Hailing

In September 2018, the City of Belleville in Ontario, Canada, launched a pilot with Pantonium, a Toronto startup founded in 2010 that optimizes routing for fleets, to test dynamic route optimization for its transit service.[144]

The pilot swaps the city's fixed routes for its night bus service with a flexible, on-demand approach that's akin to what's used for ridesourcing. Riders use a smartphone app to request a pickup and drop-off at any bus stop in town. Pantonium's software then processes the requests, continually updating itself to optimize all scheduled rides, and maps the best route for bus drivers to collect and deliver all riders to their destinations as quickly as possible.[145]

While the overwhelming majority of riders have a smartphone or a tablet upon which they can access the app, the city also allows people to book rides online or via a phone call, should they have trouble or otherwise be unable to use the app.

The pilot comes in part as a response to public feedback and requests for the municipality to adopt modern technology. It's also an acknowledgement of the inherent inefficiencies of large diesel buses operating on fixed routes and schedules, particularly late at night, when much time is spent circling around routes with few passengers on board.

Historically, Pantonium's source of growth has been providing services to non-emergency medical transportation companies that operate in the United States, transporting patients to medical appointments. The partnership with Belleville comes as "…a new approach to an old challenge for public transit in low-density public transit areas, attempting to improve upon the 'dial-a-bus' model without replacing or undercutting the existing transit infrastructure."[146]

Belleville's public transit system is small. The city has a population of only about 50,000, the transit system provided 996,000 rides last year via its 14 buses; the current pilot involves just three buses.[147] Yet if the initial pilot project goes well, as the doubling of the app's registered riders in the pilot's first two weeks indicates it might,[148] the city would like to keep its large buses on a fixed route in its central, high-traffic area, while feeding that route using the bus-hailing service by bringing passengers in from low-density zones.[149] Pantonium sees this being applied across the world in rural, suburban, and/or low-density areas; night bus services; and first/last mile challenges around transit hubs.[150]

THE FIRST/LAST MILE CHALLENGE

Though freeing up operating budgets by using less costly and complex technologies, increasing service frequency and reliability, and implementing tools such as dynamic routing and pricing can make meaningful contributions to increasing transit ridership, a fundamental challenge exists in the way that greater metropolitan areas are populated and structured.

Specifically, typical suburban communities, comprised of a spider's web of low-traffic streets and cul-de-sacs, are less conducive to transit routes, which work best on main arteries closer to population centers. As such, where population densities are lower, sustaining ridership becomes more difficult as any given route's odds of passing through an area with high transit demand decreases.

Thus, there's often a meaningful distance between a transit stop and a prospective rider's ultimate destination. This distance is historically referred to as the "last mile," but given that it also applies to the distance between the stop and one's point of origin, it has also been called the "first mile." The first/last mile challenge refers to the hurdle that any transit system – even those in densely populated areas – has to overcome in order to obtain riders, for pedestrian access to transit stations falls off dramatically at distances greater than one-half mile.[151]

A meaningful, scalable solution to the first/last mile challenge has long perplexed transit planners. No level of service frequency addresses the issue, for while increased

The first/last mile challenge refers to the hurdle that any transit system – even those in densely populated areas – has to overcome in order to obtain riders, for pedestrian access to transit stations falls off dramatically at distances greater than one-half mile.

frequency improves the attractiveness of transit as an alternative to personal cars, riders still have to arrive at the transit stop as well as their final destinations. Additionally, while increasing the number of routes and implementing dynamic routing can address the challenge to a degree, at some point both options come up against diminishing returns, whereby the cost and/or time penalty imposed by covering an extra mile of routing offsets, eliminates, or even establishes a negative correlation with supposed benefits. Yet solving the first/last mile challenge is essential not only to enable public transit, but also to prevent communities from cannibalizing their fixed-transit network by experimenting with broader-but-reduced service and/or misapplied on-demand solutions.

AFFORDABILITY, ACCESSIBILITY, INTERSECTIONALITY, AND MOBILITY

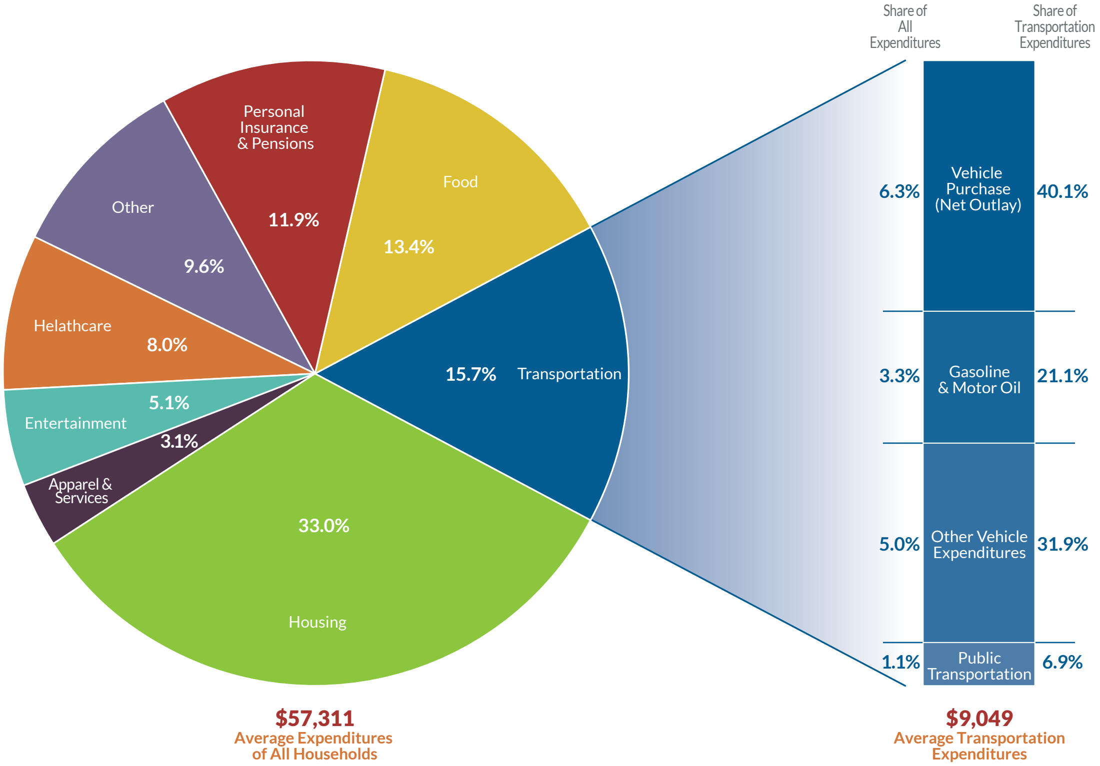
One approach to overcoming the first/last mile challenge, particularly in rural and suburban areas, is to facilitate commuters' transit connections via car. The challenge with this approach is that transit stations in more urban settings have limited or no dedicated parking, leading patrons driving to the station to rely on street parking. For those who do have dedicated parking, it's often limited and fills up early each workday.[152]

Even if it were logistically possible and cost effective to build parking structures at every major transit stop, no amount of parking could solve the first/last mile challenge, especially for those who typically ride and depend on transit. This is due to the fact that even though riders could overcome one leg of the challenge with their private automobile (e.g., the "first" leg), at their destination they'll likely face the other portion of the challenge (e.g., the "last" leg).

More importantly, premising ridership on the possession of a mode of transportation that costs an average of over $36,000 to own[153] and even more to operate doesn't align with transit's ridership profile. Transportation costs – the largest household expenditure next to housing itself (see Figure 17)[154] – have a disproportionately negative impact on lower income households,[155] and in nearly every urban area public transportation commuters tend to be poorer than those driving to work.[156]

For example, a third of New Orleans residents who commute via public transportation live in poverty, compared to only nine percent of those who drive cars. San Diego residents taking public transportation to work earn less than half as much as other city workers. A similarly large disparity exists in Louisville, Ky, Tucson, Ariz., and numerous other urban centers. Altogether, 47 percent of bus riders do not own a personal vehicle.[157]

Figure 17: Household Expenditures, 2016



Source: U.S. Department of Energy, Vehicle Technologies Office

First/last mile solutions that impose steep financial barriers, such as personal car ownership, also inherently impact racial and class disparities. Households in poverty are disproportionately comprised of minorities, with African Americans and Hispanics experiencing the highest poverty rates. Limited vehicle availability and fewer affordable transportation options afflict this cost-sensitive group.[158] In New York City, the median earnings of public transit commuters are about $35,000 per year, and only a third of those commuters are white. In Los Angeles, the disparity is even greater: the median income of public transit commuters is only $15,000 per year; 71 percent of riders are Hispanic and only 11 percent are white.[159]

The financial stress imposed on lower income levels that depend most on affordable mobility can be compounded by the impact that such access (or lack thereof) has on living costs and location. The traditional measure of affordability recommends that housing cost no more than 30 percent of household income. Under this view, 55 percent of U.S. neighborhoods are considered "affordable" for the typical household. However, that benchmark fails to take into account transportation costs, which are typically a household's second-largest expenditure. When transportation costs are factored into the equation, the number of affordable neighborhoods drops to 26 percent.[160] Even worse is the fact that the tradeoff in housing savings gained at the cost of transportation is eroding, with 77 cents being spent on transportation for every dollar spent on housing.[161] These factors, which in part determine neighborhood and community characteristics, in turn contribute to health disparities by racial/ethnic group, income level, and education level.[162]

To be clear, modal impact on socioeconomic and racial disparities isn't limited to scenarios that depend on personal car ownership. For example, the use of ridesourcing reinforces and in some ways exacerbates transportation systems' existing racially discriminatory patterns.[163] A 2016 survey found that not only is the absolute number of those who ridesource predominantly white, but also that they tend to be affluent (earning $75,000 per year or more) and university-educated (29 percent of college graduates have ridesourced as compared to only 6 percent of those with a high school diploma or less).[164] A separate survey that same year found that Uber drivers in Boston were more than twice as likely to cancel ride requests from African Americans, while African Americans in Seattle faced up to a third longer wait times.[165]

Ridesourcing as a first/last mile solution reveals other disparities as well. While 29 percent of urban residents use ridesourcing regularly, only 7 percent of those in suburbia use it to travel in and around their home region. These numbers and their implications for overall rural mobility are compounded by the fact that access to public transportation in rural areas is limited by travel times and distances, frequency of service, cost, and limitations in funding to address these challenges.[166]

Establishing viable first/last mile solutions and mobility services for seniors and persons with disabilities can be particularly challenging. Only 4 percent of those aged 65 and older have used ridesourcing services, as compared with 36 percent of those 18 to 29.[167] Beyond ridesourcing, specialized transportation services for the elderly, disabled, and economically disadvantaged are provided through more than 80 federal programs. In practice, the sheer number of programs can result in fragmented, hard to use services. Often, geographic barriers, trip purposes and a variety of eligibility restrictions restrict the use of services. As a result, customers need to contact multiple caseworkers for multiple types of trips and book far in advance. Trip times can be inconvenient, with long pick-up windows and circuitous routes.[168]

The intent of this discussion isn't to invalidate any single mode of mobility, but rather to highlight the fact that no single mode should or even can be relied upon as the sole solution. Instead, if the goal is to establish an affordable, universally accessible, and equitable system that enables widespread and convenient mobility that is independent of personal car ownership, clearly an array of travel modes and usage models that complement each other is most appropriate.

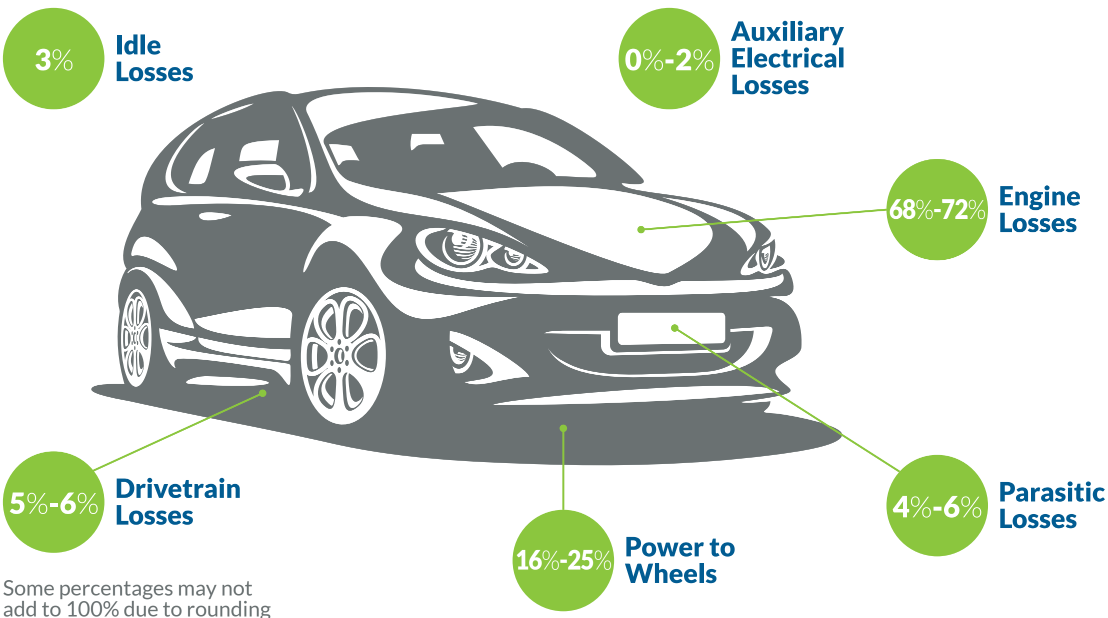
THE “MOBILITY MENU”: DOMAINS, MODES, AND USAGE MODELS

As discussed, 20th century mobility at first included public transport, but soon became dominated, and more or less defined by, the personal automobile. The emergence of this mode led to radical advancements in mobility, in a sense shrinking the landscape and making huge swaths of the country newly accessible.

Yet while it advanced in form, features, safety, and efficiency over the course of the century, the personal automobile remained for the most part the same: a multi-passenger, several thousand-pound vehicle with an internal combustion engine fueled by gasoline and driven on roadways primarily by the vehicles' only occupants. This vehicle leaves a lot to be desired. Take size, for instance: while the average light vehicle mileage-weighted occupancy is less than two (1.67) people,[169] all of the top selling vehicles in the U.S. seat at least four people.[170] Furthermore, these vehicles are rather inefficient. As illustrated in Figure 18, modern vehicles use only 12 to 30 percent of their consumed energy as a motive force; they waste the rest in the form of dissipated heat from engine and other losses.[171]

Changes to the automobile brought about by electrification, connection and automation, and shared mobility will be dramatic, but

Figure 18: Energy Requirements for Combined City/Highway Driving



Source: U.S. Department of Energy

miss a fundamental point: in its most efficient form, mobility is enabled by a system, not a mode. While that system may require multi-passenger, heavy, long-range vehicles at times, at other times it won't.

Many drivers purchase vehicles based on which ones can fulfill every need – from daily jaunts around town, shopping for groceries, and chauffeuring children; to once-a-year roadtrips across the country, and the periodic purchases of appliances and other large items. Yet the data indicates that the ways in which people actually travel can perhaps be better met by thinking differently. Simply stated, the average American man and woman who weigh 195.7 lbs. and 168.5 lbs. respectively[172], should be afforded mobility options that weigh less 4,035 lbs., the average weight for new vehicles produced in model-year 2016,[173] so as to optimize their mode for the travel purpose, mobile efficiency, and transportation expenditures.

For the most part, Americans travel short distances. Table 4 shows how the overwhelming majority of travel is local. In 2017, nearly 60 percent of all trips were five miles or less, and over 85 percent were fifteen miles or less. Only 4.9 percent were 31 miles or more.[174]

Table 4: Vehicle Trips By Distance (2017)

Trip Distance	Sample Size	Sum (Millions)	Percent
Less than 0.5 miles	31,851	11,063	5
1 mile	98,955	36,078	16.4
2 miles	84,856	30,430	13.8
3 miles	64,205	22,820	10.4
4 miles	48,361	17,357	7.9
5 miles	37,449	13,276	6
6 - 10 miles	106,830	38,153	17.3
11 - 15 miles	50,791	18,597	8.4
16 - 20 miles	28,913	10,999	5
21 - 30 miles	27,860	10,747	4.9
31 miles or more	31,228	10,895	4.9
TOTAL	**611,219**	**220,415**	**100**

Source: Oak Ridge National Laboratory

Figure 19 presents the same data visually. When examined this way, trip volume clustering reveals three primary travel domains:

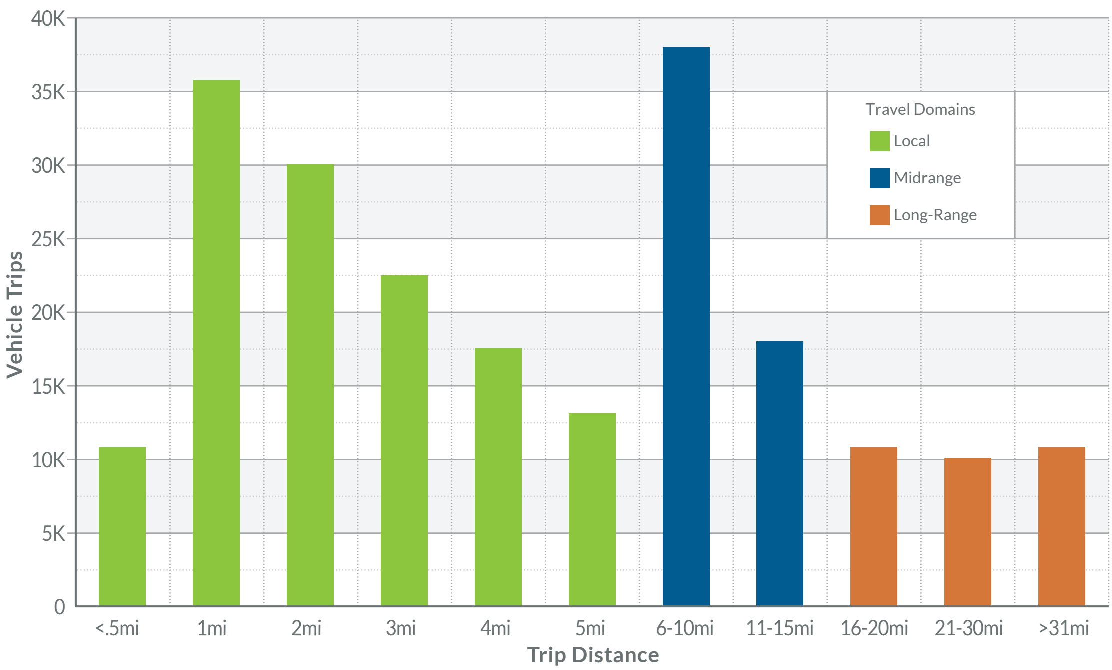
- ***Local Domain:*** Less than five miles, and comprising 59.5 percent of all trips
- ***Midrange Domain:*** Between five and 15 miles, and comprising 25.7 percent of all trips
- ***Long-range Domain:*** Trips greater than 15 miles long, and comprising 14.8 percent of trips

Understanding the way in which people travel and the domains associated with the clustering of trips is the basis for which we can now review emerging electrified, connected and automated, shared vehicles that are appropriate for each domain. Thus, when interconnected and layered upon the "backbone" of public transit, they can form the basis for a mobility system that solves the first/last mile challenge and enables personal mobility at a level equal to or better than that afforded by personal car ownership, while being more functionally appropriate for a given trip.

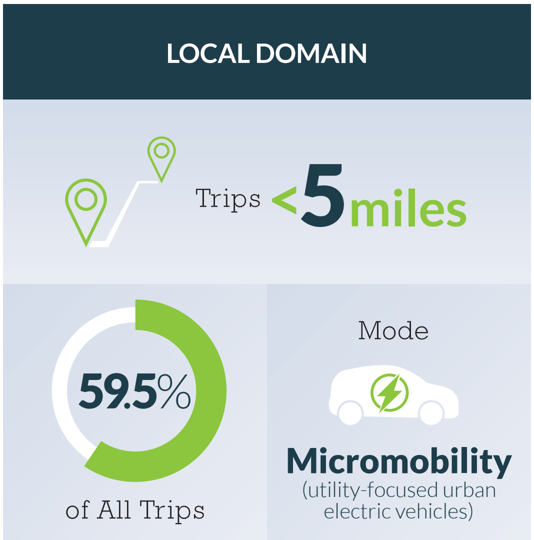
LOCAL DOMAIN: MICROMOBILITY FOR < 5 MILE JOURNEYS

Nearly 60 percent of all trips are within the Local Domain, which consists of trips less than five miles long. Vehicles designed around this domain are at the heart of solving the first/last mile challenge, and represent a significant opportunity for manufacturers and service providers.

Figure 19: Number of Vehicle Trips by Trip Distance



Source: Oak Ridge National Laboratory



Micromobility comprises just such a group of vehicles. While no official definition of micromobility exists, one proposed definition orients modes around weight classes by defining micromobility as utility-focused urban electric vehicles that weigh up to 500 kilograms (approximately 1,100 lbs.).[175] The logic for such a proposal correlates weighting with distance: ships, trains and airplanes are all very heavy and have very long ranges, while the smallest vehicles are very lightweight and have short ranges.

The first micromobility vehicle, the Segway, arrived in December 2001. But at a $4,950 price point and lack of modern day geo-locating, sharing-enabling, and other mobile phone and "gig" economy technologies, the company only sold about 100,000 units over 17 years.[176, 177] Yet by advancing the technology and building out a nimble, two-wheel, battery electric vehicle that could solve the first/last mile challenge,[178] it paved the way for the modern age of micromobility, which some consider to be comprised of three categories of vehicles based on their size: 1) Unicycles and motorized skateboards; 2) folding bikes and scooters; 3) enclosed velomobiles and featherweight cars.[179] Of these three, shared electric scooters and bicycles are the dominant driving force for micromobility's rising popularity and market growth.

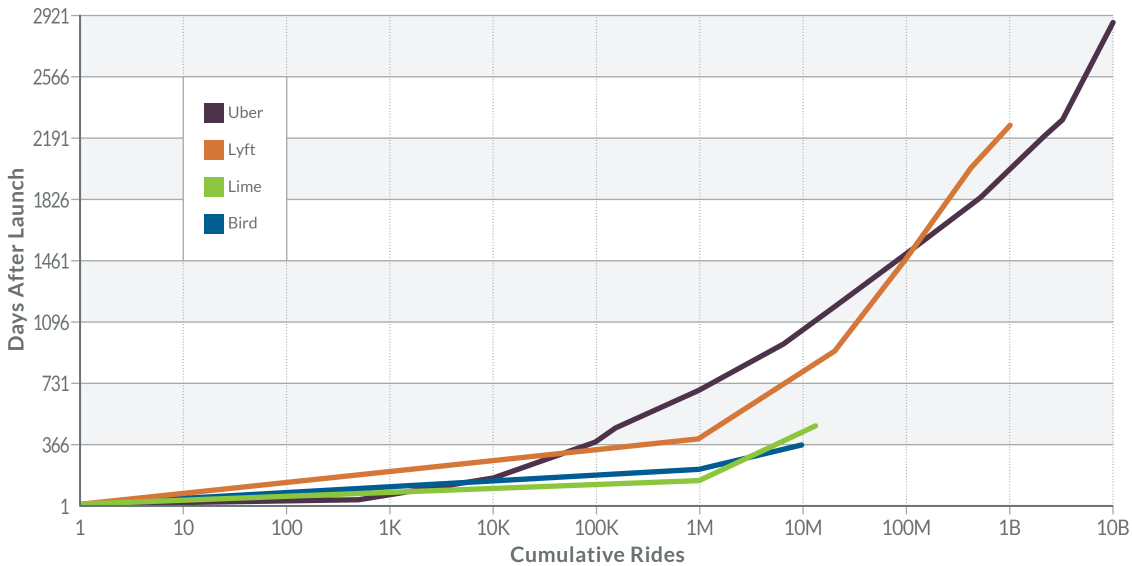
SHARED SCOOTERS AND BICYCLES

Long viewed as children's toys, scooters emerged as a viable and practical mobility mode in 2017. Two leaders quickly emerged: Lime, which was founded in San Mateo, Calif. in January, and Bird, which was founded in Santa Monica, Calif. in September. At the time of publication, both companies had scooters in service in over 100 cities around the world.[180]

Bird's and Lime's scooters were originally made by Chinese manufacturers Ninebot or Xiaomi, and retail for around $500. They have a top speed of around 15 mph and a range of around 15 miles.[181] In October 2018, Bird announced the Bird Zero, its new scooter that's built in-house, has 60 percent more battery life, improved ride stability and durability, and other advanced technologies.[182] Lime plans for its "Gen 3" scooter to be designed in-house by engineers in California and China and built by four different unnamed manufacturers. In addition to being more technology-enabled, stable, and durable, its battery will reportedly last 30 miles – about 20 percent longer than the current generation scooter.[183] Other notable scooter manufacturers and operators include Skip, Scoot Networks, Spin, and Razor.

Since its launch, the growth of scooter ridership and markets has been exponential. Bird facilitated over 10 million cumulative rides

Figure 20: Days to Reach 10 Million Cumulative Rides



Source: Horace Dediu

in less than two years, and Lime took just one year from its launch to reach 6 million rides, and reached 20 million rides by November 2018. Importantly, it's not just wealthy people taking these rides; lower income groups are more likely than high-income groups to approve of shared scooters.[184] This broad-based popularity is a factor in the mode's rapid growth. As illustrated in Figure 20, scooter growth rates far exceed those experienced by transportation network companies (TNCs) Uber and Lyft, which took over twice as long to reach 10 million rides.

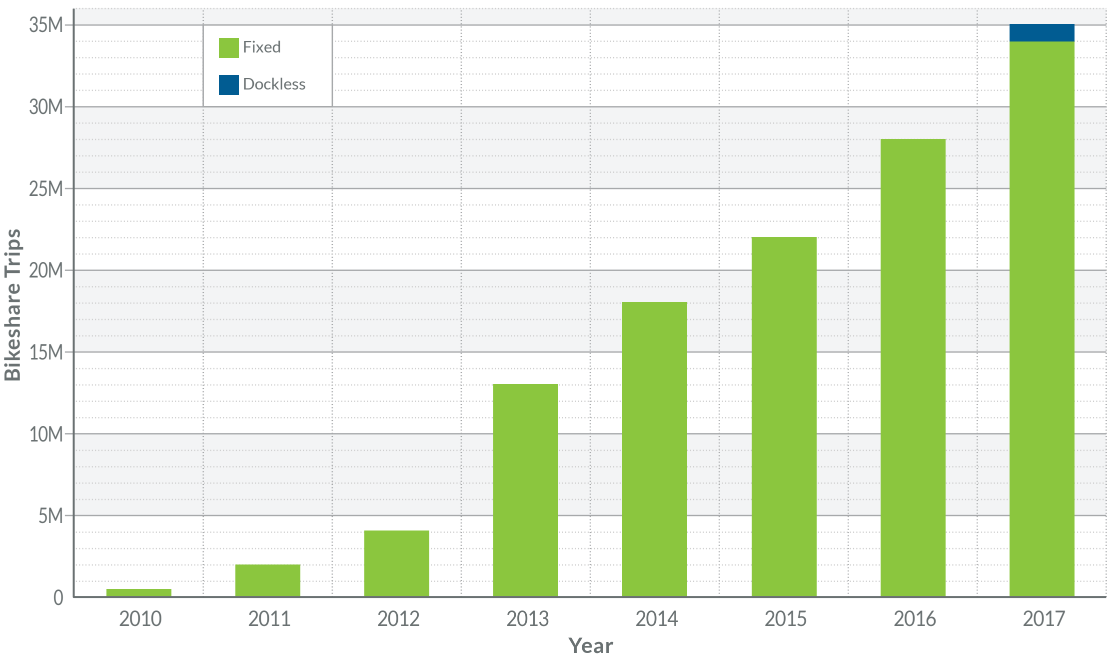
A main driver of this scooter boom has been the rise of the dockless system, which allows users to park anywhere rather than in a fixed docking station, and is more convenient and less costly to scale given lower capital costs, as operators don't have to build out fixed stations. Dockless systems were enabled by some of the same technologies whose mass-market consumer orientation was brought about by the smartphone, including GPS and mobile payments. Using these technologies, renting a scooter for a few minutes or miles is as simple as calling up a smartphone app, following the app's directions to the nearest scooter, scanning the scooter's barcode, and scooting away. The gig economy framework also enables dockless systems. At the end of each day, the scooters are collected, charged overnight, and redistributed the following morning by contractors who collect bounties based on the number of vehicles they service, the vehicles' locations, and their states of charge. Another primary driver of the scooter boom is that traffic congestion in most U.S. cities is increasing, resulting in it being faster in some instances to travel short distances (such as scooters' average trip lengths of 1.06 miles[185]) using micromobility instead of cars.[186]

While the mode of travel is still relatively new and – until recently, their user data collected by the companies kept private, making comprehensive research difficult – preliminary data indicates that scooters are offsetting a large number of car trips and have the potential to offset even more. Lime reports that 53 percent of riders in San Francisco said they might have used a car if they hadn't taken a scooter.[187] Bird believes it's possible to replace a large percentage of the nearly 40 percent of car trips in the U.S. that are less than two miles.[188] Scoot estimates that the various small, electric vehicles could make up 25 percent of all travel within global urban centers over the next 10 or 20 years.[189]

Scooters aren't the only Local Domain mode capable of replacing car trips and affording connections to transit. Bicycles are showing similar capabilities. Bikeshare has both dockless and docked models. While the dockless versions are rented and returned in the same manner as dockless scooters, docked shared bicycles must be checked out from and returned to designated docks located at fixed points.

Interestingly, while the dockless technology proved decisive in enabling scooter sharing, it is less decisive in enabling bikesharing. In fact, a Seattle dockless bikeshare pilot project showed dockless pedal bikes were only being rented an average of 0.85 times a day. That's less than half the rate of Chicago's Divvy, which sees more trips out of 5,800 bikes than Seattle saw out of 10,000 bikes. New York's Citi Bike, with 12,000 bikes, produced an average of 51,800 daily trips over six months, more than five times the rate in Seattle.[190] Altogether, while three-quarters of the new bikeshare bikes were dockless (comprising 44 percent of total shared bikes) and averaged 1.7 rides per day per bike in the U.S. in 2017, dockless bikes made up only 4

Figure 21: Dockless Bikes Represent A Small Portion Of Bikeshare's Growth



Source: National Association of City Transportation Officials percent of the 35 million bikeshare rides taken that year and averaged 0.3 rides per day per bike (see Figure 21).[191]

That said, it should be noted that dockless bikeshare only arrived in most cities in the second half of 2017, and many of the systems did not make their data available for review. This is important, for a recent survey found that 75 percent of dockless bikeshare riders in Seattle used the service to access transit. Micromobility data in Washington D.C. indicates African-American residents (representing 47 percent of the district's population) adopted dockless services 2.6 times more than docked services (compared to 1.2 times more for white residents).[192] This data potentially indicates that while its percentage of ridership may be relatively small, the value of dockless micro-modes to the broader mobility ecosystem may be large.

Instead, electrification seems to be more of a bikeshare growth factor, for according to Lime, electric bikes ("e-bikes") are twice as popular as pedal bikes.[193] The company found that battery-boosted bikes and scooters are able to attract more riders per day than traditional bikes, and they also found that when scooters are introduced to a market, bike usage also increased. New York's Citi Bike e-bikes are averaging 14 trips per day, while traditional bikes are averaging only seven rides.[194]

In addition to fueling growth, e-bikes can displace cars. An early 2018 poll by the National Institute for Transportation and Communities of nearly 1,800 e-bike owners in North America asked respondents why they bought electric bikes, what kind of trips they use them for, and how e-bikes compare to conventional bikes when it comes to barriers to cycling. 28 percent of respondents said they bought an e-bike specifically to replace car trips. Others pointed to craving a more car-free lifestyle, such as using e-bikes to carry cargo or kids, avoid parking and traffic woes, be more environmentally minded, and have a more cost-effective form of transportation.[195]

The bikeshare market has expanded significantly in recent years. In the first 18 months or so since dockless bikeshare arrived in the U.S., it spread to over 88 cities.[196] In 2017, 35 million bikeshare trips were taken in the U.S., which is 25 percent more than in the year before, and over 57,000 new bikes were added to systems, more than doubling the number available the previous year.[197] China-based Ofo, which has served over 200 million users in over 25 cities in 21 countries around the world, went from providing an average of 300,000 rides per day in the first quarter of 2017 to an average of around 30 million rides per day by mid 2018 on its bike and scooter networks worldwide, which is almost as high as the average weekday ridership of all U.S. public transit systems combined.[198] That said, whether bikeshare will experience growth levels similar to scooters remains to be seen. Results of various pilot programs indicate that riders prefer scooters to bikes, perhaps because of the inherent features of scooters, or perhaps due to highly restrictive dockless bikeshare pilot rules imposed by some city governments.[199]

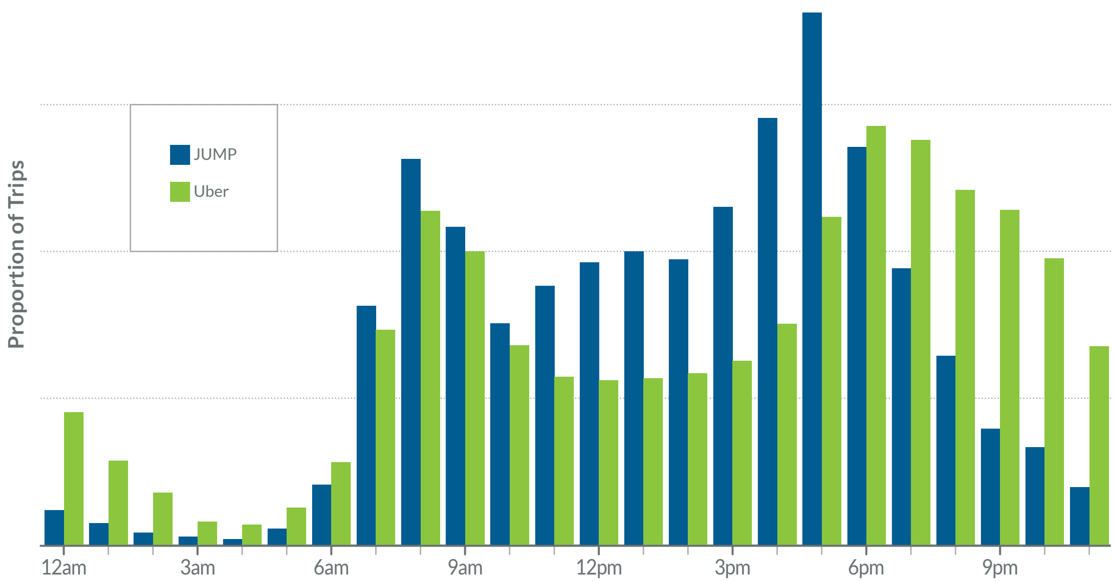
With such growth, the market potential of scooter and bike share is apparent not only to investors but also to other mobility providers. Lyft and Uber have acquired and/or offered scooters and bikesharing to travelers in select markets via their respective smartphone apps. In April 2018, Uber acquired bike-sharing company Jump Bikes, which operates in 40 U.S. cities. Three months later, Lyft bought

Motivate, the largest bikeshare operator in North America[200] and the operator of New York City's bikeshare program that Citi once paid over $40 million to sponsor.

Around the same time, Uber announced a "new modalities" unit to focus on new forms of transportation, including its bikesharing business. A month later, the company announced that it would offer Jump-branded scooters, built by Chinese manufacturers, in Santa Monica and San Francisco, but also quietly began working on building its own scooter.[201] In September 2018, Lyft launched its scooter business in Denver, Colo. as part of a one-year pilot program.[202] Even traditional automakers are partaking in the action: Ford piloted a scooter under the brand name Jelly on the campus of Purdue University in late 2018[203] and acquired Spin in November 2018.[204] In late 2018, General Motors announced plans to start making electric bikes.[205]

At this pace, the odds are that the landscape for shared scooter and bicycle brands, markets, and investors will be different – perhaps dramatically – within the near future. Yet the important point made by the frenzy of activity and modal usage patterns will remain in that scooters and bicycles have proven themselves a viable component of shared mobility that can serve the Local Domain to connect users to transit and offset the use of cars. UC Berkeley found that bikesharing does impact how people drive. In Montreal, over a quarter of surveyed people reported that they drove their car less, and in Toronto, one third reported that bikesharing changed their driving habits. Five percent of respondents to the UC Berkeley survey as well as a separate survey in Washington D.C. indicated that bikesharing had an impact in prompting them to sell their car. Figure 22 depicts Uber data released six months after its acquisition of Jump illustrating how new riders in San Francisco were likely to use Jump bikes instead of cars, especially during hours of

Figure 22: Proportion of Uber Trips Represented by Bikeshare vs. Ridesourcing



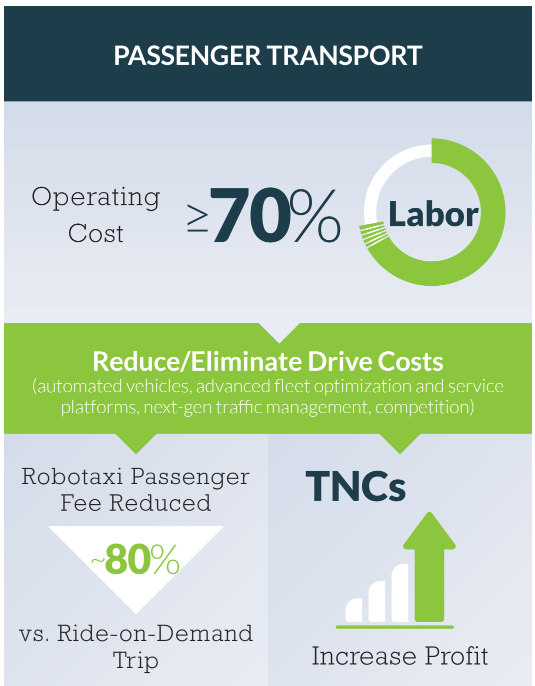
Source: Uber

peak congestion. The data also shows how the two modes exhibit temporal complementarity, with ridesourcing usage higher during the nights when riders may be less likely to ride a bike.[206] Such data may become more pronounced as the company now explicitly encourages its customers to book bicycles instead of cars for short urban trips.[207]

AUTOMATED VEHICLES AND MODES FOR THE LOCAL DOMAIN

In early 2015, Uber made what some considered at the time to be a stunning announcement. The ridesourcing company, made famous for enabling private car owners to earn income by using their own vehicles to ferry around passengers, would open the Uber Advanced Technologies Center – a research and development center in Pittsburgh to study and advance highly automated vehicles, with the eventual goal of removing the driver from the equation. The launch of Uber's self-driving car efforts was followed in July 2017 by Lyft's announcement that it too would be pursuing the development and commercialization of automated vehicles. It launched an open platform that allows manufacturers and self-driving systems to plug into its network, to gain access to a diverse set of real-life scenarios, and to develop their systems around actual experiences and behaviors[208] in an effort to bring automotive and technology companies onto this single platform to serve a nationwide passenger network.[209]

Yet traditional TNC's aren't the only ones pursuing automated ridesourcing. General Motors, who acquired Cruise Automation in 2016, aims to deploy a driverless taxi service beginning in some U.S. cities in 2019.[210] In December 2016, Volkswagen Group launched a new, stand-alone brand dubbed Moia, which is focused on providing mobility solutions including automated on-demand transportation.[211] A year later, Moia released its first vehicle, an electric six-passenger van that is centered around ridesourcing.[212] Toyota and SoftBank formed a joint venture called Monet Technologies that will roll out an on-demand mobility service using Toyota's self-driving, battery-operated electric vehicle called e-Palette for various purposes.[213] Tesla has intentions of operating "...its own ride-hailing service" that "will compete directly with Uber and Lyft." The service, dubbed the "Tesla Network," will also offer the ability for consumers to send their own cars out into the fleet, "just like how you share your house with Airbnb."[214] Perhaps the most well known automated vehicle technology developer of them all, Waymo (incubated by Google), plans on operating a ridesourcing network served by vehicles it has fitted with its own technologies.



The logic behind these respective companies' decisions to invest in automated shared mobility is sound, for human drivers currently account for a significant percentage of transport's overall costs. By one estimate, the operating cost of all passenger transport is at least 70 percent labor.[215] In fact, the shift towards shared electric automated vehicles – combined with more advanced fleet optimization and servicing platforms, next-generation traffic management and more intense competition – can reduce the fee charged to passengers of robotaxis by as much as 80 percent versus a ride-on-demand trip today.[216] By reducing or even eliminating driver costs through the use of automated fleets, TNC's can improve their profits. Yet they can also tap into what's perceived to be a much larger and higher margin market that offers vehicles as ongoing service providers rather than as one-time sales to customers. General Motors believes that operating its own network of automated ridesourced vehicles could in the long-term generate profit margins of up to 30 percent, versus the nearly 9 percent margin it posted globally in 2017.[217] The Boston Consulting Group estimates that by 2030, automated ridesourced fleets could account for one-quarter of miles driven in the U.S.[218] Intel, whose processors are used in some automated vehicles, foresees this new, so-called passenger economy – when today's drivers become passengers in driverless cars, shuttles and other vehicles – generating as much as $800 billion by 2035 and $7 trillion by 2050.[219]

The focus on using automation to reduce ridesourcing costs is prudent given that the current economics are in some cases challenging. One analysis concluded that, in many scenarios, ridesourcing could be more expensive than private car ownership. It used data from 243,838 economy-level, single-rider trips in the 20 urban markets, premised on an average of $13.15 per 6.66-mile trip, and including the use of rental cars for longer trips. It calculated that ridesourcing as primary transportation would cost an average of $20,118 a year, whereas the average cost to own and operate a new vehicle in urban areas is $10,049 for the equivalent miles driven.[220] It's important to note that ridesourcing fares in many markets are subsidized[221] and thus the true discrepancy between ridesourcing and vehicle ownership using this analysis' methodology would likely be larger.

The possible economic boon that may emerge prompts former General Motors engineer and current Waymo advisor Larry Burns to call automated ridesourcing "the $4 trillion disruption." Burns calculated this number as follows:

- Americans travel more than 3 trillion miles a year.
- The total cost of owning and operating a car is about $1.50 per mile.
- Even with the added cost of AV technology, a driverless car costs only about 20 cents per mile.
- A driver could save $5,625 a year using a shared, driverless electric car instead of a privately owned vehicle.[222]

But automated ridesourcing in dense, urban environments, where they could presumably earn the most revenue, is immensely complicated and even companies that are the furthest along in the technology (e.g., Waymo and GM) have struggled to develop self-driving vehicles that can navigate tricky traffic scenarios safely and without irritating other drivers on the road.[223] In some cases, these challenges may be delaying deployment plans.

THE $4 trillion DISRUPTION

>3T miles per year	~$1.50 per mile	~$0.20 per mile	$5,625 per year
Distance Traveled by Americans	Cost of Owning and Operating a Car	Cost of Operating Driverless Car	Saved by Drivers Using Driverless EVs

Source: Larry Burns, The Great Auto Disruption

For example, while GM planned to deploy automated taxis in 2019, unexpected technical challenges (such as a vehicle's ability to identify whether objects are in motion) mean that some now believe that deployments at scale in 2019 are highly unlikely.[224]

Not all ridesourcing scenarios are as challenging as dense, urban environments though. Operational domains comprised of more compact and constrained geographies, especially those that can be precisely mapped and restrict a vehicle to lower speeds, are more easily solvable. This recognition has, in part, given rise to an automated vehicle mode that can well serve the Local Domain. Small, 25 mile-per-hour automated shuttles built by the likes of companies such as Navya, EasyMile, and Aurrigo have become the focus of many pilot programs and automated vehicle demonstrations around the world. For some of these efforts, the shuttles operate along fixed routes only a few miles long, while others are seeking to advance the mode's role in society. Research shows current AV shuttle projects average about 1.5 miles per trip, carrying about nine passengers at a time.[225] They facilitate community introductions to automated vehicles, gather feedback from community members and data on vehicle usage and popularity, and to learn whether such AVs can earn the consumer confidence to move further onto the road.

Keolis Transit has been operating Navya's 15-passenger AUTONOM SHUTTLE in Las Vegas since November 2017. It is one of the more substantive pilot programs in the nation in terms of hours clocked, passengers carried, and function served. The shuttle operates along a tourist-heavy street, crosses eight intersections, six traffic lights, and two stop signs on its circular route, and has transported more than 35,000 passengers as of September 2017.[226]

While the largest automated shuttle pilot in the U.S. and the first to deploy an automated shuttle on public streets in mixed traffic, Las Vegas is by no means the only community seeking to trial and advance a practical role for automated ridesourced shuttles in society.

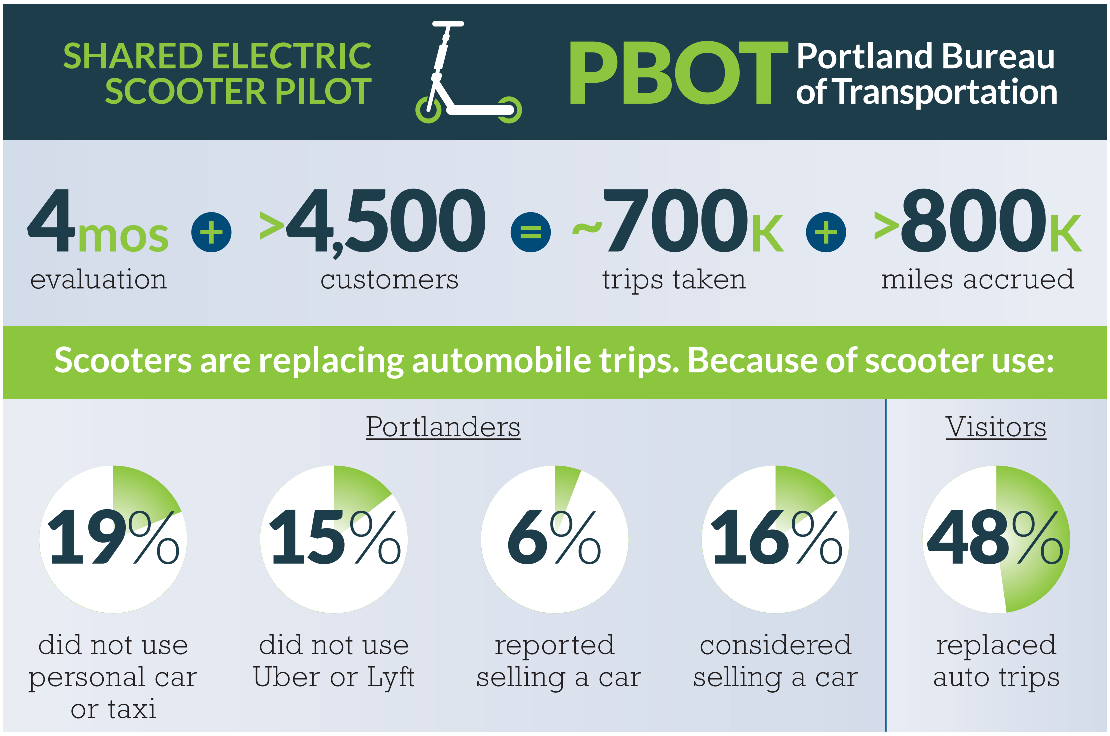
Ann Arbor, Mich.-based startup May Mobility deployed a fleet of automated six-seat shuttles in June 2018 to transport Quicken Loans employees for free along a one-mile loop, on which it completed its first 10,000 trips in 75 days. Rather than selling vehicles to service providers or transit agencies, the company offers a fully-managed transit service that includes the vehicles, maintenance, and site operations crew. May Mobility is building upon this first pilot with efforts in other cities, including Columbus, Ohio where it launched a trial in partnership with the Ohio Department of Transportation in October 2018. The pilot was comprised of three shuttles operating at 15 miles-per-hour, seven days a week, from 6 a.m. to 10 p.m. for one year around a roughly one-mile loop adjacent to the city's downtown riverfront park. The plan is to expand the trial in 2019 and test first/last mile routes through low-income neighborhoods to help make transit more equitable.

In Arlington, Texas, a 12-passenger automated shuttle manufactured by EasyMile that was dubbed "Milo" operated from August 2017 to August 2018 at 15 miles per hour on off-street trails in the Entertainment District, providing free rides to visitors and citizens at over 110 events. The electric shuttles operated for public demonstrations and before and after major events at AT&T Stadium and Globe Life Park. Ridership surveys showed that 99 percent of Milo riders enjoyed riding and felt safe riding in the vehicle.[227]

In Chamblee, Ga., stakeholders see automated shuttles as not only the answer for first-mile/last-mile concerns, given that the city is on the Metropolitan Atlanta Rapid Transit Authority line, but also a way for the city to grow an already large millennial population. The city seeks to trial such shuttles by working with the Georgia Institute of Technology and Stantec Urban Places, which is looking into possible routes, fares and other factors to operate a circulator shuttle in downtown.[228] Austin, Texas is also testing automated transit shuttles, and is planning to deploy up to a half dozen.[229]

Others are already working to use such shuttles as resources for public transit. Bishop Ranch business park in the San Francisco Bay Area partnered with automated shuttle service company EasyMile to connect the office park to a local train station.[230] Ruter, the mass-transit company for the Oslo metropolitan area, signed an agreement in late 2018 with Danish company Autonomous Mobility involving several automated shuttle pilot schemes beginning in 2019 and, in the longer run, tests of a fleet of up to 50 vehicles.[231] Finally, in March 2018, the Neuhausen transit authority in the Swiss state of Shauffhausen was the first in the world to incorporate an automated bus into regular route public transit in mixed traffic.[232]

In their effort to experiment with functionality and prove out different models for how they can aide with mobility, some automated shuttle manufacturers push up against technological, regulatory, or other barriers that impair the mode's advancement. For instance, NHTSA stopped a Florida pilot that sought to transport children to school using an EasyMile automated school bus operated by Transdev. According to NHTSA, Transdev was granted permission to use its driverless shuttle for a specific demonstration project, but not as a school bus. Buses, the agency notes, are subject to strict federal safety standards.[233]



SNAPSHOTS

Recent micromobility pilot programs documented its potential to displace automobiles, and furthered the development of tools and approaches to overcome modal challenges.

Portland, Ore. Scooter Pilot Shows Automobile Trip Displacement

The Portland Bureau of Transportation (PBOT) conducted a four-month shared electric scooter pilot the second half of 2018 in order to evaluate whether the mode can contribute to the city's mobility, equity, safety, and climate action goals.[234]

As part of this evaluation, PBOT surveyed more than 4,500 customers of Bird, Lime and Skip, the three companies permitted to operate e-scooters in Portland. The wide-ranging survey asked customers about their riding habits, their perceptions of scooter safety and popularity and whether they replaced car trips with scooter rides.[235]

With nearly 700,000 trips taken and over 800,000 total miles accrued, the survey found that scooters are replacing automobile trips. Thinking of their last e-scooter trip, 19 percent of Portlanders said they would have driven a personal car or hailed a taxi, and 15 percent would have taken Uber or Lyft had scooters not been available. The auto trip replacement numbers are even higher among tourists and visitors (48 percent). Additionally, the survey found that Portlanders are reducing or considering reducing their auto ownership due to scooters. 6 percent of users reported selling a car because of scooters and another 16 percent have considered it.[236]

Additional findings include:

- Portlanders are using e-scooters for transportation and recreation. Nearly a third of the Portlanders who responded to the survey said they most frequently used e-scooters to commute – to get to work, school, or a work-related meeting. Another third stated they most frequently used e-scooters for fun or recreation.
- Scooters are popular with local users. Eighty-five percent of Portlanders said they were "extremely" or "very likely" to recommend scooters to a friend.
- Among all respondents, e-scooters appear to be more popular among men (62 percent) than women (36 percent).
- All respondents – Portlanders and visitors – prefer to ride e-scooters on the street or in the bike lane over off-street trails, and riding on sidewalks was users' least preferred option.
- E-scooters are bringing new Portlanders to the bike lane. Forty-five percent of survey respondents reported "never" biking and 78 percent had never used the city's bikesharing system prior to using e-scooters.

Furthermore, it appears that the e-scooters might help increase bikeshare ridership. PBOT data shows that there were only five weeks during the scooter pilot program when the city bikeshare system's ridership decreased from the same weeks in 2017. Most weeks, bikeshare rides increased, in some instances by as much as 72 percent.[237]

Santa Monica's Shared Mobility Pilot Program Addresses Array of Scooter and Bike Issues

In September 2018, the City of Santa Monica, Calif. launched a 16-month Shared Mobility Pilot Program that aims to inform the development of long-term policy solutions to expand sustainable mobility options equitably while protecting public safety on city streets and sidewalks.[238, 239]

Specifically, the goals of the program are to:

- Improve access to mobility options for residents, employees, and visitors to Santa Monica.
- Create new options that meet diverse use cases in support of a new model of mobility.
- Ensure safety and public access by reducing sideway, pathway, and ADA blockages.
- Educate users about the proper rules and etiquette for shared mobility devices.
- Create a legal and enforceable framework for managing shared mobility service providers in the Public Right of Way (PROW).
- Build a good working relationship with shared mobility providers to protect the PROW while advancing new mobility options in Santa Monica.

To accomplish these goals, the program will:

- Set a dynamic device cap based on utilization.
- Require vendors to create interactive safety education for users and increase the availability of helmets for riders at the time of use.
- Require operators to share real-time utilization data with the City.
- Ensure equitable distribution throughout the City.

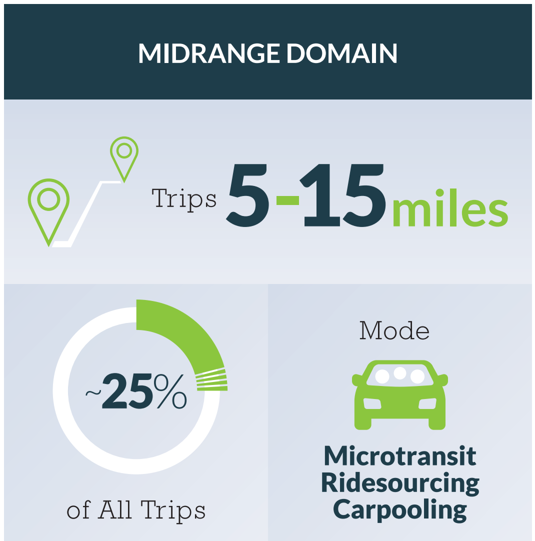
- Require operators to develop systems that will remedy improper parking, including pick up/drop off zones and incentives.
- Enhance operator customer service and responsiveness to resident and user complaints, including a 24-hour hotline.
- Set forth a broader list of recommended program components through which partners could be evaluated during the pilot term.

In August 2018, the city began installing drop-off zones for scooters, initially on sidewalks. The city reports that there were 19 sidewalk corrals and four in-street corrals as of November 2018, with the aim of having roughly 100 corrals by April 2019, about half on sidewalks and half in-street.[240]

Santa Monica also seeks to become an innovation testbed for dockless programming and policy. To assist with this effort, the city will use a mobility data platform, which was developed by the Los Angeles Department of Transportation (LADOT), to manage dockless data and infrastructure and set up systems. One system the city is testing is geo-fencing with Lime and Bird scooters, which enables the vehicles to detect their location and automatically slow down or stop to abide to the speed or usage limits in the respective zones.

MIDRANGE DOMAIN: SHARED RIDE MODES FOR 5-15 MILE JOURNEYS

About 25 percent of all trips are within the Midrange Domain, which consists of trips between five and 15 miles long. Modes that serve the Midrange Domain are those that provide larger vehicles to shuttle people between frequently-visited locations, such as places of work and shopping.



In essence, effective modes within the Midrange Domain are enabled by the volume and frequency of travel demand within the domain. They consist of private and corporate fleet-owned and driven vehicles. Vehicles that are in service are never unoccupied.

Primary modes that serve the Midrange Domain include microtransit, ridesourcing, and carpooling.

MICROTRANSIT, RIDESOURCING, AND CARPOOLING

Microtransit companies, such as Via, use smartphone and other technologies to match multiple riders going in the same direction with vehicles following flexible, optimized routes and schedules in an effort to maximize efficiency and quality of service.[241]

Microtransit operators target commuters, primarily connecting residential areas with downtown job centers. However, there are opportunities for microtransit services to either expand into the paratransit space or for paratransit to innovate along similar lines. The use of advanced technology has the potential to lower operating costs for services that target special populations, such as disabled, older adults, and low-income groups.[242]

Microtransit services typically include one or more of the following service characteristics:[243]

1. **Route deviation:** vehicles can deviate within a zone to serve demand-responsive requests;
2. **Point deviation:** vehicles providing demand-responsive service serve a limited number of stops without a fixed route between spots;
3. **Demand-responsive connections:** vehicles operate in a demand-responsive geographic zone with one or more fixed-route connections;
4. **Request stops**: passengers can request unscheduled stops along a predefined route;
5. **Flexible-route segments:** demand-responsive service is available within segments of a fixed-route; and
6. **Zone route:** vehicles operate along a route corridor whose alignment is often determined based on user input, with fixed departure and arrival times at one or more end points.

While much discussion about microtransit has been in the context of public transit, it's more appropriate to frame its discussion within the context of the Midrange Domain given its functionality. Specifically, microtransit can only replace (or enable) public transit in the same situations that ridesourcing and carpooling can. These include low-volume, nighttime, and rural routes. Microtransit can't be an effective replacement of high-throughput urban transit service for dense neighborhoods. What it can be is more efficient ridesourcing platforms, given vehicles' 15-passenger or so capacities compared to passenger vehicles' four seats.

A number of microtransit services in the U.S. are beginning to experiment with ridesourcing platforms. In Los Angeles, on-demand, microtransit service FlexLA launched in October 2018 to shuttle users around downtown.[244] The San Mateo County Transit District (SamTrans) in California began testing an on-demand microtransit route in late 2018.[245] In 2016, Alameda-Contra Costa Transit District (AC Transit) in the east San Francisco Bay initiated the Flex pilot that sought to replace low-performing bus routes with a responsive system that allowed users to book rides online ahead of time.[246] Also, a partnership between Arlington, Texas and microtransit provider Via created a service that aggregates information on people heading in the same direction, displays options for shared rides with nearby pick-up points, and delivers passengers to select stops around town for a flat $3.00 fare.[247] These and several other microtransit efforts throughout the U.S. indicate the significant market potential for microtransit. In fact, an August 2018 analysis found that corporate, public, and chartered shuttles that comprise microtransit are projected to account for more than 60 percent of the demand-responsive transit (DRT) market, which is poised to grow from $2.8 billion in 2017 to $551.61 billion in 2030, and that shuttles could comprise approximately 50 percent of the overall shared mobility market.[248]

While microtransit fleets are primarily owned and operated by companies, modern day ridesourcing uses technology that enables private vehicle owners themselves to transport third parties. In this way, ridesourcing also differs from scooters' and bicycles' application of dockless technologies in that ridesourcing technologies establish markets rather than enable the use of the vehicle itself or the management of its fleet.

Ridesourcing is perhaps the most prominent mode in the Midrange Domain. If applied as part of a system, it has the potential to reduce costs, enhance efficiencies, and reduce congestion. Yet the results of recent studies highlight mixed results on these fronts.

Some studies have highlighted positive prospective outcomes. For instance, Arizona State University found that ridesourcing services such as Uber significantly decrease traffic congestion in urban areas – perhaps due to an increase in vehicle occupancy, a reduction in car ownership, a shift among different traffic modes, the impact of surge pricing, and/or increases in vehicle capacity utilization.[249] Massachusetts Institute of Technology's (MIT's) Computer Science and Artificial Intelligence Laboratory (CSAIL) determined that a ridesourcing fleet of 3,000 cars could perform the duties of all 13,000 New York City taxis.[250]

Alternately, the University of Colorado concluded that ridesharing increases traffic and makes transportation systems less efficient by mode-shifting passengers away from transit, biking, and walking trips.[251] That study's same authors, now with NREL, found that ridesourcing leads to approximately 83.5 percent more VMT than would have been driven had it not existed, partly due to the fact that at least 40.8 percent of VMT are deadheaded (i.e., without passengers).[252] Another study drew a similar conclusion regarding Uber's operations in New York City, noting that in 2013 (the last year before Uber's presence was felt in the city) use of subways, buses, and bicycles grew substantially, while by 2016 the net growth in travel by Uber and other TNC's far outstripped growth in those modes, tripling between June 2015 and the fall of 2016.[253] A December 2017 study

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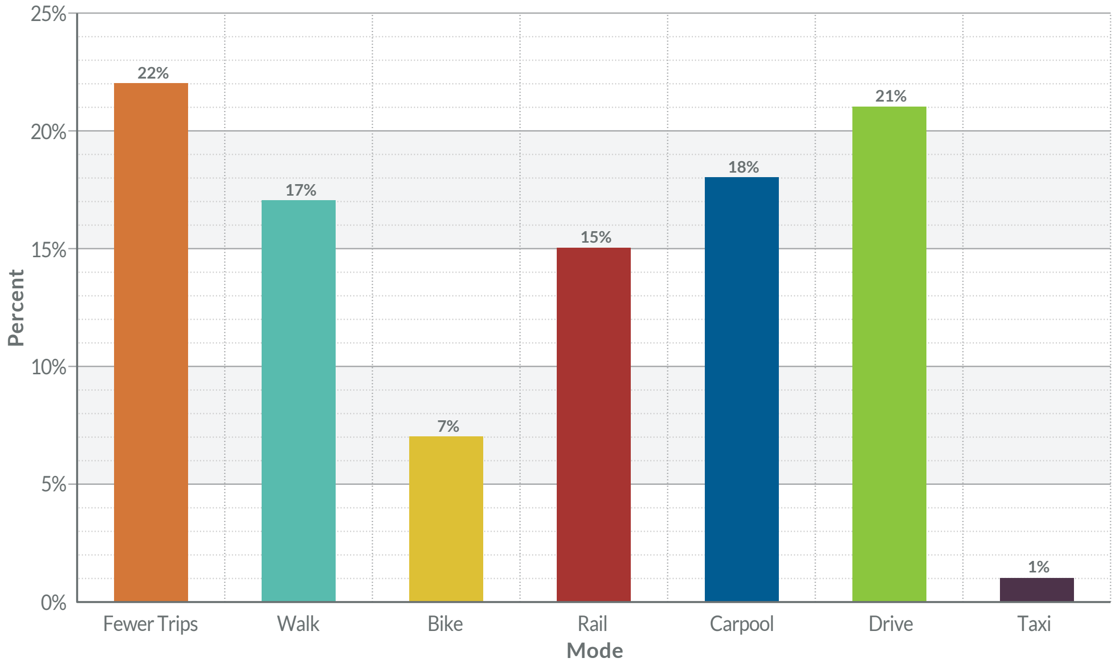
showed that each mile of personal driving Uber and Lyft eliminated added 2.8 miles of professional driving, representing a 180 percent increase in total traffic, and that a 15 percent increase in ride-hailing trips can put 59 percent more vehicles on the streets, 30 percent of which are deadheaded.[254] Perhaps most alarming, the University of Chicago determined that not only does ridesourcing increase the number of car registrations by 3 percent, it also increases the number of fatal accidents by 3 percent.[255]

The UC Davis Institute of Transportation Studies surveyed 4,000 users in seven major metro areas between 2014 and 2016. It concluded that "…[ridesourcing] is likely adding vehicle miles traveled to transportation systems in major cities" due to the fact that between 49 and 61 percent of trips either wouldn't have been made at all, or would have been accomplished via transit, carsharing, bike, or foot. Regarding vehicle ownership among users who don't use transit, there are "no differences in vehicle ownership rates between ride-hailing users and traditionally car-centric households."[256]

While concerning, many studies indicating that ridesourcing is worsening traffic congestion, VMT, and other metrics are far from conclusive. In fact, some studies draw mixed or incomplete conclusions. For instance, the San Francisco County Transportation Authority (SFMTA) concluded that Uber and Lyft were responsible for 51 percent of the daily vehicle delay hours increase, 47 percent of the increase of vehicle miles traveled, and 55 percent of the average speed decline on roadways in the city between 2010 and 2016.[257] Yet a challenge in drawing such conclusions comes from the fact that historically, service providers – and others who impact congestion – are private and, thus, some if not most of their trip data is inaccessible. The SFMTA study didn't have exact information on the growth of freight and delivery during the sample period, which is when services such as Amazon Prime grocery delivery grew exponentially. Nor did it have information on construction in the region, which could also have contributed to traffic slowdowns. This lack of information is in addition to the shortage of data from the TNCs themselves, thus leading a lot of the data to be induced or inferred.

This is starting to change, for while ridesourcing companies are still resistant to sharing their data, larger markets such as New York City have been successful in negotiating access as part of granting jurisdictional provisions to operate. As cities now deal with the rapid influx of scooter sharing, it seems that many have learned from experiences managing ridesourcing by insisting on access to travel data. As more data flows from private to public companies – and as cities figure out the best ways to aggregate, integrate,

Figure 23: Stated Modeshare if Ridesourcing Weren't Available Indicates an Addition of Vehicle Miles Traveled



Source: UC Davis

and process multimodal data – greater insight will be gained into how shared mobility affects the broader transportation ecosystem, which in turn will help cities and other decision makers make wise policy choices.

We've also entered an age of adaptation and innovation for ridesourcing, as providers begin offering features and services that go beyond simply matching drivers with passengers and according a price-per-mile and time. The first innovations were shared ride services, such as Lyft's "Lyft Line" and Uber's "Uber Pool," which allowed multiple passengers from different origins who are heading to different destinations to ride in a single vehicle by identifying proximate travelers and establishing intelligent routing.

Since then, additional innovations have come about. For instance, in October 2018 Lyft launched an all-access subscription plan that covers users for up to 30 rides per month for an upfront monthly fee of $299. Each ride can be for a value of up to $15, and if an individual ride goes over that amount, the user pays the difference through the usual means.[258] That same month, Uber launched its own subscription-based model in Los Angeles, Austin, Orlando, Denver, and Miami. Dubbed "Ride Pass," the service charges between $14.99 and $24.99 per month to unlock discounted, fixed rates for as many UberX and UberPool trips subscribers wish to take. The company states the service can save riders up to 15 percent on their overall monthly travel, based on historical data.[259]

> *Various studies have documented possible societal benefits that could result through increased carpooling, such as a substantive reduction in fuel consumption and a 75 percent reduction in traffic congestion.*

In September 2018, Lyft announced a pilot program in 35 cities that offers to pay drivers $500 to $600 in Lyft credits to park their cars for a month. About 2,000 people participated in the program, which relies on the honor system for drivers to self-report their progress. The program follows up on a smaller pilot that offered 100 residents of Chicago $550 each in credit to avoid personal vehicles for a month, an effort the company deemed successful.[260] While the program will run for only one month, it's part of a broader effort by ridesourcing companies to shore up their business by scaling – i.e., facilitating peoples' ridesourcing habits, especially as an alternative to personal car use – and to diversify their business models.

New entrants are arriving and offering creative models as well. Dallas, Texas-based Alto launched in November 2018. The company has a dedicated fleet of cars it owns and maintains with a basic business model revolving around both a monthly membership fee and individual booking fees for each ride.[261] Flywheel is a Bay Area-based ridesourcing app company that seeks to unite taxicabs into one organized ridesourcing network. The company offers two main products: a ridesourcing app for riders, and a smartphone-based operating system for taxi drivers that replaces the jumble of meters, dispatch, advertising, navigation systems, and credit card readers currently clogging the interior of the vehicle.[262]

Carpooling, which involves groups smaller than seven traveling together in one car,[263] is similar to ridesharing in that they both share vehicles for travelers heading in the same direction. Key differences include the fact that rather than earning income, carpooling drivers simply focus on reducing their costs by splitting fuel and usage charges. Additionally, the drivers themselves are part of the group needing to travel in the same direction, rather than just facilitators. Various studies have documented possible societal benefits that could result through increased carpooling, such as a substantive reduction in fuel consumption[264] and a 75 percent reduction in traffic congestion.[265]

Recent notable carpooling efforts include the Alphabet-owned mapping and navigation app Waze's June 2018 launch of Waze Carpool, a new carpooling app that lets drivers across California offer rides to people traveling on a similar route. Unlike TNCs, which take a commission from each ride and whose drivers use it as a source of income, Waze Carpool operates more like traditional carpool, where riders chip in only to cover the cost of gas. The desired result is one in which passengers obtain an affordable and convenient ride while drivers receive fuel money and carpool lane usage.[266]

SNAPSHOTS

Several examples are furthering or highlighting the potential that Midrange Domain modes have in connecting travelers to or supplementing transit, including cities' efforts to subsidize ridesourcing, transit agencies and TNCs working together to link journeys via travel hubs, and automated vehicles' first/last mile services.

Cities Subsidize Ridesourcing as a Cost-Effective Supplement to Transit

The rise, popularity, and in many cases cost-effectiveness of ridesourcing has prompted a number of transit agencies to consider it as a tool for augmenting transit lines, or outright replacing lines, with lower ridership.

In March 2016, Altamonte Springs, Fla. launched a one-year pilot that allocated up to $500,000 over a year to pay for residents' Uber rides within a geo-fenced area around the 9.4-square-mile town. Specifically, it offered a municipal subsidy that covered 20 percent of a ride that began and ended in the city, and 25 percent if it began or ended at the local light rail station.[267] The pilot comes on the heels of a failed effort to secure $2 million in funding from the Florida Transit Authority to introduce a demand-responsive bus program that would transport citizens to and from the local rail station. While chosen as an alternate in the wake of being denied funding, the city feels that its effort with Uber accomplishes much of what the bus program set out to accomplish, but at a lower cost.[268] Shortly thereafter, the nearby cities of Lake Mary, Longwood, Maitland and Sanford joined the program, which was completed in July 2018 at a cost of nearly $64,000 for the cities. The cities and Uber subsequently launched a second phase, which ran from August 2017 through August 2018, for which the five cities paid a combined $330,000 to support more than 186,000 local rides.[269]

In August 2016, the City of Centennial, Colo. launched Go Centennial, a six-month pilot program that combined a multimodal trip-planning mobile app and a fully-subsidized Lyft Line ridesharing service to help solve the first/last mile challenge. This private-public partnership teamed with Conduent, Lyft, Via, and the Denver South Transportation Management Association to test a new platform for door-to-door transit planning that incorporated information across multiple transportation modes to facilitate connections to and from the city's Dry Creek Light Rail Station. In total, the pilot provided approximately 1,300 trips for 127 riders, of which 36 percent were new to using a ridesharing service. Wait times from the Dry Creek Station were reduced from 2 hours to 5.25 minutes, which helped foster a 73 percent satisfaction rate for the program. 69 percent of riders used the program more than once and ridership remained stable for the existing Call-n-Ride service, which suggests the Go Centennial program attracted new light rail riders.[270]

In March 2018, the city of Monrovia in Los Angeles County kicked off a multimodal transportation program called GoMonrovia. Through the GoMonrovia program, the public is able to access Lyft and Lift Line rides within the GoMonrovia service area for $0.50 and $3.00, respectively. In addition, Lime placed more than 200 bikes throughout the city, which can be rented by the public for $1.00 for a 30-minute ride.[271] The idea for GoMonrovia came from a need to improve or replace the city's dial-a-ride program given that it serves only a very narrow range of public transportation users, is inconvenient for general everyday use, and is an expensive way to move people around, costing the city around $19.70 per person per ride. More broadly, the city started to rethink its role as it relates to the provision of public transportation in response to local housing growth, an expanding job base, and regional population trends.[272]

Transit Agencies and TNCs Launch Partnerships to Connect Riders to Transit Hubs

Research has found that transit systems could build upon and bolster public transit offerings by adopting on-demand dynamic route transportation technology.[273] As such, municipal governments, metropolitan planning organizations, and transit agencies around the country are embracing the idea that greater synergy between TNCs and transit services can enhance mobility. Most partnerships are motivated by a desire to improve mobility in areas in which transit options are inadequate or nonexistent, or where the supply of parking is insufficient. Nonetheless, some initiatives also reflect a desire to bolster the "brand image" of transit, address budgetary shortfalls, or promote economic development. Deficiencies in taxicab service may also be a factor.[274]

King County Metro in Washington launched a pilot in October 2018 offering on-demand shuttle service to and from transit hubs throughout the region using mobile apps from 6-10 a.m. and 4-8 p.m. The shuttles, which are operated by Chariot and Ford Smart Mobility, launched at no cost to passengers but will eventually charge the same amount as a Metro bus ride.

Using an app designed by Ford Smart Mobility, commuters within a designated region

> *Research has found that transit systems could build upon and bolster public transit offerings by adopting on-demand dynamic route transportation technology.*

surrounding the Eastgate Park-and-Ride – which is the largest in the region with nearly 1,600 fully-occupied parking spaces – request a Ford mini-shuttle to pick them up from their homes. Similar to Uber and Lyft, commuters input their location on the app and the shuttles collect them either from their home or at a designated collection point nearby. Riders are then ferried to the park-and-ride, where they can access public transportation for the remainder of their trips.[275]

King County Metro plans to expand the on-demand shuttle service throughout the Seattle region during the year-long pilot. By offering this new shuttle service, an estimated 44,000 residents are afforded the option to travel without depending on their personal cars, nor hunting for parking spaces.[276]

In October 2018, Los Angeles County Metropolitan Transportation Authority launched its "Mobility On Demand" pilot, the result of a partnership with ridesourcing company Via to provide a new way to access transit.[277]

The Mobility On Demand pilot is basically subsidized ridesharing that will serve first/

last mile needs for specific Metro Stations.[278] Using the Via app, passengers are able to instantly book a seat in a shared, dynamically routed vehicle to or from three key Metro stations. Via's algorithm matches passengers with others traveling in the same direction in a vehicle following an optimized flexible route that seeks to minimize detours and delays. Additionally, Via is working with Metro's Office of Extraordinary Innovation to expand LA's mobility menu, improving access to public transportation and providing an affordable, equitable, and accessible way to Go Metro.[279]

The program is supported by a $1.35 million grant from the Federal Transit Administration's Mobility on Demand (MOD) program.[280] Via will collect and keep fare revenues, $287,000 of which is their "risk-sharing contribution" against their $2.5 million annual contract. The total 12-month pilot cost is just short of $3.4 million.[281]

Austin, Texas completed a year-long experiment it called Pickup, also in partnership with Via, which sought to enable riders to summon smaller buses to pick them up from low-density areas and shuttle them to main routes and stations.[282] The goal was to upgrade a legacy dial-a-ride system to a fully on-demand service that responds in real time to rider demand and to improve mobility in transit deserts efficiently without fixed routes. While most users used the service as an area shuttle rather than a connection to transit,[283] the information collected and insights derived from the pilot are informing the city's subsequent efforts to create a feeder service that connects smaller communities to the larger urban transit system.

Additional notable efforts include:[284]

- The transit authority in Dayton, Ohio partnered with Lyft to provide free rides between select transit stops.
- The city of Charlotte, N.C. will contribute $4 to every Lyft trip to and from selected light-rail stations. They will do this for up to 40 rides for monthly transit pass holders, and up to two rides for those with non-monthly passes.
- The city of Vallejo, Calif. partnered with Lyft to provide $2 or $3 rides to the Amtrak station that links Sacramento to San Jose. Rides were limited to those who work in social services, food manufacturing, and hospital organizations.

Altogether, DePaul University identified 29 partnerships between TNCs and public bodies to improve mobility are in place around the United States, the locations of which are shown in Figure 24.[285]

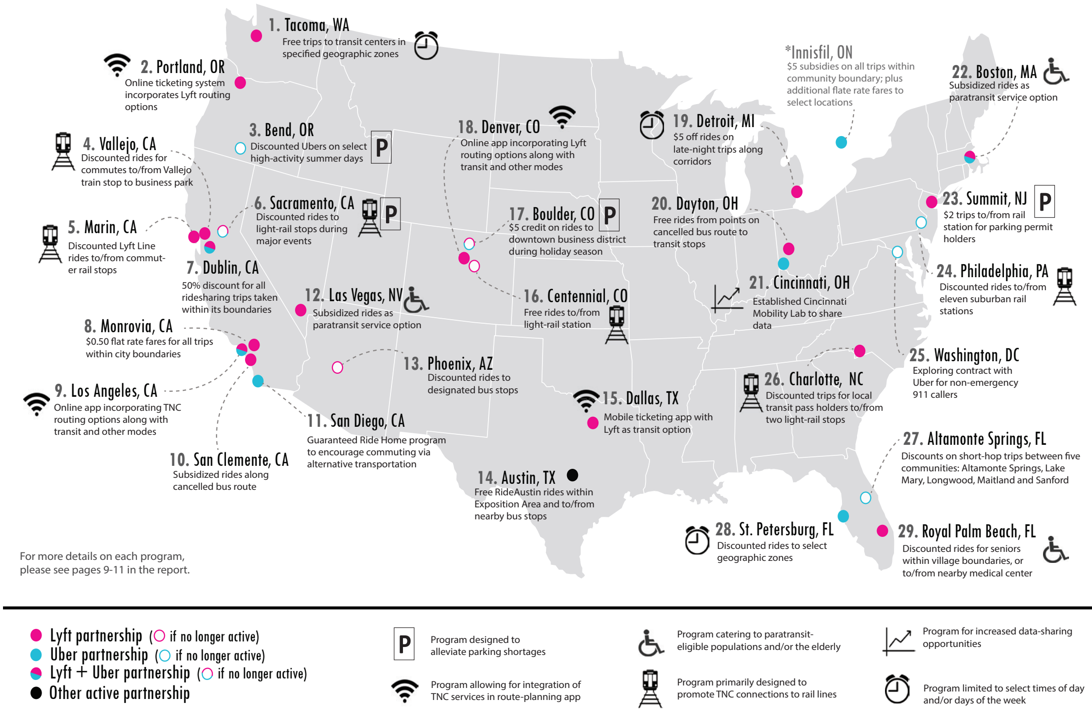
Waymo Focused on Automated Ridesourcing Service That Connects to Transit

In July 2018, Valley Metro, the transit authority serving greater Phoenix and Maricopa County, and Google's automated vehicle technology spinout Waymo announced a partnership to use Waymo's fleet of self-driving vehicles for first/last mile transit trips.[286]

The effort helps add substance to one of Waymo's core long-standing focal points –

Figure 24: Partnerships Between Transportation Network Companies and Public Agencies

Past and Present



Source: DePaul University

connecting people to public transportation. The company's other three focal points are: creating a ride-hailing service, developing self-driving trucks for logistics, and licensing with OEMs for personally-owned vehicles – each of which already had significant efforts behind them. This announcement demonstrates the company's first significant effort to connect people to public transportation.

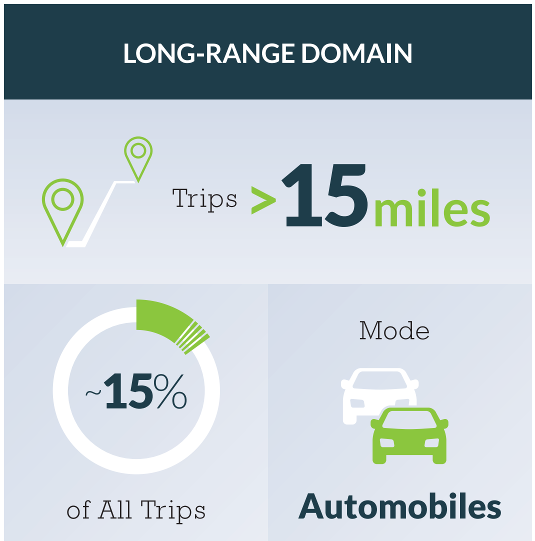
The first phase of this partnership, launched in August 2018, offers first- and last-mile transit connections for Valley Metro employees, helping to connect them with public transportation. These riders can use the Waymo app to hail a ride to take them to their nearest public transportation option.

The company then plans to expand the partnership by providing first- and last-mile travel to Valley Metro RideChoice travelers, which covers groups traditionally underserved by public transit. This will form the basis of joint research to evaluate the adoption of Waymo technology, its impact, and its long-term potential to enable greater access to public transit.[287]

The greater Phoenix and Maricopa County region has been a major testing hub for Waymo for several years. In addition to testing its self-driving vehicles there, Waymo also launched an early rider program in April 2017 that allowed area residents to ride in Waymo vehicles for free,[288] and subsequently launched its first commercial service called Waymo One in December 2018.[289] The latest partnership builds upon this and other earlier regional efforts.

LONG-RANGE DOMAIN: ON-DEMAND, SHARED-ACCESS MODES FOR > 15 MILE JOURNEYS

Almost 15 percent of all trips are within the Long-Range Domain, which consists of trips beyond 15 miles long. For such trips, access to and use of automobiles is primary.



In the context of discussing electric, connected, automated, and shared vehicles, some have hypothesized that the age of the personal automobile will soon be coming to an end, swapped out in their entirety for fleets of self-driving, on-demand automated taxis.

However, such a future is unlikely. At a minimum, personal automobiles will be available for recreational purposes, for there will always be a market for those who enjoy controlling vehicles from behind the wheel. Beyond that, there will be scenarios for which automobiles are simply the most appropriate and functional mode. Distances beyond 15 miles long and the common purposes for which such trips are taken generally require routing and timing flexibility, and often space for multiple passengers and cargo as well. Facilitating access to such vehicles can be accomplished via carsharing and car-subscription models.

While not all vehicles will end up in automated, shared, electric fleets, one trend that likely will be seen is the addition of new vehicular types that fill ownership, sharing, and subscription model niches. So-called vehicle "rightsizing" is the alignment of a vehicle's size and weight with the domain in which it serves and the function it performs.

Of particular note when it comes to vehicle rightsizing is the emergence of vehicles much smaller than what's currently common. Small vehicles were once the norm in European countries, and still populate the landscape to some degree. The Smart ForTwo emerged in 1998 and, at less than 100 inches long, two could fit in one standard sized parking spot. It soon made its way to the United States. The Volvo Monitoring and Concept Center (VMCC), the company's Southern California design studio, thought of narrow vehicles as a way to enable lane sharing and thus improve traffic flow and congestion. They conceived of the Tandem, which sat two occupants inline, was only 57 inches wide yet engineered to be safe and crashworthy.[290] Recently, the Renault Twizy emerged as a 92-inch long and 47-inch wide popular electric car that's on European

> *While a disproportionately large personal expenditure, personal vehicles tend to be used only about five percent of the time.*

roadways.[291] In the future, we may see more vehicles like these, as well as emerging concept vehicles including the Toyota i-ROAD – a single-passenger, three-wheeled urban vehicle with "Active Lean" technology that enables it to corner as a motorcycle does.

It's important to highlight rightsizing and the emergence of new and uncommon vehicles before launching into the various models by which people can access (as opposed to own) them given the disruptive potential embodied by these vehicles. In fact, a November 2018 report by the Christensen Institute implies that small, narrow, electrified vehicles are truly disruptive innovations given that they serve the lowest budget existing buyers of vehicles with a lower-cost and differently featured offering, and/or are bringing entirely new consumers to the market with a solution.[292]

With new types of vehicles such as these emerging to fill functional gaps left by the sedan, sports car, minivan, sport utility, pickup truck, and other current and common vehicle types, carsharing and subscription models are well positioned to enable travelers in the Long-Range Domain to access the type of vehicle they need when they need it, rather than purchase – and thus be locked into – one or two types.

CARSHARING AND CAR SUBSCRIBING

Carsharing is about having access to a fleet of vehicles that is owned by somebody else. A platform operator could own the fleet, or the fleet could be dispersed.

When owned by fleet operators, carsharing services can resemble traditional car rental services in terms of vehicle selection and consistent branding, but differ in their use of technology to ease the check out and in processes, and pricing models to facilitate shorter-term rentals.

Given the similarities between the two, it's therefore not surprising that some of the major car rental companies now own or operate carsharing companies or services, such as Avis's Zipcar and Hertz On Demand. Yet a key differentiator between the two is that traditional car rental is oriented around supply, and typically offer daily rather than hourly usage.

When dispersed, vehicles are owned by individuals who then rent out their vehicles using peer-to-peer (P2P) networks, akin to home sharing platforms such as Airbnb. The emergence of P2P networks is a reflection of the inefficiency inherent in car ownership. While a disproportionately large personal expenditure, personal vehicles tend to be used only about five percent of the time.[293] Thus, P2P carsharing networks enable owners to generate income during times when their cars are unused.

Regardless of whether the vehicles are owned by fleet operators or peers, carsharing platform members use cars as needed and only pay for the time used and mileage incurred. Other vehicle expenses – including gas, maintenance, and in many cases insurance – are covered by the owner. In most cases, insurance is provided, or at least offered by, the carsharing platform provider.

Round-trip carsharing is the most common model for repetitive trips, and enabled by both fleet operator and P2P platforms. For this model, the vehicle is checked out from and returned to the same location. A newer model for carsharing is one-way, which is also referred to as point-to-point, and usually only enabled by fleet operator-owned platforms – unless the P2P platform comes with vehicle collection and delivery. For this model, a driver can collect a car at one location and then drop it off at another location within the service area. The locations can be designated and branded, or similar to dockless scooter and bikesharing technologies, can be at any street parking spot, with some companies establishing parking arrangements with cities so customers don't have to feed meters.

Like ridesourcing, scooter sharing, and bikesharing, modern carsharing is enabled by smartphone technologies. A driver establishes an online account, stores a form of payment for the account, downloads a smartphone app, and subsequently uses the app to locate, reserve, access, and pay for vehicles. While not currently as familiar or popular as ridesourcing, carsharing is quickly growing and – should current market and usage trends continue – familiarity of carsharing could soon approach that of ridesourcing. As of October 2016, carsharing was operating in 46 countries and six continents, with an estimated 2,095 cities and approximately 15 million members sharing over 157,000 vehicles. Asia, the largest carsharing region measured by membership, accounts for 58 percent of worldwide membership and 43 percent of global fleets deployed. Europe follows behind with 29 percent of worldwide members and 37 percent of global vehicle fleets.

Daimler's Car2Go first launched in 2008 in Germany and, as of mid-2017, had more than 2.4 million members in 26 cities across nine countries, with more than 800,000 members in North America. While it started with the company's Smart ForTwo, the service now lets customers rent the company's more luxurious Mercedes GLA and CLA models.[294]

In 2016, UC Berkeley's Transportation Sustainability Research Center published results of a three-year study of nearly 10,000 Car2Go members in five North American cities. The report – co-sponsored by the U.S. Department of Transportation, Car2Go, and other funders – found that the service creates a net reduction on the number of vehicles on the road and miles traveled. Specifically, Each Car2Go vehicle removed up to 11 privately-owned vehicles from city streets, and that every 1,000 vehicles shared reduces up to 50 million pounds of carbon dioxide. Between 2 and 5 percent of the Car2Go members sold a vehicle, and an additional 7-10 percent did not acquire one because of the service.[295]

BMW began its first carsharing service, DriveNow, in Europe in 2011 in a joint venture with the rental car company Sixt. As of mid-2017, it had about 875,000 members. In 2016, it established ReachNow, its North American carsharing service, as a wholly-owned subsidiary based in Seattle. Now more than 50,000 members in that city, Portland, and Brooklyn can rent various models from BMW's Mini brand, along with other BMW models.

General Motors formed a carsharing service in 2016 called Maven after the company acquired the assets of the start-up Sidecar. The following year, GM introduced a related service, Maven Gig, that lets drivers for Lyft, Uber and ridesharing services rent electric Chevy Bolts.

Volkswagen plans to launch all-electric carsharing under its "We Share" sub-brand in Berlin in the second quarter of 2019, and subsequently in North America in 2020. The first fleet of vehicles will be comprised of 1,500 e-Golfs, and an additional 500 e-up! minicars will be added later. We Share is the first service in the new ecosystem "Volkswagen We" aimed at non-owners. Its operational model is internally referred to as "free-floating" carsharing, ensuring the spontaneous availability of electric vehicles for customers at all times. At a later stage, We Share will be adding smaller vehicles as micromobility solutions to its fleet of electric cars.

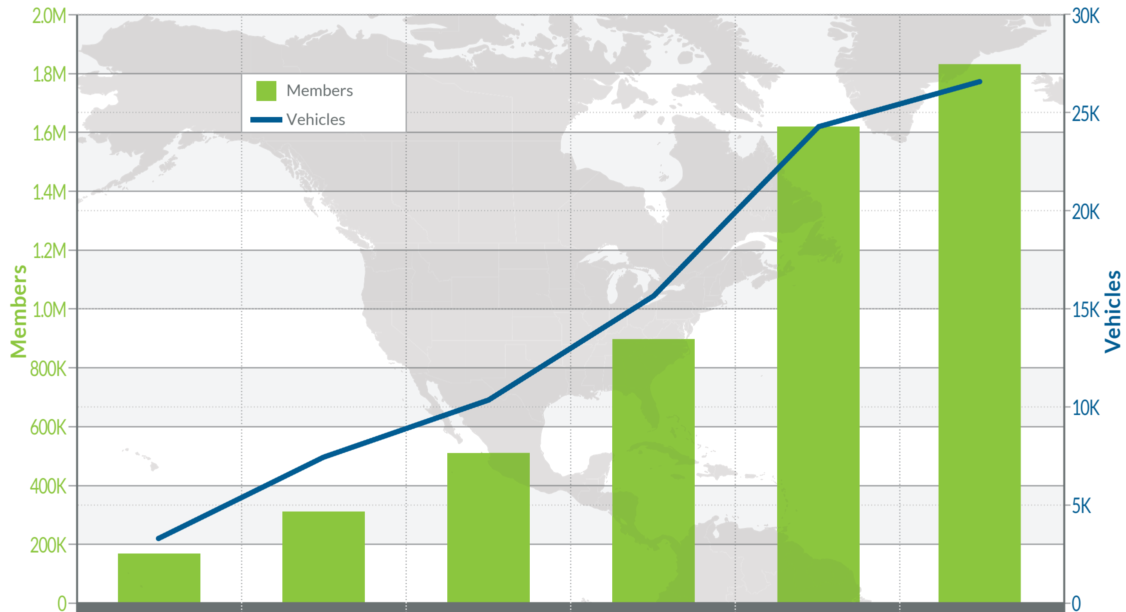
Even micromobility companies are partaking in carsharing action. Just as automakers like Ford and ridesharing platforms like Uber and Lyft began offering scooters, Lime indicated its intentions in the fall of 2018 to begin offering carsharing by applying for a permit in Seattle. Given trends towards vertical integration and the proven and growing market potential of carsharing, we can expect similar moves by others who consider themselves mobility providers.

Growth opportunities are emerging not only in traditional ways, but also in more integrative avenues, as society becomes more accustomed to – and reliant upon – sharing. For example, carsharing providers are striking deals with developers to supply new developments with vehicle access in lieu of large parking structures. Daimler AG's Car2Go, for example, has eyed partnerships like one it struck in Calgary. The partnership involved the developer purchasing Car2Go minutes and splitting them among tenants in the building, eliminating the need to own a vehicle and thus parking.[296]

Altogether, there were over 1.9 million carsharing members in North America as of January 2017, more than double the number five years before that. Additional members lend and borrow vehicles via P2P platforms that include Turo and Getaround. Getaround partnered with Uber to launch Uber Rent, a P2P car rental service within the Uber app that first deployed in a pilot program in San Francisco.[297] GM has also broken into the P2P space, launching a new carsharing service in March 2018 that's in addition to its flexible carsharing platform Maven. Called Peer Cars, the program allows owners and eligible lessees to rent out their personal GM vehicles to willing renters.[298] The company has stated that Peer Cars will be in 10 U.S. cities by the end of 2018.[299]

As indicated by Figure 25, in 2006, carsharing in North America was comprised of nearly 118,000 members and more than 3,300

Figure 25: Regional Carsharing Market Trends, 2006-2016



	2006	2008	2010	2012	2014	2016
MEM	117,656	318,898	516,100	908,584	1,625,652	1,837,854
VEH	3,337	7,505	10,420	15,795	24,210	26,691

Year

Source: Transportation Sustainability Research, UC Berkeley

vehicles. By 2016, those numbers reached approximately 1,840,000 and 27,000, respectively.[300]

In what could be argued is a version of carsharing, car subscription models have emerged as the newest alternative to car ownership. Similar to leasing, car subscriptions allow subscribers to control a single vehicle for extended periods of time. Yet just as carsharing varied the duration of car rental services, so does car subscription to traditional car leasing, for subscribers can change vehicles weekly or monthly rather than having to wait one or several years while avoiding down payments and end-of-lease fees. Users typically pay a one-time membership fee and a subscription payment for their vehicle access that includes insurance, maintenance, taxes, roadside assistance, and services such as home pickup and mounting and storing winter tires. Thus, car subscriptions are meant to fill the gap in vehicle access between hourly carsharing and yearly car leasing, and to do so more economically and conveniently than traditional car renting.

While only beginning to gain traction and currently only available in select markets, an August 2018 study determined that 25 percent of consumers have heard of car subscription services. It is most appealing to young males and new-vehicle buyers, with 10 percent of consumers indicating they would be open to a vehicle subscription service instead of purchasing or leasing a vehicle the next time they are in the market. Access to the latest technology is the key draw to subscription services (44 percent). Worry-free maintenance (36 percent), the ability to swap vehicles based on needs (35 percent), and flexibility (35 percent) also are strong benefits.[301]

Volvo executives say its Care by Volvo program has delivered promising results. Launched in November 2017 with the company's new XC40 crossover as its signature vehicle, Care by Volvo allows customers to subscribe to a service that bundles car, insurance and maintenance costs into a single payment that's $650-$850 per month, depending on the vehicle. Customers sign a two-year agreement that lets them swap for a new vehicle after a year. Within its first four months of operation, Volvo sold the number of subscriptions it had anticipated for its first year of operation. Consumers signing up now for the XC40 as part of Care by Volvo are on a long wait list. Care by Volvo claimed as much as 15 percent of the available crossovers, pinching supply that dealers had otherwise expected would be available for traditional vehicle sales.[302]

Other manufacturers including Ford and Toyota have started car subscription companies and services, and Porsche, Mercedes-Benz, and Cadillac each let drivers in select cities exchange high-end models several times a year for approximately $1,000-$2,000 a month. Yet altogether the model is still relatively new and its full potential for displacing private vehicle ownership and on-road vehicles remains to be seen.

SNAPSHOTS

The provision of carsharing services is proving to be an asset not only to cities and communities, but also to others who might seek to travel in the Long-Range Domain and avoid personal car ownership.

Carsharing Becomes a Real Estate Perk

As previously discussed, the cost of car ownership can be substantial. In urban settings, such as New York City and other dense downtown areas, this substantial cost can be even higher once the steep cost of parking is figured in. One UC Los Angeles (UCLA) study found that 700,000 renters in the U.S. who don't have cars are nevertheless paying $440 million a year for parking.[303] This cost is in addition to the inconveniences associated with finding parking spots.

With these points in mind, it's not surprising that real estate developers and building operators are offering carsharing services as a perk for residences. From a building management perspective, the leveraging of carsharing in condominium communities reduces the need for parking spaces in the building, while allowing tenants more cost-effective access to mobility compared to traditional car ownership and monthly parking space fees. Condo amenities may now include 24/7 access to shared vehicles for its owners; something that can be a big selling point for condo buyers.[304] Sensing the opportunity, carsharing providers are actively pursuing the market and striking deals that land their services in a development's garage.

Let's Drive NYC is GM's carsharing program for eligible residents of The Ritz Plaza, owned by Stonehenge Partners in midtown Manhattan. Since 2015, residents can use a General Motors' developed smartphone app to reserve a Chevrolet vehicle and access parking in one of 200 garages.[305]

Equity Residential and Zipcar, the world's largest carsharing network, announced a strategic partnership in 2011 that brought Zipcar's carsharing services to Equity

The reduction in parking spot buildout requirements can save developers a substantial amount of money, thus adding to the market drivers fueling the linking of carsharing and real estate.

Residential apartment properties. As part of this agreement, Zipcars were placed at Equity Residential apartment properties in New York, Boston, Washington, D.C. and Seattle. The companies claim that these vehicles are accessible to more than 17,000 residents living in participating properties.[306]

ReachNow, BMW's carsharing service, has served the 700 residents of the Solaire, a residential tower in Battery Park City, N.Y., since December 2016. BMW says it plans to expand the ReachNow program to residential and business complexes across the U.S.

Recognizing carsharing's potential to reduce car ownership and thus the need for parking spaces, city planners are changing the laws to facilitate carsharing's link to real estate. In the city of New Rochelle, N.Y., for example, real estate developers can now drop three conventional car spaces for every carshare space due to a provision added to their city bylaws. The reduction in parking spot buildout requirements can save developers a substantial amount of money, thus adding to the market drivers fueling the linking of carsharing and real estate.

BlueIndy Deploys Popular European Electric Vehicle Carsharing Program to Become Largest in the U.S.

In September 2015, Indianapolis, Ind. became the home to the largest electric carsharing service in the United States with the launch of BlueIndy, an EV carsharing company started through a mutually beneficial public-private partnership between the City of Indianapolis, the local electric utility Indianapolis Power and Light (IPL), and the Bolloré Group.

The latter party, which obtains its name from the company's chairman and largest shareholder, Vincent Bolloré, is a French holding company whose subsidiary, BlueSolutions, is focused on the development of electric vehicles, carsharing, and integrated transportation solutions. In 2011, Bolloré Group started Autolib, an electric car rental business that was popular in Paris and other parts of France. As of 2017, the Paris program alone had approximately 4,000 vehicles and 6,100 charging ports.[307] Building upon this success, Autolib expanded into Italy, London, Singapore, and Indianapolis – it's first North American city.[308]

Part of the Bolloré Group's motivation for bringing its program to Indianapolis was to test what it deems to be its superior lithium metal polymer batteries in Indianapolis' cold winters and hot summers. Bolloré Group executives argued that the batteries' solid-state design make it safer than the standard lithium-ion batteries used in other electric vehicles, which contain flammable liquid electrolytes. They also argue that it will eventually surpass the lithium-ion battery in its ability to operate between recharges.[309] The company received further support from the city's mayor and municipal government at the time, which helped seal the deal.

The Indianapolis project had its share of hurdles as it progressed towards launch, including the Indiana state utility regulator's approval of only $3.7 million of the requested $16 million electricity rate increase to help pay for it, and the siting of publicly available charging infrastructure. Greater stakeholder engagement and a more robust case for the public benefit of a program might have helped overcome these challenges.[310] Nonetheless, after Bolloré and the city agreed to make up the cost difference, providing funding that was in addition to Bolloré's original $35 million investment,[311] the project moved forward.[312] Altogether, Bolloré has invested approximately $41 million into BlueIndy, representing the overwhelming majority of the effort's $50.7 million total funding.[313]

BlueIndy is a subscription-based service, whereby users who have a credit card and a driver's license can sign up for the program online or at a BlueIndy enrollment kiosk. Included with BlueIndy membership is insurance while driving any one of the company's 500 vehicles and parking at any of its 200 charging stations.[314] Members can book either round-trip or one-way journeys via BlueIndy's mobile app or at a kiosk, and can check out and unlock vehicles by using a pre-supplied keycard.

In its first year of service, BlueIndy reported that it had 2,800 members with 32,000 rides, and that over 80 percent of members signed up for the yearly membership.[315] The BlueIndy program gained traction in its first year by successfully attracting members and continuing to push forward to deploy additional stations. Although government stakeholders sometimes disagreed over the details, a broad consensus formed on the value of BlueIndy to the people in the metropolitan region of Indianapolis.[316] Such bullish early results indicated that consumer interest in electric mobility solutions is robust even in a place like Indiana, which is outside of primary EV markets. With its expansion into the suburbs, BlueIndy may further show how innovative mobility solutions do not have to be restricted to areas with high population density and can accommodate the needs of residents outside the city center.[317]

Perhaps as exciting as the initial ridership results is the city's demonstrated perspective that BlueIndy is part of a larger, emerging mobility ecosystem. While Indianapolis' transit system ranked the lowest in terms of per capita ridership before the launch of BlueIndy,[318] the city has since developed a plan for smart corridors through the city that highlights how it hopes to develop and integrate the BlueIndy fleet and its electric bus rapid transit line currently being constructed.[319] Furthermore, the plan proposes to automate BlueIndy's popular airport-to-downtown route to demonstrate the value of automated capabilities in urban and highway roads, thereby indicating how the service can be a platform for additional increasing layers of emerging mobility technologies.[320]

ENABLING TECHNOLOGIES AND MARKET DRIVERS

The rise of electrified, connected and automated, shared vehicles that connect to and help modernize transit and that serve the Local, Midrange, and Long-Range Domains has not occurred in a vacuum. Instead, their rise has been enabled by, and is in turn influencing, a number of adjacent technologies and market drivers. One – the mobile phone – has already been discussed, given its prominent role in enabling this transition. Others include: "big data," modeling, and predictive and real-time analytics; freight and commerce; intelligent transportation systems; land use, urban design, and traffic congestion; prize competitions; public policy; safety; smart cities; and venture capital.

"BIG DATA," MODELING, AND PREDICTIVE AND REAL-TIME ANALYTICS

The ability to generate, collect, store, process, and synthesize very large datasets based on travel preferences and patterns has been a core enabler of shared mobility. These abilities lead to the brokering of rides among travelers, vehicles, and/or drivers, as well as the routing, optimization, low latency, billing, and eventual profitability of these various platforms.

Yet many of the issues pertaining to the generation, processing, and ownership of data going forward are unresolved and underutilized, yet are paramount to realizing the full potential of shared, integrated, multimodal mobility.

One issue is the sheer volume of data that's being generated, which according to IBM equates to 2.5 quintillion bytes of data from all sources.[321] Emerging mobility technologies compound this issue given the extraordinary amount of data they're projected to generate. For instance, Intel projects that once essential components including cameras, radar, sonar, GPS and lidar are factored in, automated vehicles will generate approximately 4,000 GB – or 4 terabytes (TB) – of data a day,[322] which is almost equivalent to what 3,000 people currently produce per day by using PCs, mobile phones and wearables. Automated vehicle technology company Aptiv states that by 2020, connected vehicles will exchange one million pieces of data every second.[323]

Companies whose business models are premised on big data synthesis are well positioned to leverage this data, but many public agencies are unprepared and/or underequipped to process – or even collect – the data. Those who are collecting and processing mobility data are able to derive powerful insights.

For example: South Bend in Indiana asked bikesharing firm Lime to share data when it launched there in June 2017. Lime provides a dashboard for cities showing statistics like how many of their residents rented bikes, how many trips they took, and how far and long they rode. It also has heat maps showing where most rides occur (it says all data is non-identifiable). Accordingly, authorities in South Bend could see that as of September 2018, residents have taken 340,000 rides, have traveled 158,000 miles, and are now using trip-level data to decide where to place new bike paths.[324]

Other prospective insights derived from processing mobility data include a city's

> **A**utomated vehicle technology company Aptiv states that by 2020, connected vehicles will exchange one million pieces of data every second.

allocation of parking, design of ridesourcing pickup and dropoff zones, designation of bike and scooter lanes, equitable access to transportation,[325] and where to locate bike racks and parking pads for electric scooters and recharging equipment, among others. Such insights are only possible if the private companies and others operating mobility services are open – or forced – to share the data they collect. Historically, companies have been resistant to such data sharing propositions, given that a significant portion of their business is predicated upon the data they collect. Additionally, less than 30 percent of the more than 1,000 transit agencies in the United States have an open data policy.[326] Even if mobility service operators do share their data, a fundamental reality is that for every one engineer or data scientist working for a city there are 10 to over 50 in the private sector,[327] making the processing of the data for public benefit difficult.

But driven by regulations, collaborations, and emerging third-part data platforms, that situation is quickly changing. For example, Ford Motor Company, Uber, and Lyft committed to SharedStreets, a universal data language for sharing information about city streets – such as road traffic data – and a platform for public-private collaborations to manage streets, reduce traffic deaths, and prepare cities for the technological advancement emerging in cities. As part of this effort, Uber is releasing data on the speeds traveled on individual streets to more cities to help them better assess traffic conditions and manage congestion, thereby helping to facilitate the opening up of what was once closely guarded travel data. Separately, Uber has also released some of its data on pickups and drop-offs as part of another effort to help cities reimagine the use of curb space that is usually reserved for parking,[328] and rolled out its Jump bike mobility platform for cities via its insight platform, Uber Movement, that displays metrics such as number of vehicles on the road and user trip details.[329]

Already operating in over 30 cities around the world, the SharedStreets platform provides city leaders with new instruments for managing transportation networks.[330] SharedStreets is the result of a collaboration with the National Association of City Transportation Officials (NACTO), the Open Transport Partnership, and with financial support from Bloomberg Philanthropies.[331]

Other examples include:

- ***The Populus Mobility Manager***, a platform that integrates real-time data feeds from major mobility operators of shared fleets (bikes, scooters, cars) with an interface for city policymakers and planners. It launched in September 2018 as an advanced analytics platform that seeks to help cities and private mobility companies work more seamlessly together through better data. This third-party data platform is meant to aggregate data from mobility providers within cities and subsequently deliver insights required to design data-driven policies and transportation plans, while protecting information that requires safeguarding.[332]

- ***TransitScreen's MobilityScore*** turns big data about supply, demand, and access to all forms of mobility into maps and analytics.
- ***Remix***, a platform that brings together and enables collaborations between public transit, streets, and new mobility to generate insights, is working with Lime and Spin to make use data available to the Los Angeles Department of Transportation (LADOT). Los Angeles transportation officials will have access to real-time location data related to the bikes and scooters as well as trip route and device status information.[333]

In the future, it can be expected that datasets generated by mobility technologies will continue to grow and, if properly processed, yield even greater insights into preferences and usage patterns, among other things. The private sector will continue to make use of these insights using its wealth of resources and talent, and the public sector will increasingly have options to access post-processed data via collaborations with third-party aggregators for use with policy making.

FREIGHT AND COMMERCE

Any emerging technology is greatly – or perhaps only – enabled when there are existing market applications. Additionally, for any emerging technology whereby a variety of configurations predicated upon market applications can alter systemic complexities and costs, those that are simplest, cheapest, and/or yield the greatest economic reward in the shortest timeframe have an advantage.

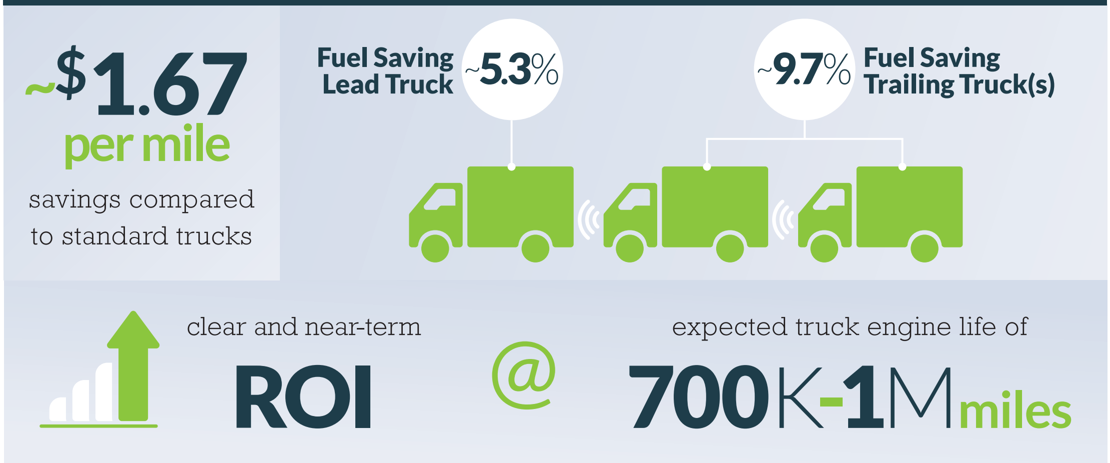
The race to commercialize automated vehicles illustrates these two points well. As discussed, the technological challenge of automation is being pursued via a number of strategies that range in cost and complexity. It remains to be seen if there is a universal "winning" combination of lidar, radar, optical, and ultrasonic sensors that can achieve maximum versatility at minimal cost, or whether there will always be innumerable sensor quantities and combinations based on operational domains, developer preferences, or other factors.

Yet even without answering this question, market opportunities tied to the delivery of commercial goods have emerged in long-haul trucking, small-load urban delivery, and aerial drones that are driving a select group and application of automated and other mobility technologies. This same subset of technologies has the potential to drive other micromobility applications as well.

LONG-HAUL TRUCKING

Platooning – vehicles closely following one another so as to offset wind resistance – and other higher levels of automated truck technologies can provide a clear and near-term return on investment. Testing done by NREL demonstrated fuel savings up to 5.3 percent in the lead truck while the trailing truck saved up to 9.7 percent.[334] Given typical truck engine lives of 700,000 to 1 million miles, savings between 5.3 and 9.7 percent can yield significant fuel cost savings. Trucks able to engage in higher levels of automation are estimated to save about $1.67 per mile compared to standard trucks.[335]

PLATOONING AND AUTOMATED TRUCK TECHNOLOGIES



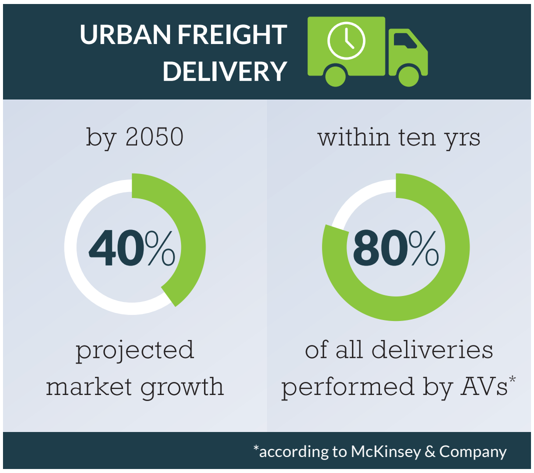
Source: NREL

Platooning is one application of automated technologies closest to market, not just because of the demonstrable return on investment, but also because the technologies required to enable platooning are simpler and less costly than those required to address higher levels of automation. For instance, urban automated taxis such as those envisioned by Uber and Waymo might require a full suite of lidar, optical, radar, and ultrasonic sensors, yielding a vehicle potentially costing more than $250,000 and requiring extensive programming to fully enable. However, platooning doesn't necessarily require lidar and optical sensors, nor extensive programming to handle complex urban situations, for highway operations can be easier to manage. Instead, a combination of V2V communications, radar, and ultrasonic sensors can be sufficient to enable trucks to platoon and reap the financial rewards that come along with saving fuel.

Accordingly, while fully automated trucks are still years away from commercialization, one leading platooning technology developer, Peloton, has announced plans to imminently begin operating its two-truck platooning system in day-to-day commercial operation.[336]

PERSONAL DELIVERY DEVICES (PDDS)

A great deal of freight traffic in urban areas is now comprised of delivery vans,[337] which is causing gridlock and pollution. The problem is expected to become worse, as urban freight delivery is projected to grow by 40 percent by 2050.[338] In an effort to capitalize on the market opportunity that this freight traffic poses, automated vehicle and other mobility technologies are being applied to vehicles without passengers that ferry goods. McKinsey & Company believes that automated vehicles will deliver 80 percent of all packages within 10 years.[339] KPMG predicts that such vehicles will serve "islands of autonomy," metropolitan markets with unique mixes of consumer living, working and travel patterns that will drive requirements for locally tailored delivery services.[340] Early modes for such vehicles that have emerged and already have market orientation include small, automated personal



delivery devices (PDDs) that are designed primarily for last-mile logistics using sidewalks and driveways, rather than public roads and highways.[341]

One company making PDDs is Starship Technologies. Founded out of Estonia, Starship Technologies has initiated a number of automated delivery trials in recent years, covering food and other small packages, in more than 100 cities. Though the robots are automated, they can also be monitored and controlled remotely by humans if the situation requires it.[342] Designed using readily available components, the robots are lightweight and low-cost, enabling the company to bring the current cost of delivery down by 10 to 15 times per shipment.[343] The vehicles travel at a maximum speed of six kilometers per hour and carry a maximum payload of ten kilograms, equivalent to three shopping bags. The vehicles use optical sensors and GPS to obtain a localization accuracy of two centimeters.[344]

In Mountain View, Calif., Starship has been running a pilot on Intuit's corporate campus in conjunction with food service provider Compass Group. Through the pilot, Intuit workers have been able to request robotic food deliveries via the Starship app. In the wake of this pilot, as well as another one in Washington D.C.[345] that led to more than 7,000 deliveries by the company,[346] Starship launched a large-scale commercial automated delivery service in April 2018 aimed at corporate and academic campuses in Europe and the U.S. The company planned to have around 1,000 robots by the end of 2018 on a number of campuses, delivering groceries, campus cafeteria food, business and other package deliveries.[347] One such effort launched in the U.K. in November 2018, allowing participating residents to receive an unlimited number of parcels at a time of their choosing for approximately $10 per month.

Another company making delivery robots is Marble, which was the first company to bring on-demand delivery robots to the streets of San Francisco in April 2017. The company's vehicles are larger than those produced by Starship, but nonetheless are similarly focused on food and package deliveries. The company launched an effort with Yelp Eat24 to ferry food from restaurants to customers in two San Francisco neighborhoods.[348] Marble also deployed vehicles in Dallas beginning November 2018 as part of a six-month pilot program that allows companies to deploy up to 20 robotic delivery devices.[349] The program in Dallas comes on the heels of another pilot in the state whereby the Austin Transportation Department partnered with private tech companies and PDD operators in August 2017 to test the feasibility of battery-powered delivery robots in the city.[350] Other notable early stage efforts include San Francisco-based Postmates' sidewalk-based robotic food delivery carts to residents of Los Angeles,[351] PepsiCo's fleet of "snackbot" snack-carrying robots on the University of the Pacific's campus in California,[352] and Nuro's partnership with Kroger-owned Fry's Food Store that uses two of its small (104 inches long by 43 inches wide by 70 inches high), 25-MPH electric cars to deliver groceries to nearby homes.

To see how the automated PDDs can expand beyond the PDD market and influence the broader commercial and mobility paradigms, one only has to look to the partnership established between Starship and Mercedes-Benz that is focused on rethinking traditional logistics behind last-mile fulfillment. Mercedes invested more than $13 million to co-develop a "mothership" concept comprised of Mercedes delivery vans that can hold up to eight delivery robots and a day's worth of parcels.[353] At scale, such a platform has the potential to relieve stress on a city's infrastructure by orienting commercial deliveries around smaller modes.

The platform also has potential to improve logistics within the personal mobility market, for example by transporting, recharging, and servicing micromobility devices.

THE "CENTER CONSOLE"

Historically, vehicles' center consoles have been places where radio stations and temperatures can be modulated. But with the advent of connectivity, as well as large, high-resolutions touchscreens that mimic smartphone operability, the center console in current and future vehicles is shaping up to be so much more. While the typical entertainment options – namely music – will still be accessible, the center console is positioned to be the location where vehicle occupants can access a much broader array of entertainment, goods, and services.

Perhaps no company illustrates this better than Samsung. The world's largest smartphone maker had virtually no presence in the auto industry until 2016 when it acquired Harman International Industries Inc., a U.S.-based automotive technology manufacturer, for $8 billion. That acquisition immediately catapulted the company towards the top in the market for the top-of-the-line "infotainment" systems: Samsung was the second-largest auto infotainment supplier in 2017, with $4.8 billion in revenue, second only to Panasonic and Sanyo's $5.1 billion.[354] The company's current plan is to create a high-tech "digital cockpit" that updates a car's dashboard design for an ultra-connected vehicle by placing a bank of screens from one side of the car to the other. The screens would allow drivers to control everything from the interior's temperature to home appliances, while enabling passengers to surf the web and watch streaming videos.[355]

Leadership positions among center console infotainment system suppliers are enviable given these systems' anticipated role in driving potentially very large commercial opportunities. Altogether, U.S. drivers are responsible for $212 billion of spending during their commutes. A survey of 2,000 people found that nearly three quarters of all commuters surveyed, and 82 percent of millennials with long commutes, said they would shop more if the ability to browse and pay for products and services were integrated into their car.[356]

As such, initial efforts are already underway to facilitate easy in-vehicle transactions to bring both virtual and physical goods into vehicles. The Visa Connected Car system, which was unveiled in 2015, is integrated into a car's dashboard to enable the driver to use voice-activated technology or the touch screen to place orders at participating vendors who are near a vehicle or on its route. As a proof of concept, the company partnered with Pizza Hut and Accenture to test mobile and online purchases using Visa Checkout, Visa's online payment service, cellular connectivity, Bluetooth Low Energy (BLE), as well as Beacon technology deployed at Pizza Hut restaurants to alert staff when the customer has arrived and is ready to pick up the order.[357]

OEMs including General Motors, Ford, Toyota and Volkswagen have developed connected car commerce systems with varying capabilities ranging from on-demand music streaming to automatic payments at gas stations. Retailers like Starbucks, TGI Fridays, Applebee's, Dunkin' Donuts and Wingstop are exploring how their customers are using these systems.

Accordingly, connected car eCommerce platforms are projected to exceed 8.2 billion transactions and reach $265 billion by 2023, according to Juniper Research.[358] Such substantial commercial potential is serving as a potent driver not just for the development of advanced, user-friendly infotainment units, but also for overall vehicular connectivity. It could be a deciding factor in swaying OEMs to adopt 5G technologies, given that 5G has the potential to facilitate commercial transactions in addition to automated applications, as the need arises.

LIGHT ELECTRIC FREIGHT VEHICLES (LEFVS)

Bicycles have long been personal mobility vehicles and, as discussed, are participating in the current wave of advancing micromobility via docked and dockless bikeshare platforms. Yet the mode of transportation has potential for additional market growth as companies eye them for freight and commercial purposes.

So-called light electric freight vehicles (LEFVs) and "cargobikes" are those that are attached to or housed within cargo storage capacities. They're cheap, navigable, easy to park, have electrically-propelled assistance, and thus can be well-suited for urban deliveries. According to research by the municipality of Amsterdam, the average loading and unloading time for delivery vans and trucks is 12 minutes; the same amount of freight can be unloaded from an e-cargobike in as little as three minutes.[359] As such, mobility developers, package shipment companies, and others (including DHL, UPS, TNT) and others are exploring prototypes, business models, and pilot projects to experiment with, refine, and perhaps commercialize the mode.

Volkswagen Commercial Vehicles plans to produce the Cargo e-Bike, a three-wheel electric "last-mile deliverer," beginning in 2019. The vehicle is what the company calls a “pedelec” (pedal electric cycle) that adds power assistance to its rider's pedaling with a 250-watt (48V) mid-mounted motor at speeds up to 25 km/h. It is equipped with two wheels at the front, with the load platform positioned low between them. Mounted on this load platform is a cargo box with a storage volume of 0.5 cubic meters.[360]

The Tern GSD is designed to carry two children, a week’s worth of groceries, or 180 kg of cargo, but it’s only 180 cm long—the same length as a standard bike – and can pack down small enough to fit in a VW Touran or an urban apartment.[361]

German manufacturer Speedliner makes UPS’s first iteration of a “modular urban delivery system.” The firm’s new Rytle MovR cargotrike is similar to a van: it has two hub motors on the two back wheels, a canopy to protect the rider from the elements, and is narrow enough to fit in a bike lane or even on a sidewalk, thus avoiding traffic in dense urban areas. It also has a modular loading system that allows a cargo box to slide easily on and off the chassis of the bike[362] and can hold about 15-20 packages. The company began testing the bike in Seattle in October 2018,[363] and previously tested an earlier version of an e-bike in Portland and Pittsburgh. It’s partnering with the city as well as the University of Washington Urban Freight Lab to study the vehicle’s performance, particularly whether the bikes can reduce the company’s overall “dwell time” of trucks, helping cut both pollution and traffic.[364] Since the University transitioned to electric cargo bikes for delivering mail around campus, deliveries take 10 percent less time, miles traveled have been reduced by 30 percent, and the university is saving $10,000 per year in fuel/maintenance costs.[365]

INTELLIGENT TRANSPORTATION SYSTEMS

Any new mobility technology or mode is inserted into and operated with a context. That context is the transportation infrastructure comprised of roadways, overpasses, intersections, junctions, sidewalks, signs, and others structures that govern where and how we operate vehicles. Many of these infrastructures have technologies embedded within them that enable a certain level of functionality upon which to enable features and govern vehicles and traffic.

Intelligent Transportation Systems (ITS) improve transportation safety and mobility, reduce environmental impact, promote sustainable transportation development and enhance productivity. ITS combines high technology and improvements in information systems, communication, sensors, controllers, and advanced mathematical methods with the conventional world of transportation infrastructure.[366]

Thus, ITS technologies enable vehicles and infrastructure to act as a system, and can play a meaningful role in alleviating congestion and promoting multiple mobility modes. Just as mobility technologies are evolving, so too are traffic management approaches. Historically, such approaches have focused on monitoring solutions based on embedded road sensors and centralized, manually operated control centers. New closed loop systems are leveraging real-time, hyper-granular crowdsourced traffic data and enabling active response management.[367]

Some agencies and companies are integrating both legacy and evolving approaches to solve not just the issues pertaining to current generation vehicle but also to future vehicles, such as those that are connected and automated. For instance, TriMet, the transit agency serving the Portland, Ore. metropolitan area, is exploring a next-generation transit signal prioritization system that goes even further than simply lengthening a green light for a bus that may be running behind schedule. The new system, which is projected to come online in 2019, seeks to track how many passengers are on the bus, where it's headed, its relationship to other transit vehicles, and other data points to pass on to the intelligent traffic signal.[368]

Connected Signals, a provider of real-time predictive traffic signal information, is working with the City of Gainesville, Fla. to securely aggregate real-time traffic signal information via its data capture device and to feed it through predictive algorithms to determine information, such as when lights will change colors. The information is then delivered to drivers via the company's mobile phone app and, ultimately, through direct integration into connected cars' displays and powertrains. The company states that its green wave speed indicator is particularly effective in helping drivers safely synchronize their speed with waves of green lights to avoid stopping altogether. This data, when shared with vehicle and drivers, can improve fuel efficiency by up to 15 percent and reduce red-light crashes by 25 percent.[369]

Connected Signals' example is particularly apt given that intersection management – specifically, the opportunity to optimize traffic flow and improve safety – is an area receiving significant attention from multiple companies. Another company pursuing intersection solutions is Virtual Traffic Lights (VTL), a startup based on an algorithm developed by researchers at Carnegie Mellon University. The algorithm allows cars to collaborate using their onboard communications capabilities to keep traffic flowing smoothly and safely without the use of traffic lights. The technology was proven effective in pilot projects on roads near the Carnegie Mellon campus since May 2017, and in Saudi Arabia in July 2017.

VTL states that its technology doesn't need to use cameras or radar (which are common ITS intersection sensors) or even lidar or other sensors, for it obtains all the orientation information it needs from DSRC on-board units and roadside units.[370] Hence, there's no reason why other modes – including micromobility, and even walking – couldn't be integrated into the system simply by equipping them with DSRC.

In fact, more deeply integrating other modes into traffic management will likely be the case as higher quantities and more diversified modes permeate. As this happens, ensuring the safety of these new modes' users as well as the avoidance of congestion will be paramount.

The "fundamental law of road congestion" states that adding 10 percent more lane miles to a city increases vehicle miles traveled by 10 percent. That is, in less than 10 years, new roads increase traffic at a rate directly proportional to their increase in capacity.

New systems such as those advanced by Connected Signals, VTL, and others can play a significant role in ensuring this happens, but others will also be required given that congestion alleviation paradoxically leads to more road traffic, which increases congestion.

LAND USE, URBAN DESIGN, AND TRAFFIC CONGESTION

For decades most local, regional, and state governments have focused on increasing street/road capacity as a solution to infill development, access, and congestion. The result of this approach is a landscape that, in many places, is dominated by roadways that segregate neighborhoods and increase driving. In fact, the "fundamental law of road congestion" states that adding 10 percent more lane miles to a city increases vehicle miles traveled by 10 percent. That is, in less than 10 years, new roads increase traffic at a rate directly proportional to their increase in capacity.[371]

The arrival of advanced mobility technologies and modes has the potential to break this cycle. The form and format of the emerging modes, their needs, usage patterns, and in the case of automated vehicles, the ways in which machine-driven vehicles differ from human-driven vehicles.

To this last point, while current automated vehicle programming is oriented around the way roads and traffic patterns presently are, as CAV technologies advance and become commonplace, changes can be made to roadways to reclaim land – roadways' total number, overall width, numbers of lanes, and lane width. Fewer and narrower lanes can still carry more vehicular volume given that robots are predicted to drive more efficiently. Research indicates that even a single automated vehicle mixed into a group of 20 vehicles can smooth out traffic oscillations and reduce congestion.[372]

Similar – if not more – potential exists as smaller mobility modes displace vehicles. As is the case with CAVs, current micromobility deployments are taking place within the context of cities as they currently are. Therefore, riders must conform to current structures and norms; for instance, by choosing to ride either on sidewalks (and risk collisions with humans), bike lanes (when they exist), or in the flow of traffic (and risk collisions with vehicles). Yet micromobility is premised on small vehicles that by definition offer the most in terms of potential to reduce the space allocated to roadways.

Forthcoming land use and urban design decisions can take into account CAVs, micromobility, and other emerging mobility technologies and systems to create a new "fundamental law" that promotes the use of efficient forms of transportation and, in turn, yields more green and productive space as the vehicles become more common. For instance, Portland is increasing road space for buses and bikes from 4 to 6 percent, which it projects will increase the total people-carrying capacity of the streets rises by an average of 60 percent.[373] Other examples include:

- The increased use of CV-equipped roundabouts to reduce riders' placement within low-visibility street crossings and to separate them from pedestrians, while also enabling coordinated entrance/exits by CAVs;
- Incentives to trucks to make their deliveries during off-peak hours to make room for micromobility;
- Reallocating car parking spaces to dockless bikes and scooters;

- Establishing multiple bike and scooter lanes with different speed limits/ requirements for each; and
- A return to older city designs that use narrower streets and sharper turns, which are ideal for human beings and smaller modes of transport.[374]

PRIZE COMPETITIONS

Prize competitions have a more than 300-year track record of attracting attention, overcoming complex and lingering challenges, identifying innovators, advancing innovation, and engaging people, organizations, and communities.

The push to be the first person to fly solo non-stop across the Atlantic wasn't motivated solely by personal pride and determination. A financial incentive and the potential for global fame brought about by the Orteig Prize drove Charles Lindbergh and his competitors to find a way to make the seemingly impossible possible. Not only did his success make Lindbergh famous, it created excitement about aviation that helped catapult commercial air travel from curious startup into a global industry.

The same model of innovation through competition jumpstarted the automated vehicle industry. In 2004 and 2005, the Defense Advanced Research Projects Agency (DARPA) offered a "Grand Challenge" that awarded a $1 million, then subsequently $2 million, prize for the first competitor whose automated vehicle could successfully navigate a 150-mile course in the California desert. The winner of the competition was a team from Stanford University, which was led by Sebastian Thrun, who went on to found Google's automated vehicle program. That program became Waymo, which Morgan Stanley says could be worth $175 billion.[375]

Prizes take a strategic approach to advancing an issue. The prize design process is deliberate: colleagues, partners, and subject matter experts work together to carefully select and define problems likely to be solvable through prizes. They collaborate with stakeholders inside and outside their organizations to determine the outcomes they wish to achieve, and then use those decisions to drive a prize design process that yields specific outputs. The prize, its requirements, and its results are publicized in language that resonates with the audiences they seek to engage. Finally, to realize the full benefits of the prize, legacy activities are initiated to provide resources and support to the prize participants who remain engaged after the challenge comes to a conclusion.[376]

Beyond the DARPA Grand Challenge, numerous prize competitions have been focused on advancing transportation and mobility solutions. The Progressive Insurance Automotive XPRIZE sought to inspire a new generation of fuel-efficient vehicles that meet consumer expectations for safety and performance. Ten million dollars in prizes were awarded in September 2010 to the teams that successfully navigated a staged competition for clean, production-capable vehicles that exceed 100 miles per gallon or energy equivalent (MPGe).[377]

The EcoCAR Mobility Challenge is a four-year Advanced Vehicle Technology Competition sponsored by the U.S. Department of Energy, General Motors, and The MathWorks, and is managed by Argonne National Laboratory. Students are challenged to increase vehicle efficiency by developing connected and automated vehicle technologies and implementing advanced propulsion systems and electrification. The goal is to reduce energy consumption while maintaining the performance, safety, and overall sporty design and feel of the original vehicle, specifically for a carsharing market.[378]

In October 2018, the Mobility Open Blockchain Initiative (MOBI) and the Trusted IoT Alliance (TIoTA) launched the three-year MOBI Grand Challenge (MGC) in an effort to unlock new blockchain-enabled connected and automated vehicle solutions. The first part of the challenge is a four-month long tournament to showcase potential uses of blockchain in coordinating vehicle movement and improving transportation in urban environments, culminating in a public demonstration of selected technologies.[379] The ultimate goal is the creation of a viable, decentralized, ad-hoc network of connected vehicles and infrastructure based on a blockchain-secured data exchange protocol that can reliably share data, coordinate behavior, and thereby improve urban mobility.[380]

The SAE AutoDrive Challenge is a three-year automated vehicle competition sponsored by SAE International and General Motors focused on spurring university-based teams to build fully automated passenger vehicles. The technical goal of the competition is to navigate an urban driving course in an automated driving mode as described by SAE Standard (J3016) level 4 definition by 2020, the third year of the competition.[381] Competing teams include Kettering University, Michigan State University, Michigan Technological University, North Carolina A&T University, Texas A&M University, Virginia Tech, the University of Toronto, and the University of Waterloo.

Washington, DC is running the $34,000 GigabitDCx competition to spur the generation of mobility and transportation apps that run on 5G wireless networks. Specifically, the competition website defines appropriate apps as "high-performance application[s] that leverage the power of gigabit-speed networks to address real-world challenges." For example, sponsors suggest that mobility apps could work on traffic safety or directing users to multimodal transportation options near them.[382]

Formula E features battery-electric open-wheel racecars that compete on racing circuits laid out on city streets. The racing series is a place for electric vehicle makers to test out new ways of addressing the unique challenges of battery-powered transportation: range, charging technology and heat management.[383] The current competition rules prescribe that all the cars use a 28 kWh battery supplied by Williams Advanced Engineering, a subsidiary of the Williams Formula One enterprise; however, the competition demands are prompting technological improvements in battery cooling, bus bars, and detail design around supporting the cells.[384] While teams' batteries are currently standardized, some speculate that once manufacturers are allowed to build their own batteries, which could happen in or after 2025,[385] teams could double their budgets[386] and perhaps meaningfully advance electric vehicle batteries and their management.

PUBLIC POLICY AND REGULATIONS

Cities and regions are struggling with how to greet, integrate, and regulate emerging mobility technologies, which is affecting the ways in which the modes are being deployed, their market size and successes, and other factors. Reactions such as capping ride hail car licenses in cities like New York,[387] forbidding the use of motorized scooters in cities like Beverly Hills,[388] and considering the ban on automated vehicles in cities like Chicago[389] demonstrate an inconsistent and uncertain approach among local governments to mitigating the new technologies' downsides. Other policies that provide incentives for technology or mode adoption are helping to create markets where none previously existed. The following are samples of some of the various ways in which public policies and regulations are affecting emerging mobility technologies.

MICROMOBILITY

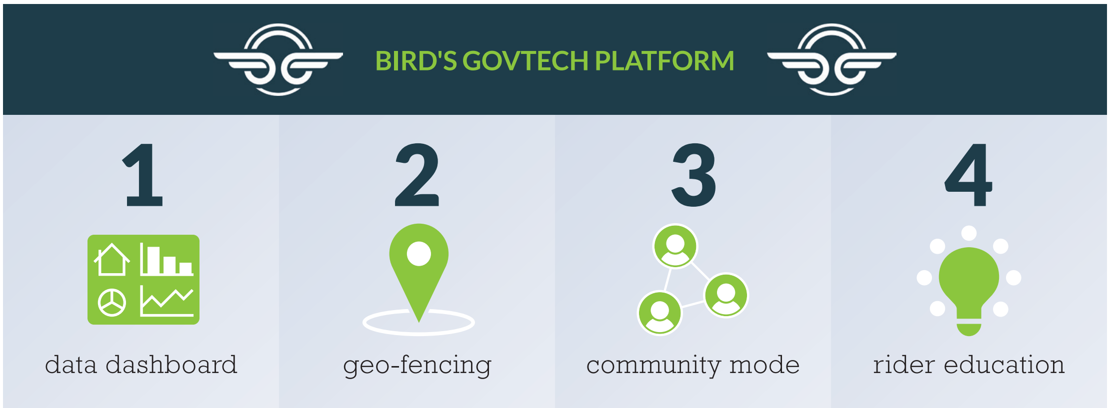
San Francisco was one of the first cities to tackle scooter regulation. Annoyed and offended by the mass deployments undertaken without permission by scooter companies such as Bird, Lime, and Spin, the city banned those companies from deploying. Instead, the city awarded permission to two other companies, Scoot and Skip, of which the city perceived as having more of a focus on safety. The city also capped the number of scooters each company could operate at 625.

A similar script is playing out in cities throughout the country. Scooter companies, following the "move fast and break things" approach used by shared mobility companies – most notably Uber – are dropping hundreds of scooters into new markets – sometimes in a single night – in an effort to build a user base that would help resist efforts to ban the vehicles, should that happen. Given this approach, those jurisdictions where rules are not yet in place are an advantage to the companies. In fact, Bird's CEO has stated, "The places where there are no laws, that's where we go in."[390]

While many jurisdictions are dealing with fundamental issues such as where and how many scooters can be deployed and used, some are already addressing next-level issues, such as affordability and accessibility. In Oakland, Calif., the city council passed a plan that requires scooter companies that are deployed in the city to meet several requirements, including offering unlimited short rides for just five dollars per year (or a package of "equivalent" value) to those with low incomes. Those who receive food stamps or subsidized energy bills qualify for the affordable membership. The scooter ordinance also calls for scooters to be "distributed equitably throughout Oakland" in an effort to improve access.[391] Other cities can be expected to include affordability and accessibility provisions in ordinances of their own, as awareness of such issues increases.

A consequence of a new, high profile market with nascent regulatory protocols is the ever-present threat of legal action. This threat is magnified when the new market entrants are well funded and supported by investors with large budgets. Such is the case with micromobility companies such as Bird and Lime. Accordingly, some law firms have carved out dedicated spots on their websites urging people to file scooter-related claims,[392] and in October 2018 the first major class-action lawsuit against scooter companies was filed in California.[393] The lawsuit accuses Lime, Bird, and other e-scooter firms of "gross negligence" and "aiding and abetting assault" by "dumping" scooters on public streets without an appropriate warning, among other things. It's possible that lawsuits such as these will only become more common and thus will affect not only the involved companies' business plans, but more generally strategies by which micromobility is deployed and adopted.

Recognizing that regulations can, and in many instances already have, an outside role in determining market dynamics and success, scooter companies are hiring transit advocates,

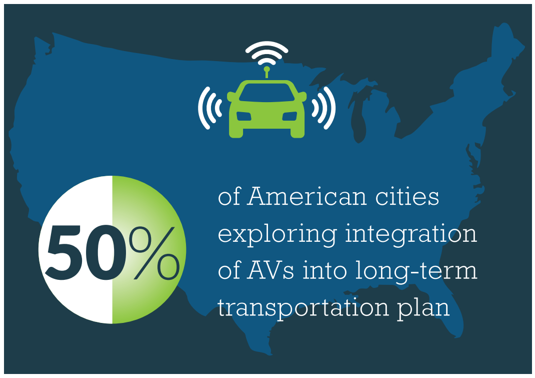


lobbyists, and others with government and nonprofit experience in an effort to shape regulations.[394] For example, in October 2018, former U.S. Secretary of Transportation Anthony Foxx, who helped spearhead federal automated vehicle regulations and the Smart City Challenge, became Chief Policy Officer and Senior Advisor to the President and CEO at Lyft,[395] which had recently expanded its fleet to include scooters and e-bikes.[396] In addition to Foxx, Paul Steely White, former executive director of New York's Transportation Alternatives, joined Bird around the same time that Foxx joined Lyft.[397] Lime hired a formidable lobbyist firm, Akin Gump Strauss Hauer & Feld, for work on "policies supportive of electric bike and scooter sharing."[398] Experienced, well-connected professionals and agencies such as these are primed to help micromobility companies avoid some of the political and regulatory missteps they've made when entering new markets.

Micromobility companies are also taking collaborative and unilateral actions to improve cities' abilities to deploy vehicles. While these actions may be viewed as a preemptive move to avert excessive or otherwise onerous regulations, they can also be viewed as a way to enable an effective balance between regulation and ad hoc deployments of dockless vehicles. Invariably, companies' efforts involve some level of organizing and sharing data. In August 2018, Bird released its GovTech Platform to help local governments manage its scooters. The platform includes four key elements: data dashboards, geo-fencing, community mode, and rider education. The dashboards allow cities to track anonymous data related to scooter use; geo-fencing will show city-designated no-scooter zones; community mode allows citizens to report irresponsible scooter behavior on the Bird app; and education will occur through in-app messages to Bird users before every trip.[399] Given that the tool only works with Bird scooters, there's a strong element of self-interest tied into its development, provision, and adoption, and the platform may be limited in its overall effects.

The provision of this tool also reflects an elemental truth, which is that data is core to regulation. Primary data sharing policy features include trip and fleet availability data, update frequencies, customer feedback and other data, and data sharing agreements between private vendors and public authorities to meet transportation, safety, and equity goals.

In an effort to codify minimal requirements for fields and content from providers for both its own and others' use, the Los Angeles Department of Transportation has created a data sharing standard via an iterative, public process on Github. Dubbed the Mobility Data Specification (MDS), this data-sharing standard prescribes a format for trip data, fleet status, and communication expectations between city regulators and private fleet providers. It meets most of the broadly specified policy aims from cities like Nashville, Santa Monica, San Francisco, and others.[400]



CONNECTED AND AUTOMATED VEHICLES

The efforts undertaken by companies and cities to deal with and regulate the influx of micromobility have direct applicability to the issues they'll be faced with as automated vehicles deploy. This could be helpful given that a study of 68 large U.S. cities' transportation plans revealed only 6 percent considered how driverless cars would affect urban mobility.[401] Foremost among the applicable lessons learned is the need for both parties to engage with each other – perhaps to co-develop tools and platforms similar to Bird's – to determine and enable appropriate regulations. Transferable issues include promoting competition within a confined landscape, fleet sizes and management, pickup and drop-off zoning, and equity and accessibility, among others.

As of October 2018, 29 states have enacted legislation related to automated vehicles. Governors in 10 states have issued executive orders related to them.[402] The challenge with these various regulations and executive orders is that they're inconsistent. For instance, state laws spell out at least three different definitions for "vehicle operator." In Texas, it's the "natural person" riding in the car, while in California, teleoperators also fall under that definition.[403] In such a situation, one might look to the federal government as a standardizing force. But the federal government has taken a decidedly hands-off role, electing to provide states with guidance on how each one can regulate automated vehicles rather than pushing for its own regulations.

In 2018, NHTSA released its latest guidelines for self-driving vehicles in its "Preparing for the Future of Transportation: Automated Vehicles 3.0" – the follow up to guidance provided in versions 1.0 and 2.0 in 2016 and 2017, respectively. It provides guidance and policy considerations for a range of industry sectors, including: manufacturers and technology developers, infrastructure owners and operators, commercial motor carriers, bus transit, and state and local governments. Of particular note, the guidance provides several updates to the U.S. Department of Transportation's (USDOT's) initiatives relating to automated vehicles, by:[404]

- Stating that the USDOT will interpret and, consistent with all applicable notice and comment requirements, adapt the definitions of "driver" or "operator" as appropriate to recognize that such terms do not refer exclusively to a human, but may include an automated system.

- Identifying and supporting the development of automation-related voluntary standards developed through organizations and associations, which can be an effective non-regulatory means to advance the integration of automation technologies.
- Affirming that the USDOT is continuing its work to preserve the ability for transportation safety applications (i.e., DSRC) to function in the 5.9 GHz spectrum.

Given the non-binding approach taken by the federal government and the inconsistent approaches taken by states, cities are leveraging their control of test sites and streets to take the lead in regulating automated vehicles. In fact, 50 percent of large American cities are now exploring how to integrate AVs into their long-term transportation plans. Cities throughout the country have embraced different types of AV pilots, ranging from informal agreements to structured contracts between cities and companies. Many city leaders have taken an active role in AV deployment where possible by introducing executive orders and resolutions, issuing requests for proposals, forming partnerships with companies, hosting conferences and engaging the public.[405] The city of Arlington, Texas operated automated shuttles in order to obtain a better understanding of AV technology, and how it might fit into the city's mobility landscape, increase opportunity for public engagement and education by familiarizing residents with AVs, and to position Arlington as an innovative city. In Chandler, Ariz., AVs have been present since 2016, as the city focuses on easing the transition to full deployment through zoning changes and other policies.[406]

Connected vehicles are in a similar federal regulatory limbo. In an effort to overcome the chicken-and-egg barrier regarding DSRC, whereby the effectiveness of any single equipped car depends on the sufficient existence of others as well as roadside infrastructure, NHTSA and the USDOT published the notice of proposed rulemaking (NPRM) for what is expected to become Federal Motor Vehicle Safety Standard (FMVSS) 150, which seeks to mandate V2V communications for new light vehicles and to standardize the message and format of V2V transmissions."[407] As drafted, the standard would require vehicle manufacturers to install DSRC radios in new vehicles starting around 2023, and to transmit BSM. However, current federal efforts have stalled, and the overall status and timeframe of the rulemaking is questionable.

Smaller automated vehicles for commerce are sorting out their own regulatory issues. Regulation of PDDs is truly nascent. Today, a limited number of states currently or soon will have PDD-specific statutes or regulations, including Arizona, Florida, Idaho, Ohio, Utah, Virginia, and Wisconsin. Each of these statutes has a few common features: requirements related to size, speed, and weight limits; and active control and monitoring by an operator. Similar frameworks are also being developed at the city level, including in Washington, D.C. and Walnut Creek, Calif. The regulations are far from uniform. For example, while the Idaho statute includes an 80-pound weight limit excluding cargo, the resolution establishing a PDD pilot in Austin, Texas allows for up to 300 pounds, excluding cargo.[408] In December 2017, the San Francisco Board of Supervisors voted to severely restrict the devices and regulate the zones in which the robots could operate.

CARSHARING AND TNCS

Automated vehicles aren't the only vehicles whose deployment models and market success are highly influenced by public policies and regulations. A handful of states have enacted legislation regarding carsharing that includes incentives, taxation, electrification, and creating a regulatory framework for peer-to-peer carsharing. California is even regulating emissions.[409] In some states and municipalities, short-term carsharing is taxed at very high rates, in part because shared vehicles are categorized as rental cars and are taxed at a daily rate even though the vehicle may be used only for 15 minutes or an hour. A few state legislatures have taken action to more clearly distinguish carsharing from car rentals and tax carsharing at lesser rates or based on the actual amount of time the vehicle is being used.[410] Pressure to tax carsharing often comes from traditional car rental agencies, who seek the imposition of the same taxes they're forced to pay in order to eliminate one of carsharing's competitive advantages.

At least 28 states have established some sort of regulatory framework for TNCs. Delaware has a memorandum of understanding between its Department of Transportation and Uber. New Hampshire and Rhode Island have convened official legislative study committees. The scope of these states' laws varies, dealing with issues including[411]

- Insurance requirements;
- Background checks for drivers;
- Standards and timeline for vehicle safety inspections;
- Record-keeping for drivers and vehicles;
- Communication of estimated fares and the final receipt to a customer;
- Operation at airports;
- Restricting the hailing of a TNC from the street and other requirements;
- Hours a TNC driver can provide service;
- The categorization of TNC drivers either as contractors or full-time employees;
- Congestion charges; and
- Capping the number of TNCs that can operate within a city (a policy most notably undertaken by New York City in August 2018).

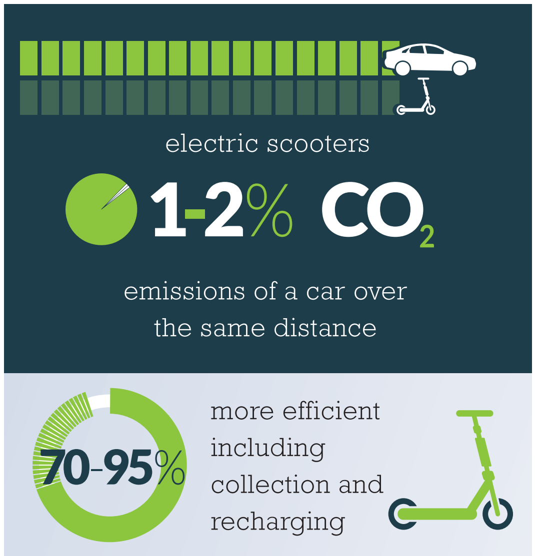
While influenced and advocated by the taxi industry, policies to cap TNCs are primarily being driven by concerns about increasing congestion. Some TNCs are attempting to address this issue and, in turn, preempt such regulations. Uber is spending $10 million to help cities develop more efficient transportation policies and reduce congestion and vehicle emissions. The company plans to distribute the money over three years as part of a campaign to support efforts that prompt people to take greener alternatives to the personal automobile, such as car pools, public transit and bikes. To that end, some of the money will be used to advocate for congestion pricing plans, which charge drivers for entering the busiest neighborhoods at peak traffic times.[412]

ELECTRIFIED VEHICLES

The creation of the modern electric vehicle industry was prompted by regulation. Specifically, it was the Zero Emission Vehicle (ZEV) Program introduced by the California Air Resources Board (CARB) that prompted large investments by automakers in electric vehicle technologies. This program – which at the time it was introduced in 1990 required that a percentage of the vehicles produced for sale in California had to have no emissions of criteria pollutants[413] – was a classic example of "technology-forcing" regulation, whereby a mandated outcome is virtually unachievable using the technologies available at the time it's mandated. Given that the program was technology agnostic, it prompted widespread investments in battery, hybrid, fuel cell, and other low- and zero-emission technologies.

While electrified vehicles' manufacturing costs continue to decline, which serves as a significant market driver on its own, it's likely that regulations will continue to assist their advancement. Transportation recently became the single biggest source of greenhouse gas emissions in the U.S.;[414] in cities, it tends to represent an even larger share. As such, policies are seeking to advance the deployment of ZEVs. For instance, CARB built upon the precedent established by its ZEV program in December 2018 when it unanimously passed a rule that bars transit agencies from purchasing new gas-powered buses by 2029, and requiring only zero-emission buses by 2040.[415]

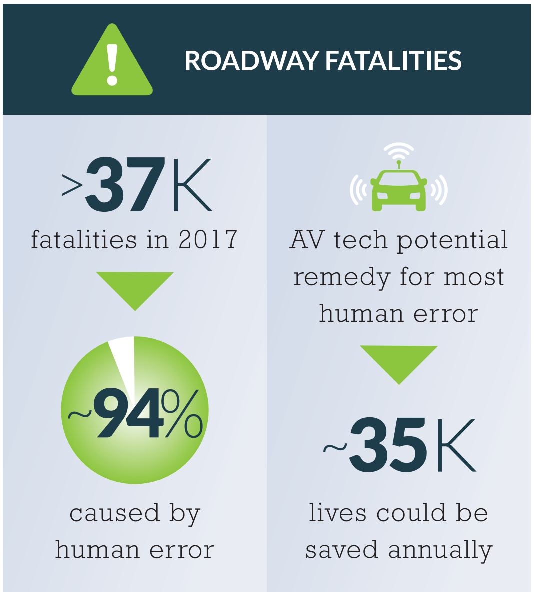
Meanwhile, 246 American cities signed on to the Paris Climate Agreement, which represents a commitment to reduce greenhouse gas emissions to 17 percent below 2005 levels by 2020, and even more by 2025. Some cities have gone further: Los Angeles recently pledged to produce zero net carbon emissions by 2050. Washington, D.C. pledged to reduce greenhouse gas emissions from transportation by 60 percent by 2032.[416] Several countries, cities, and jurisdictions throughout the world have announced plans to outright ban internal combustion engines.[417] Such commitments mean that public policies focused on spurring the use of electrified vehicles (i.e., mandates, subsidies, or economics-based approaches such as congestion charges, etc.) is likely if cities are to meet their goals.



What might be different with forthcoming electric vehicle policies than previous ones is the modes that may be encouraged. While previous policies focused on prompting electric passenger vehicles and transit buses, the viability and popularity of electric scooters and other micromobility means that this mode might now be emphasized. All told, electric scooters account for only 1-2 percent of the carbon dioxide emissions that driving a car the same distance does. Even having to be collected/recharged, they're still around 70-95 percent more efficient.[418]

SAFETY

One of the early markets for automated vehicle technologies – and thus a driving factor – is their ability to help make streets safer. There were more than 37,000 roadway fatalities in 2017,[419] and of those approximately 94 percent were caused by human error.[420] AV technologies have the potential to remedy most if not all of those human errors, which could lead to nearly 35,000 saved lives each year.



ADAS technologies, which comprise the lower levels of automation, include automatic emergency braking (AEB), lane-keeping assist (LKA), and others that aide humans' abilities to drive and help overcome their short fallings, such as attention averted away from roadways and falling asleep. Some studies indicate that lane departure warnings and blind spot detection systems cut the rate of sideswipe crashes and injuries[421] and AEBs reduce rear-end crashes by 39 percent.[422] Higher levels have even greater potential to avert collisions, given their presumed abilities to sense, anticipate, and communicate intentions with each other.

That said, AV technologies' safety enhancement is far from given. As previously discussed, many drivers don't understand current ADAS technologies, and some of those technologies don't work as promised. A study on higher levels of automation indicates that while AVs might largely eliminate low-speed crashes, they could produce more severe high-speed crashes as vehicle redesigns prioritize lower speed functionality over high-speed driving, among other factors.[423]

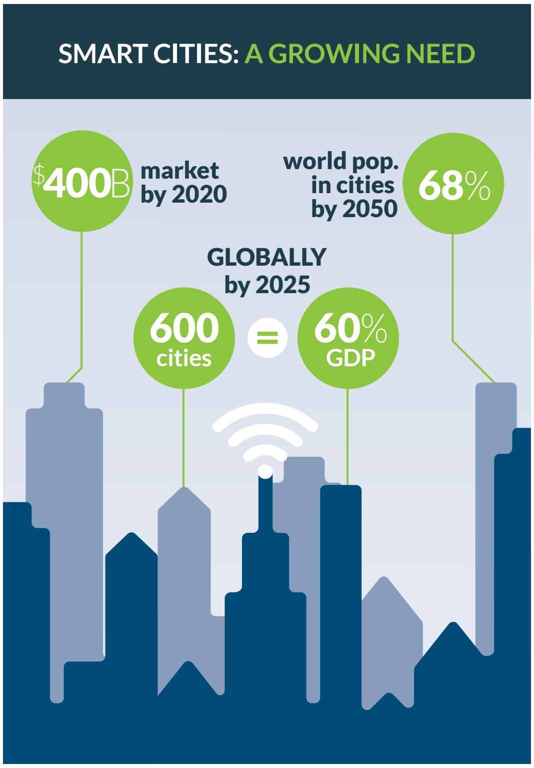
Additionally, the issue of avoiding increased safety risks during the transition from conventional to AVs has emerged as a major challenge, especially given that it is a challenge likely to persist over decades as at least some number of conventional vehicles will remain on roadways. Safety questions exist for infrastructure and traffic operation, and law enforcement. To minimize such risks, AV early adopters may concentrate on closed communities, precincts and campuses. Local agencies will need to deal with the most challenging conditions: dense, complex urban environments.

Safety also affects micromobility. Users of micromobility devices instead of personal cars are reducing the odds of collisions, especially those that are fatal, given that micromobility devices weigh a fraction of the amount of a regular car. That said, their exposed design means that users are subject to hazards in new and perhaps more impactful ways. For instance, potholes experienced in cars are nuisances whereas on a scooter the same pothole could derail a ride. Given micromobility's nascency, its total effect on safety is a long way from being solved. Still, many are already considering the issue, including micromobility providers themselves. Lime launched a $3 million educational campaign, Respect the Ride, to promote responsible use of the company's dockless bikes and e-scooters by asking riders to sign pledges and providing free helmets.[424] Similar and even more comprehensive initiatives can be expected from others in the near future.

SMART CITIES

Smart cities refers to the distribution and connection of a variety of sensors and other instruments to track and subsequently optimize vital city functions such as energy and water consumption, mobility, and waste disposal. Basically, a smart city is one in which so-called "Internet of Things" (IoT) technologies have permeated and are being leveraged to improve the quality of life and overall well-being of its residents.

Mobility factors largely in a smart city, and technologies that improve mobility are seen as core to achieving the quality of life goals. These technologies range from simple (e.g., the broader use of mobile phone apps to optimize drivers' journeys around traffic patterns) to those that are more advanced and revolutionary (e.g., highly automated vehicles and passenger drones). Regardless of the actual mode, the core point of a smart city mobility technology is that it furthers the overall goals and integrates with the broader IoT architecture.



This last point is essential, for the purpose of a smart city is not the isolated deployment of technologies for one-off uses, but rather the systemic application of a broad array of connected technologies that can work together to optimize across the system. For instance, deploying scooters is a smart city component, but on its own doesn't necessarily constitute a smart city. Instead, an example of what might occur in a smart city, especially as it pertains to mobility, might be as follows: A rider uses a smart phone app to locate a scooter; they take it to an electric transit bus stop, are informed via their app precisely how long they'll wait for the next bus, are transported to an electric carsharing terminal where a car has automatically been reserved for them; and each of the electrified modes of transportation has been optimally charged during off-peak hours as guided by smart meters. As riders reach their destinations, building lights are automatically turned on, thermostats activated, and other "smart home" features initiated.

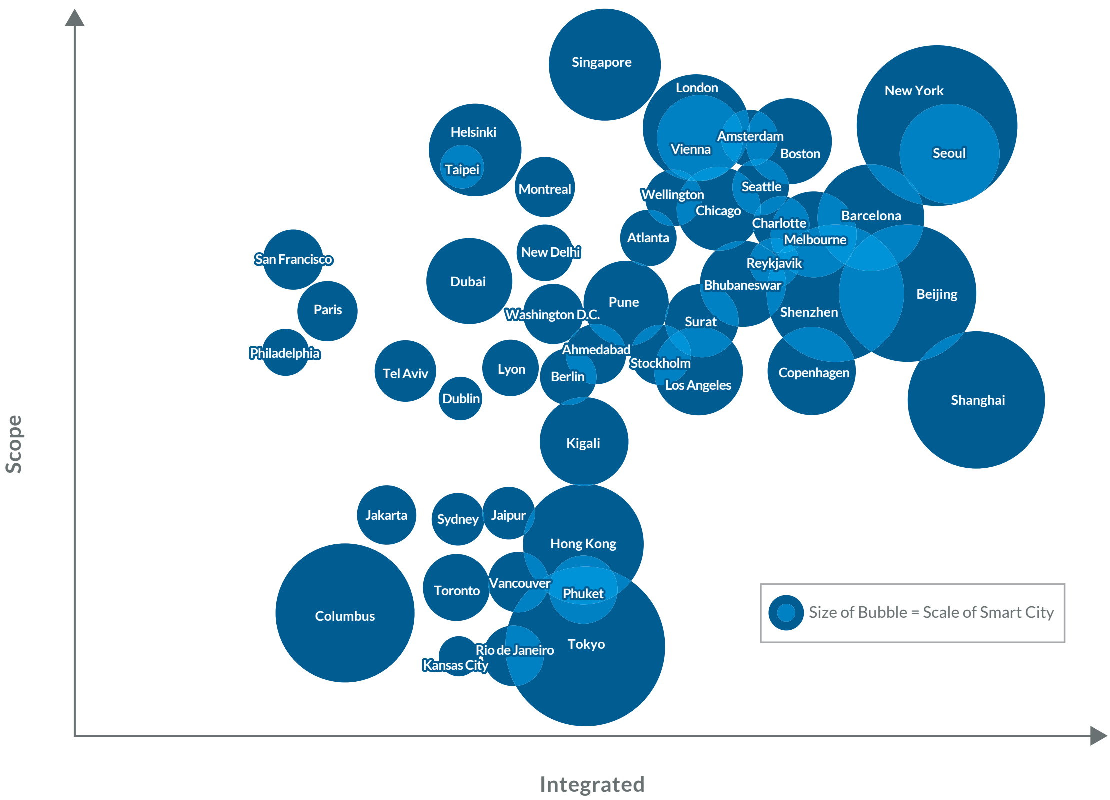
The smart city industry is projected to be a $400 billion market by 2020, with 600 cities around the globe expected to generate 60 percent of the world's GDP by 2025.[425] Smart cities are not just a growing market, but also a growing need, given that 68 percent of the world's population is expected to live in cities by 2050.[426] In such a world, smart resource management is essential.

Accordingly, efforts are already underway to advance and realize the full potential of smart cities. In a study of 140 cities worldwide, 50 were identified as the "smartest" – i.e., those that are most advanced in categories such as vision, leadership, budget, financial incentives, and six other categories. Figure 26 graphically illustrates the study's ranking methodology. The top smart cities were London, Singapore, Seoul, New York, and Helsinki.[427] Interestingly, while a maximum score of 50 was possible, the top city of London was scored at 33.5, indicating room for significant advancement even among the leaders.

The second place winner, Singapore, adopted the title of "Smart Nation" in 2014. Its Smart Nation initiative, funded to the tune of $2.4 billion in 2017, seeks to turn Singapore into a modern laboratory for conceptualizing, testing and implementing ideas to tackle problems unique to urbanized areas. To begin, the government has decided to focus on housing, health and transport.[428] Part of this effort includes a comprehensive and advanced automated vehicle pilot project and deployment strategy that includes the construction of miniature a town dedicated to the vehicles' use.[429]

In the United States, smart cities efforts that include a prominent role for mobility include the $50 million Smart City Challenge, which was launched by the USDOT and

Figure 26: Ranking Methodology for 2018/19 Top 50 Smart Cities



Source: Eden Strategy Institute and ONG&ONG (OXD)

Vulcan Inc. in December 2015. Its objective was to consolidate data-driven ideas that make transportation safer, easier, and more reliable. The Smart City Challenge attracted the following:[430]

- Approximately 300 companies interested in participating in the Challenge;
- 78 applications, leading to the naming of seven finalists (Austin, Texas; Columbus, Ohio; Denver, Colo.; Kansas City, Mo.; Pittsburgh, Pa.; Portland, Ore.; and San Francisco, Calif.) in March 2016 and the winner (Columbus) in June of that year; all proposals had CAVs as central enabling technologies.

The Smart City Challenge further attracted attention to extending the benefits of the challenge beyond the winner. In 2018, Columbus began sharing its playbook for smart cities – including contracts, program materials, presentations, white papers, videos, webinars and data – with hopes of educating one million city officials, policy makers, business leaders and influencers on the Smart Columbus successes and challenges by 2020.[431] Many of the unsuccessful applicants are advancing parts or all of the smart city visions proposed in their applications. Broad interest has been mobilized among private companies and nonprofits that specialize in fields such as wireless transmitters for vehicles and infrastructure, urban innovation, cloud computing, telecommunications, solar-powered charging stations for electric vehicles, engineering design software, and pedestrian- and cyclist-detection for buses.[432]

Nonprofit and industry stakeholder organizations are also assisting with the effort. The Smart Cities Council, a leading industry coalition for smart cities education and advocacy, runs an annual "Readiness Challenge" that helps cities and states advance their smart cities initiatives. The Challenge offers communities interactive workshops, mentoring and digital tools that help them develop their smart cities plans, build community support and strengthen their projects to deliver more widespread and inclusive results. Entrants are judged not on their previous smart city work, but on the quality of the programs and projects they wish to implement next.[433] Winners of the 2018 Readiness Challenge were: Birmingham, Ala.; Cary, N.C.; Las Vegas, Nev.; Louisville/Jefferson County, Ky.; and the Commonwealth of Virginia. These jurisdictions shared three winning traits:[434]

- They focused on breaking down silos to help departments provide better, more efficient service by working together;
- They emphasized coordinated collaboration, not just internally, but also with the community and nearby regions; and
- They used smart cities strategies to lift up underserved and vulnerable populations.

Altogether, it's likely that as cities increasingly think comprehensively about mobility, the built environment, technologies, and the use of their investment dollars, the adoption of explicit smart city policies and programs will propagate.

VENTURE CAPITAL

Private investor dollars have played a leading role in advancing new mobility technologies. Almost $3.5 billion of early stage venture capital (VC) investments flowed into transportation-related startups from January through August of 2018. As Figure 27 highlights, such an amount represents a 10-year high and constitutes the bulk of energy-related investments.

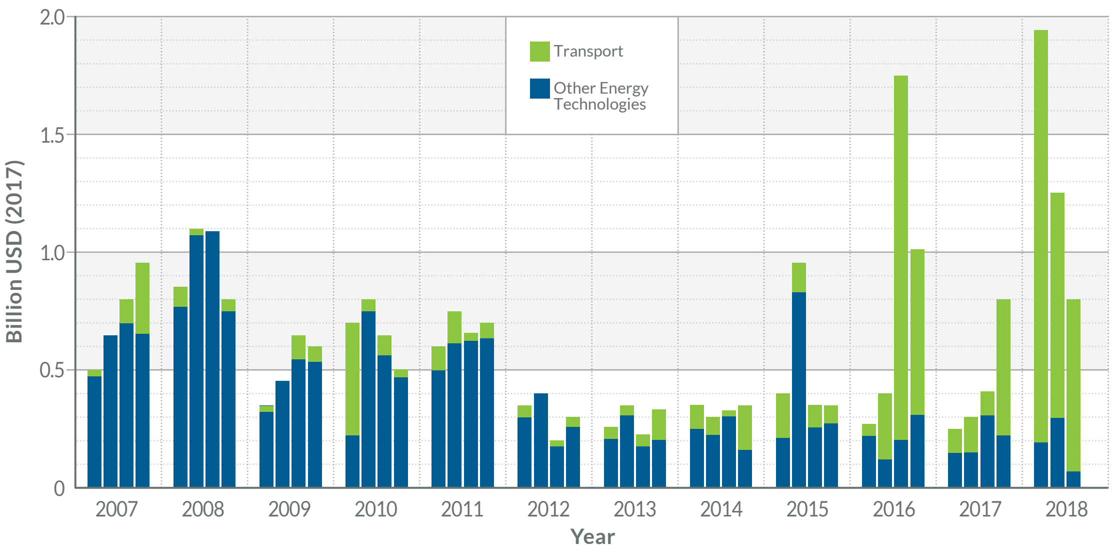
Electric vehicle technologies and companies, especially those in Asia, have received the bulk of this funding in the form of smaller investments to a greater array of companies, according to the International Energy Agency.[435] That said, the past four years have seen a frenzy of investment activity in automated and related vehicle technologies, with $80 billion invested between August 2014 and June 2017,[436] punctuated by $4.2 billion in investments into such companies in the first three quarters of 2018. These investments have been focused on early-stage companies whose products can fulfill specific use cases, such as managing a logistics AV fleet or enabling last-mile deliveries, while larger funding amounts have gone to companies building complete vehicles.[437]

Analysis found that transportation upstarts raise capital more frequently than the global average. Whereas the world average is roughly 24 months between rounds, the average transportation startup raises a new VC round roughly every 18 months. The need to raise money more often may result from capital intensity – such as the costs to develop, test, and bring to market automated vehicles, or the acquisition of large quantities of bikes or electric scooters.[438]

Private investor dollars complement larger corporate mergers, acquisitions, and other substantial deals that have helped catalyze established companies. For example, Honda plans to spend $2.75 billion to support development and deployment of automated vehicles with General Motors and its Cruise Automation subsidiary, whose seed funding round was for $4.3 million in March 2014. Such a rapid scale-up and increase in investment dollars is common in an industry hungry for technological promise and solutions.

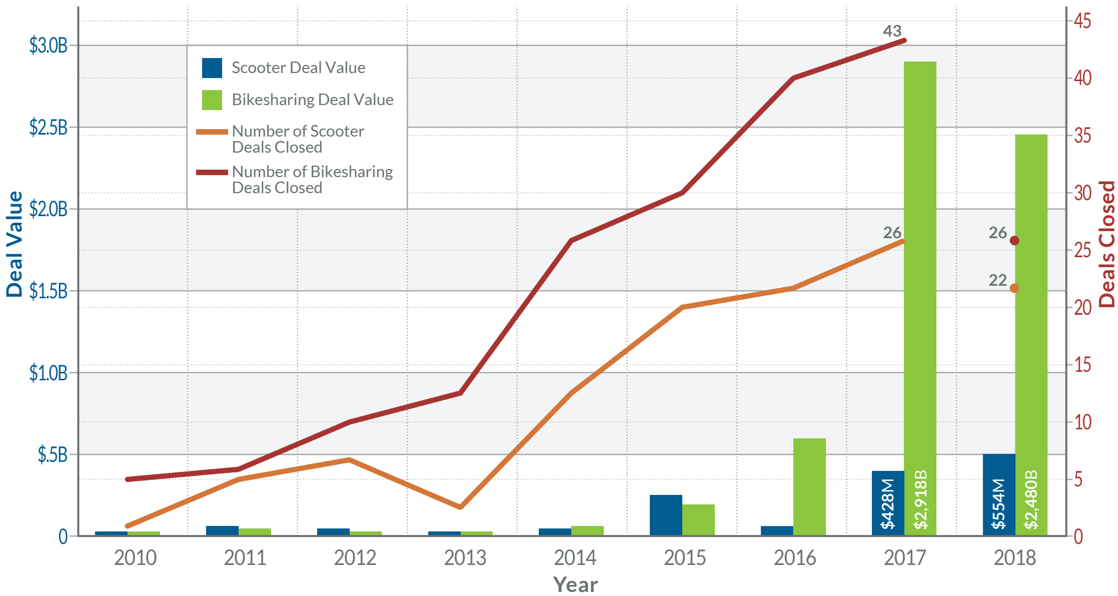
Micromobility also benefited from a substantial infusion of capital. Its rapid rise has fueled –

Figure 27: Venture Capital Investments in Energy Technologies by Quarter



Source: International Energy Agency, September 2018 (citing data from the Cleantech Group i3 Database)

Figure 28: Global Venture Capital Scooter and Bikesharing Investments



*Source: PitchBook *As of August 8, 2018*

and was fueled by – an influx of hundreds of millions of dollars from investors looking to catch the post-ridesourcing shared mobility wave. Bird has raised $415 million in capital, the bulk of which was raised in the first half of 2018, which led to its valuation of $2 billion as of October 2018.[439] Lime raised $335 million in July 2018, bringing its total amount of funding to $467 million and a valuation of $1 billion as of October 2018.[440] The amount of venture dollars going into bikesharing companies like Lime, Ofo, Mobike and Hellobike has increased by at least 172 percent in each of the past five years, including a jump of more than 300 percent each of the past two years, as of August 2018 (see Figure 28).[441]

Another investment category that is helping to propel emerging mobility technologies is the Long-Range Domain, with a recent example being a $300 million funding round in August 2018 by peer-to-peer carsharing company Getaround. Smart cities is another area of VC as investment funds are being established specifically around the smart city framework, such as Pictet's UCITS-compliant Pictet-SmartCity fund launched in August 2018.[442]

With such large amounts of capital infusions, startups have been able to scale up rapidly, develop and advance pre-commercial technology architectures and pilot projects (e.g., automated vehicles), flood new markets with products to make them ubiquitous and convenient for prospective riders (e.g., scooters), and altogether take advantage of current market opportunities and enthusiasm.

REALIZING THE VISION: URBAN MOBILITY INDEPENDENT OF CAR OWNERSHIP

The trend towards electrified, connected and automated, shared mobility and the emergence of multiple commercially-viable modes that fulfill travel needs within the Local, Midrange, and Long-Range Domains means that the opportunity to establish and scale mobility systems that don't depend on personal car ownership has never been better. Yet for such a goal to be realized, core enablers need to be established and adopted, foremost among them being the systemic integration and dynamic coordination between modes and domains, to facilitate users' seamless point-to-point travel (see Figure 29).

THE ESSENTIAL NEED: SYSTEMIC INTEGRATION AND DYNAMIC COORDINATION BETWEEN MODES AND DOMAINS

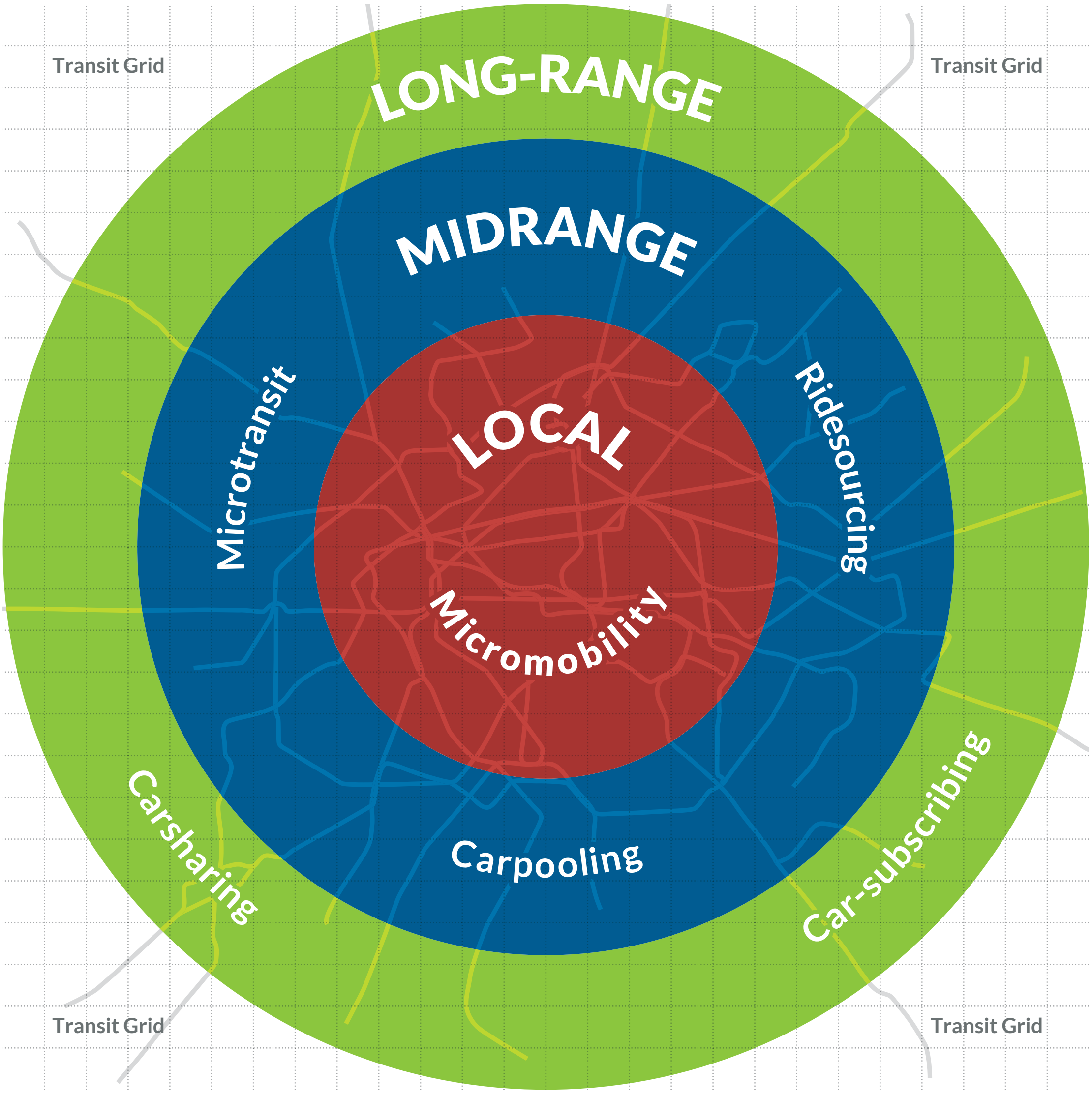
Smartphone applications are emerging as the preferred tool to stitch together mobility options and offer prospective users clarity on modes, availability, travel options, and step-by-step travel instructions so as to facilitate modal viability and use. Efforts are now focused on the broad linking and integration of all of the various shared mobility modes to enable seamless point-to-point travel. An ultimate goal is the creation of a system for modes to work together; not just passively providing availability and route timing information, but actively performing essential tasks like ensuring modal availability by repositioning micromodes and coordinating bus stop departure times, much as an airline would for flight connections.

One platform that is making progress towards these goals is the Whim app by Finnish startup MaaS Global. Available in a number of European cities, Whim offers users access to both public and private transportation, including everything from buses to bikes to scooters, all in one platform. It allows travelers to book a door-to-door trip with a click, automatically reserving a car, bike, bus, train or multiple transit modes to complete a journey. Users can either pay for all modes that comprise a given journey on a per-ride or monthly unlimited-use subscription basis. Whim charges approximately $50 per month for limited service including public transit, bikeshare, and limited ridesharing, and $500 per month for full ridesharing service.

In the United States, a number of comparable smartphone apps have emerged and are gaining users:

- ***Citymapper*** lets users tap on a nearby bus stop on their app map to see real-time arrival information, and also allows trip comparisons by time as well as cost.
- The ***Transit*** app presents users with real-time information for every nearby public transportation service and many other modes, and links modes to present point-to-point mobility options, prices, and timeframes. Transit+, which launched in December 2018, feeds rides from private mobility services onto buses and trains and includes planning, booking, and payments.[443]

Figure 29: The Interrelations Between Domains, Modes, and Transit That Establishes a Mobility Framework Independent of Personal Car Ownership



- ***Moovit*** divides routes and trips into three simple categories – directions, stations, and lines – enabling users to route trips or search for real-time arrival information at bus stops or train stations.
- ***Cowlines***, which is working with hundreds of transit agencies and private providers in over five dozen cities, seeks to solve complex commutes by offering customized routes that aggregate and combine any transportation option to

move around the city, and claims to deliver approximately 40 percent faster routes for non-car trips compared to other apps.[444]

- ***SoMo***, built by HERE Mobility, is an app that provides information on transit, taxis, ridesourcing, bike-share and more. It combines aggregated transit and mobility information with a social aspect to give users the ability to share their rides and choose who to ride with, connect with people based on common interests, and ride together to events organized by other users.[445]

Even public agencies are making inroads. Los Angeles announced its Metro Transit Access Pass ("TAP") Smart Card Program would be developed into an account-based system that will become a one-stop shop for payments and signups across all mobility services including bikeshare, microtransit, electric vehicle (EV) sharing and charging, ride-hailing and parking.[446] Columbus, Ohio selected MTECH Solutions LLC to develop its multimodal trip-planning and common payment system app that seeks to allow the end user to pay for multiple forms of transportation with one payment.[447]

Apps like Citymapper, Transit, Moovit, Cowlines, and SoMo are more or less vendor agnostic, seeking to integrate available options from all providers. Others have emerged that take a "walled garden" approach: a vendor-specific aggregation of modes that offers consistent branding and perhaps eventually even active modal coordination, but also limits the information and options available to a user.

Foremost among these providers are the traditional ridesourcing providers Uber and Lyft. Uber expanded its service offerings in a few ways: acquiring Jump Bikes, partnering with public transportation platform Masabi to enable users to buy a public transportation ticket from inside the Uber app, and partnering with peer-to-peer carsharing firm Getaround to launch Uber Rent. The company also invested $335 million in scooter-sharing company Lime and announced a partnership with the startup focused on co-branding the scooters and making them available through Uber's app. Additionally, the company plans to integrate public transit so as to become a true mobility platform, as part of a broader effort dubbed "Mode Switch,"[448] to provide real-time traffic estimates to help inform users' modal selection,[449] and announced plans to spend $10 million over three years as part of a Fund for Sustainable Mobility to support campaigns for safety and improved transit.[450] Such moves are consistent with corporate statements and goals targeted towards reducing ridesourcing's share of Uber's business to less than 50 percent by 2028.[451]

Lyft is also working on an offering of integrated transportation services. The company acquired Motivate, the largest bike-sharing operator in the U.S., and also announced that it would launch a scooter-sharing service. In addition to these moves, Lyft is working with city programs to facilitate bike- and scooter riding, with initiatives including protected bike lanes and providing public transit information within its app.[452] Lyft also launched a "ditch your car challenge" in Chicago in August 2018. Through this challenge, Lyft provided 100 residents with $550 in credit for Lyft trips, public transit, bikeshare, and carshare in exchange for pledging to give up their car for one month. This included $300 in Lyft credits, $105 for bus and train service, $45 for a Divvy bikeshare pass, and $100 in Zipcar credits. Based on the positive results from this pilot, Lyft expanded the challenge to 35 additional cities.[453]

Traditional OEMs are offering their own vendor-specific, turnkey multimodal services. Perhaps foremost among them are BMW and Daimler, who merged their diverse portfolios of mobility investments into a single multimodal network. Daimler's Moovel was already a leader in carsharing in Europe, and recently opened a marketplace for bundled mobility passes that enables transit authorities to integrate everything from ridesourcing to micromobility to traditional public transit[454] Through the merger, Moovel will now be combined with other services, including the following: ReachNow/DriveNow and Car2Go (for carsharing); mytaxi, Clever Taxi, Chauffeur Privé, Clever Taxi and Beat (for ridesourcing); ParkNow and Parkmobile (for parking locations); and even electric vehicle charging. Other OEMs pursuing multimodality include Ford, who acquired scooter-sharing and other modality providers in recent years;[455] General Motors, principally through its Maven platform; and Toyota, who, among other things, led the series A investment in MobilityX, a Singapore-based "mobility-as-a-service" startup owned by the city-state's largest transport operator (SMRT Corporation) that allows transport operators to run their own multimodal versions of transportation network apps.[456]

As efforts to integrate and coordinate modes and domains advances, more creative usage models may emerge that combine a grab-bag of modal trip quantities, combinations, and even distances. For instance, plans might include a dozen public transit rides, another dozen bikeshare or e-scooter trips, and one ridesourcing trip less than 10 miles. Such mixing and matching can allow users to fine-tune product packages to meet their specific needs. It might also unlock other models, such as sponsored usage whereby retailers provide targeted assistance to enable shoppers' visitation; medical assistance, in which health providers subsidize rides to and from hospital appointments; occupational support whereby employers cover employees' multimodal trips; and others.

FUTURE ENABLERS AND MARKET DRIVERS

While big data, freight and commerce, ITS, smart cities, and other technologies and market drivers are currently enabling the emergence of mobility technologies and systems, technologies and market drivers on the horizon will play a role in the emergence of the 21st century mobility paradigm.

Future Enablers and Market Drivers
Aerial Vehicles
Automated Micromobility
Blockchain
"Land Traffic Control"
Ultra-Fast EV Charging
Vehicle-to-Grid

AERIAL DRONES AND FLYING CARS/TAXIS

Aerial drones, or unmanned aerial vehicles (UAVs), have received attention in recent years as prospective package delivery devices. Much of this attention has been driven by Amazon, which announced in December 2013 its intentions to use drones to ferry customers' packages.

While utilizing several technologies commonly found on automated vehicle platforms to geolocate and navigate from point to point, the application of these technologies to airborne vehicles overcomes core challenges associated with commercializing highly automated vehicles – namely assimilating with traffic, existing roadways, and infrastructure. Additionally, by focusing on the small package delivery market, drone developers are able to provide a core service that's in immediate demand, while potentially scaling up platforms and services once the platform is fully proven.

Amazon is partnering with the United Kingdom to explore the steps needed to make the delivery of parcels by small drones a reality, allowing Amazon to trial new methods of testing its delivery systems. The work is meant to help Amazon and the government understand how drones can be used safely and reliably in the logistics industry, identify what operating rules and safety regulations will be needed to help move the drone industry forward,[457] and altogether help advance Amazon's Prime Air service, which is focused on using drones to deliver packages up to five pounds to customers in 30 minutes or less.

Alphabet's "Wing" spinoff plans to launch a drone delivery service in Helsinki, Finland in spring 2019 – its first operation in Europe. It will just be a small-scale trial, with the drones only able to carry packages weighing up to 3.3 pounds (1.5 kilograms) on a round trip of up to 20 miles. Wing is pitching the drones as an environmentally friendly choice, claiming they have a carbon footprint less than 1/20 that of traditional deliveries. Wing is asking Finnish would-be users what they would like to have delivered, with options including medicine, groceries, and lunch.[458]

The advancement of aerial delivery drones is just the first step in what's perceived to eventually be a meaningful mode for personal mobility. In fact, some manufacturers and innovators have examined the concept of pairing vehicles with drones. Daimler produced a vision for a concept delivery van with roof-mounted drones, Local Motors produced a concept car with a traffic-identifying drone mounted on its rear, Cincinnati-based Workhorse Group is working with the University of Cincinnati to launch delivery drones from the roof of its trucks, and Ford is investigating ways in which drones can help AVs solve navigation problems.[459]

In May 2018, the Federal Aviation Administration (FAA) selected 10 entities for its Unmanned Aircraft Systems (UAS) Integration Pilot Program (IPP).[460] Many of those selected are examining projects that can help reduce traffic congestion on city streets and enable governments and private companies to explore how drones can be used to make everyday life more efficient. Over two and a half years, the selectees will collect drone data that will help the USDOT and the FAA with several objectives:

- Craft new enabling rules that allow more complex low-altitude operations;
- Identify ways to balance local and national interests related to UAS integration;
- Improve communications with local, state and tribal jurisdictions;
- Address security and privacy risks; and
- Accelerate the approval of operations that currently require special authorizations.[461]

Testing began in September 2018, with companies like AirMap and other private sector partners providing traffic management and software among other services.[462]

Once proven and scaled, the advancement of commercial services via drones has potential applications beyond the established format. Several developers already have plans to commercialize passenger drones and taxis – a market that Morgan Stanley says could rise to $1.5 trillion by 2040.[463] Lilum has produced an electric vertical takeoff and landing jet for use as a pay-per-ride flying taxi that is affordable for anyone.[464] The new five-seater is claimed to use only 10 percent of the energy of a quadcopter-style aircraft and has a range of over 300 km (186 mi) at a speed of 300 km/h (186 mph), allowing it to travel from JFK Airport to Manhattan in five minutes instead of the 55 minutes by road. It is also claimed to cost the same as a regular taxi because its small takeoff and landing footprint means less and cheaper infrastructure.[465] The company will conduct its first manned test flight in 2019 and is targeting early 2020s for commercial operations.

Boeing is currently building flying taxi prototype vehicles that it expects to have airborne sometime in 2019 and a commercial reality in five years.[466] In 2017, the company acquired Aurora Flight Sciences, which has worked extensively for the U.S. government on electric and automated aviation, and is working with Uber to develop flying taxis in a move that Boeing sees as accelerating its efforts around automated aerospace vehicles.[467] Boeing is also working with a start-up called SparkCognition to develop unmanned aircraft system traffic management (UTM) solutions for the safe integration of automated air vehicles. To help advance UTM and next-generation travel, Boeing created Boeing NeXt to leverage the company's research and development activities and investments in areas such as automated flight and advanced propulsion, as well as focus on modeling smart cities and exploring new market opportunities to solve for the transportation challenges of the future.[468]

Additional aerial taxi efforts include:[469]

- ***UberAir***: The ridesourcing company envisions rooftop aerodromes servicing a fleet of fixed-wing air taxis, carrying four passengers plus a pilot. The company plans to have ongoing demonstrator flights in the air by 2020, and commercial operations by 2023 in at least three cities: Dallas, Los Angeles and one more to be named. The initial business plan states that the company would eventually use fully automated technologies to remove pilots from the aircraft.[470]
- ***EHang***: The "EHang 184" is an electric drone capable of carrying a single passenger who weighs less than 220 pounds over 60 miles. Travel is controlled mostly by an onboard tablet inside the pod-like cockpit, where a passenger selects the flight's destination.[471]
- ***Rolls-Royce Holdings PLC***: The company, which is separate from the motor vehicle division, unveiled an electric vertical-takeoff-and-landing concept in July 2018 that can carry five passengers 500 miles at speeds of up to 250 mph. The company is targeting the early 2020s to have commercial vehicles in the air.
- ***Aston Martin***: Working with Rolls-Royce Holdings PLC, Aston Martin unveiled its concept "sports car of the air," dubbed the Volante, in July 2018 that it states will take flight commercially no earlier than 2025.
- ***General Motors***: The company has had conversations with air taxi companies

about using the carmaker's autonomous and electric vehicle technology to create flying cars but acknowledged that "it's some years away" before widespread production and sales of such a vehicle get off the ground.[472]

- ***Audi***: In conjunction with Airbus and Italdesign, Audi presented an operational prototype of Pop.Up Next, its flying taxi concept that's a hybrid between a drone and an automated car. The system has a ground module and a drone module. A separate passenger compartment can be transported by, and passed between, both transport modules.[473]
- ***Bell***: The 80-year old helicopter manufacturer is pursuing the flying taxi market by undertaking a three-phase study to determine what types of control systems will allow "minimally trained" pilots sufficient control and oversight without necessarily requiring them to have the same skills possessed by crews flying modern helicopters and airliners.[474]

Altogether, the work advancing aerial drones and the application of the platform and technologies to personal mobility market has potential to significantly disrupt personal mobility, perhaps beginning as early as 2022, which is when close to a dozen current efforts have announced commercialization.

AUTOMATED MICROMOBILITY

A core challenge faced by micromobility providers as they scale up is the (nightly) collection and repositioning of their fleet. Specifically, because these vehicles are electric and often dockless, they need to be recharged and strategically repositioned to maximize their utility.

Providers are currently solving this challenge by leveraging "gig economy" workers, essentially paying part-time contractors a bounty to collect, recharge, and deposit a vehicle to a designated location before a certain time. The solution has enabled providers to enter, become operational, and scale-up quickly in new markets. Yet questions surround the model's sustainability. Paying contractors to collect and charge vehicles already represents approximately 47 percent of the average $3.65 of gross revenue that Bird generates per ride.[475] As a market grows and more vehicles deploy to a wider array of locations, this percentage might become larger, and perhaps drive up overall user costs, as higher wages may be required to attract sufficient quantities of gig workers to manage the fleet.

Whereas this publication has addressed the role that automation can – and likely will – play in ferrying passengers and goods, this micromobility challenge highlights another potential value-add for the technology. As automated technologies' costs continue to decrease, they may make their way to micromobility, where fleets of the future might be programed to congregate at centralized collection or recharging areas at the end of each day or after their batteries are depleted by a certain percentage, repositioned at opportune locations before the beginning of the next day, and always parked neatly in designated locations so as to avoid public clutter. The public might not even notice such a use of automated technologies, should repositioning continue to take place at night.

One company, Singapore-based Scootbee, is already beta testing such an approach. The company aims to produce the world's first on-demand, self-driving scooter that enables

> *Beyond cryptocurrency, speculative uses of blockchain include insurance contracts, loyalty points, and distributed electricity generation. Because of its orientation around transactions, many have also envisioned blockchain playing a role in enabling shared mobility.*

users to summon one of its three-wheeled scooters with an app, ride to a destination, then leave the scooter to park itself.[476] As micromobility continues to scale, hits up again economic and logistic challenges, and as the price of AV components continues to decline, it can be expected that more providers follow Scootbee's lead.

BLOCKCHAIN

Blockchain is a digital asset tracking technology that was first envisioned by Bitcoin inventor Satoshi Nakamoto in 2008 and has since found prospective uses in numerous markets and applications that require precise, secure, and low-cost tracking and authentication.

Blockchains are decentralized ledgers with no singular authority that are spread across thousands of computers. When blockchain-based transactions take place, they are recorded permanently and firmly in a block, which refers back to a previous block, creating chains of blocks. This transaction record, which includes a unique identifier that cannot be covertly duplicated and used, is meant to foster transparency, security, and trust. It is also meant to reduce transaction costs, given the decentralized ledger and avoidance of any central authority who might charge a commission.

Beyond cryptocurrency, speculative uses of blockchain include insurance contracts, loyalty points, and distributed electricity generation. Because of its orientation around transactions, many have also envisioned blockchain playing a role in enabling shared mobility. For instance, current ridesharing and carsharing platforms such as Uber and Turo, respectively, create markets that facilitate the provision of services between two individuals. The value is in the creation of the market and its user base, as well as the establishment of a way to quickly and securely provide and receive payments.

But that value comes at a cost to those engaging in the transaction – namely a percentage (typically 25 percent[477]) of the overall payment to the market-making platform and/or transaction fees paid to payment facilitators, such as credit card companies (typically 0.5 percent to 5.0 percent of the transaction amount, plus $0.20 to $0.30 per transaction[478]). With blockchain, the potential is to enable the same secure large marketplace, but to do so using distributed computing that avoids user fees. Such a blockchain-based platform could help owners better monetize their vehicles, their driving data, and any number of other services or value streams.

For example, in the case of carsharing, a smart contract might verify that the vehicle's claimed owner actually owns the car, indicate if and when an owner would share it, and establish a threshold for sharing based on reputation scores. The technology would be structured such that someone meeting these criteria could "check out" the car and provide payment (perhaps using a dedicated currency) directly to the owner (while avoiding transaction fees), unlock its doors, start the engine, and drive away. Infineon Technologies AG and XAIN are working together on bringing blockchain technology into the car, with a first demonstrator showing how access rights, such as those for carsharing, can be decentrally granted with a smartphone app.[479]

Blockchain technology has potential to serve the broader mobility ecosystem beyond carsharing. Pittsburgh, Penn.-based iomob aims to be a user-friendly, open and inclusive form of mobility-as-a-service aimed at addressing "inefficiencies" in a multi-modal but "fragmented mobility landscape." It allows end-users to discover, combine, book, and pay for the mobility services that best cover their needs at a given point of time. Iomob will be implemented as an open-source, decentralized platform that leverages blockchain to allow all mobility providers to easily join the platform. By connecting all the mobility operators in an area, iomob aims to help users to find better combinations of services for any given trip.[480]

Other prospective uses of blockchain for mobile applications include enabling insurance premiums to better reflect the risk of a particular driver by incorporating factors for actual usage and reputation, rather than applying a crude derivative of a marketwide average. The aggregation and sharing of vehicular data such as that that informs and validates the integrity of automated vehicle programming, and enabling dynamic V2X spectrum sharing of V2X as well as its communications' secure transmission and interpretation are additional prospective blockchain use cases. General Motors has even filed a patent on how blockchain can be used to distribute event information relevant to the decision making of automated vehicles.[481]

To this last point, an intriguing example illustrates one prospective application whereby cars use tokens such as Streamr's DATAcoin to pay for data they require from other cars. This includes weather forecasts, gas prices nearby, congestion data, and more. Vehicles could then earn tokens simply by sharing their data or choosing to sell it to advertisers or manufacturers. With this strategy, blockchain can create a V2V closed ecosystem that incentivizes and rewards participation simultaneously.[482]

In 2017, Toyota Research Institute formed the Mobility Open Blockchain Initiative ("MOBI")[483] with several startups, academic institutions, vehicle manufacturers, and consumer-facing mobility providers to explore applications of blockchain technology in the mobility space. MOBI is a nonprofit organization working with forward-thinking companies, governments, and NGOs to make mobility services more efficient, affordable, greener, safer, and less congested. The organization promotes standards and accelerates adoption of blockchain, distributed ledger, and related technologies.[484]

It remains to be seen what precise role(s) blockchain will have in serving and/or driving the adoption of emerging shared, electrified, automated mobility modes. But with such a broad roster of companies supporting its advancement for mobility applications, and the technology's overall potential to remove redundant intermediaries and improve transactional efficiencies, there is little doubt that the technology will be present. The question simply comes down to figuring out and enabling winning, mass-market use cases.

HEALTHCARE

Transportation is the third most frequently identified reason for missed medical appointments among older adults. Nearly 3.6 million individuals did not access medical care in 2017 because they did not have a ride, and four percent of children missed a medical appointment because of transportation barriers.[485] According to one estimate, missed appointments as a whole cost the industry $150 billion annually,[486] and the transportation access gap has created a market worth over $3 billion.[487]

This challenge and resulting market opportunity has prompted healthcare providers and transportation service companies alike to develop technologies and mobility solutions that can help overcome these barriers. So-called "dial-a-ride" collection and drop off shuttles were historic offerings by healthcare providers, but the solution's typical requirement that patients schedule rides via phone at least 24 hours in advance (rather than via more tech-friendly and real-time platforms such as smartphones) means that it has done little to overcome the access gap.

Recognizing this shortcoming, industry stakeholders such as insurers, providers, and electronic health record (EHR) companies, among others, are embracing new technologies and engaging directly with ridesourcing companies to structure solutions to provide non-emergency medical transportation (NEMT) to their patients. A one-year pilot between Lyft and Hitch Health conducted at Hennepin Healthcare internal medicine clinic in Minneapolis focused on patients who historically have missed appointments and reduced their absences by 27 percent. The program, which used Hitch Health's automated SMS technology to offer Lyft rides to patients in need, also increased revenue at the clinic by an estimated $270,000 and yielded an estimated return on investment of 297 percent.[488]

A separate pilot led to similarly promising results. Lyft and Cigna-Health Spring, the parent company's Medicare Advantage arm, partnered to provide non-emergency rides to members in in Alabama, Georgia, Maryland, North Carolina, Pennsylvania, Tennessee, Texas and the District of Columbia. Between May and November of 2017, Lyft provided more than

TRANSPORTATION AND HEALTHCARE

~3.6M did not access medical care due to transportation in 2017

3rd highest reason for missed medical appt. among **older adults** - transportation.

4% of **children** missed a medical appointment due to transportation

annually, missed appts. cost industry	market worth due to trans. access gap
$150B	**>$3.0B**

14,500 non-emergency rides to Cigna-Health Spring members. Furthermore, 92 percent of members who used the service made it their preferred means of transportation.

In May 2017, Blue Cross Blue Shield (BCBS) began partnering with Lyft to enable patients in high-need areas to access Lyft's transportation services. The technology analyzed population data for 106 million BCBS beneficiaries and determined which patients needed more transportation support.[489] Nearly a year later, the partnership expanded its array of services to provide a way for enrollees who don't have adequate transportation to travel to Walgreens Boots Alliance and CVS Health pharmacies.[490]

These and other pilots represent what many believe could be the tip of the iceberg when it comes to healthcare's potential to drive the adoption of emerging mobility technologies. While NEMT is already a Medicaid covered benefit,[491] there's a possibility that the Centers for Medicare & Medicaid Services (CMS) could allow managed Medicare plans to offer a transportation benefit. In April 2018, CMS began "reinterpreting the standards for health-related supplemental benefits in the Medicare Advantage program to include additional services that increase health and improve quality of life," a move that could lead to a broadening of the definition of "primary health related" in the Medicare Advantage program and, therefore, potentially enabling the provision of transportation services.[492] Should this happen, more healthcare dollars could be used to support an array of mobility modes and technologies that include not just ridesourcing, but also other modes such as microtransit and even automated technologies, as they mature and are applied to lower the cost of ridesourcing services.

"LAND TRAFFIC CONTROL"

With the advent of commercial air travel and the subsequent volume of air travel, air traffic control systems became a staple in coordinating the mass movement of travelers arriving and departing on increasingly sophisticated machinery. So too could be the case as seamless mobility ecosystems – comprised of large, mixed modes, and leveraging technologies to enable increasingly higher levels of automation – emerge.

At what stage such systems begin to emerge remains to be seen. To date, most work has focused on automating individual vehicles and proving their functionality, safety, and other abilities. Little attention and even fewer demonstrations have been devoted to such broader level cooperation and management. Yet as previously discussed, if AV developers and fleet operators flood cities with vehicles, poorly managed fleets could increase overall energy consumption and traffic congestion. Efficiency requires vehicles, operators, and users to communicate and coordinate to match supply and demand.

The University of Southern California laid out the foundation for such a coordinated approach in 1998, when it described an "Intermodal Transportation Operation System."[493] A number of cities have already put into place components of such a system:[494]

- ***Columbus***, Ohio: The winner of the U.S. DOT's Smart City Challenge is creating a Smart Columbus Operating System. The system will share near-real-time data on conditions throughout the city, focusing initially on mobility but eventually encompassing a full range of smart city domains.[495]

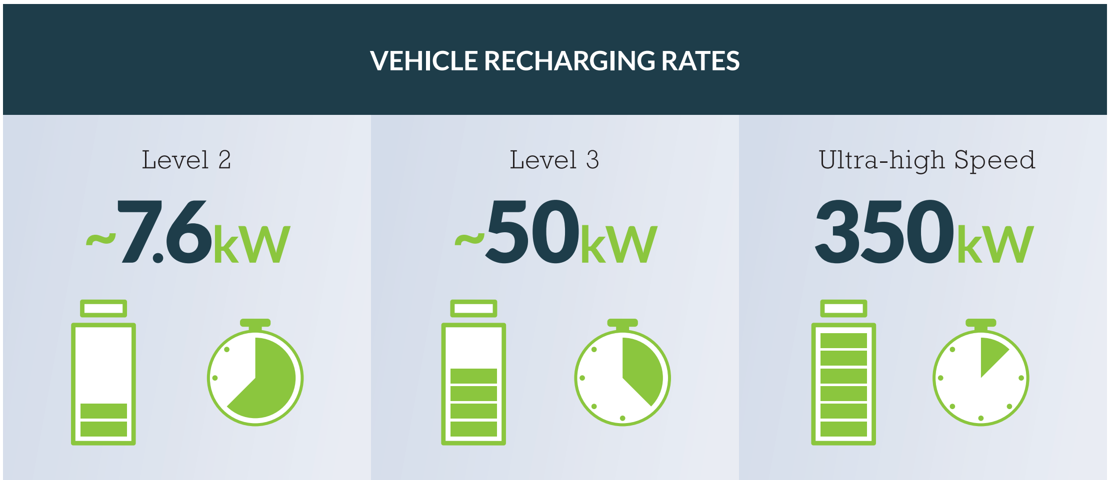
- ***Singapore's*** Intelligent Transport System incorporates electronic road pricing, congestion charges, and traffic monitoring via highway sensors and taxi GPS applications, all funneled to a control center that allows tracking and traveler notifications.[496]
- ***Copenhagen***, Denmark launched the world's first city data marketplace, a real-world example of the mobility data exchanges that could form a key component of a broader mobility platform.[497]
- ***Barcelona***, Spain and surrounding cities implemented an open-source platform called Sentilo that brings together data from multiple sources and underpins the deployment of smart parking and smart transit services, as well as energy consumption monitoring and smart waste collection.[498] The City Council has also implemented City OS to connect various city projects and services on a single platform.[499]
- ***Dubai***, United Arab Emirates (UAE) launched a "Smart Dubai" initiative in early 2014, led by the city's Road and Transport Authority, which has initiated several pilot projects in traffic management, parking, electronic toll systems, and congestion management. The city also announced the creation of a "Smart Dubai Platform," in partnership with Dubai-based telecom company du, which it aims to make the "digital backbone" of the city, enabling open data sharing.[500]

To be clear, such efforts should be seen as a first yet essential step in the establishment of a land traffic control system; the ultimate vision being one in which demand is captured and used to evenly distribute vehicles, pool travelers, and manage key performance indicators such as wait and travel times,[501] while alleviating congestion, balancing electrical grid loads, and improving safety. Other elements required to see such a system arise is the standardization of vehicular communication and control protocols for onboard hardware and software, as well as the development of broad-based, system algorithms that are capable of such efficient coordination. To this latter point, work is progressing, as evidenced by the U.S. DOE's Lawrence Berkeley National Laboratory's application of deep reinforcement learning to train automated vehicles to drive in ways to simultaneously improve traffic flow and reduce energy consumption.[502] This is but one of several efforts underway that may gain more prominence as larger numbers of connected, automated vehicles deploy.

ULTRA-FAST ELECTRIC VEHICLE CHARGING

Modern "Level 3" EV chargers' specifications are typically around 50 kW by 480 V, 125 A direct current (DC). While such specifications enable vehicle recharging rates that are magnitudes faster than conventional "Level 2" 240 V charging (delivering about 60 to 80 miles of range in 20 to 30 minutes), it's still by no means comparable to the range enabled per time devoted by conventional gas stations.

In the United States, light passenger vehicle pump flow rate can be as high as 10 gallons per minute,[503] which means that the average U.S. light-duty vehicle in 2016 can obtain 220 miles of range or more in a single minute.[504] As previously discussed, the usage profile of EVs can differ significantly from conventional vehicles, thus making infrastructure comparisons – specifically those around quantities – less appropriate. Yet faster recharging times can



do much to accelerate EVs' adoption rates, at a minimum by helping to overcome the impression that electrification is somehow inferior to internal combustion engines, but more importantly by eliminating range anxiety and enabling longer distance travels.

Several efforts are already underway to develop and commercialize ultra-high speed chargers. Tesla's "Superchargers" are currently the gold standard in high-speed charging, with over 11,000 Superchargers worldwide[505] offering 145 kW charger capacity (capped at 120 kW by the vehicles) that is more than double what's typically offered by CHAdeMO and Combined Charging System (CCS) Level 3 systems. Still, the company is looking to increase this capacity, citing its planned deployment of Supercharger V3 technologies that have the capacity to deliver 200 to 250 kW. Tesla aims to eventually offer 360 to 480 kW Supercharger capacities, which it framed as the limit of the technology for passenger electric cars, and reduce vehicle charging times down to 5-10 minutes.[506]

Others are advancing ultra-fast EV chargers as well. Five automakers – BMW, Daimler's Mercedes, Ford, and Volkswagen's Audi and Porsche – created a joint venture to build out a network of about 400 ultra-fast, 350 kW CCS-based charging stations throughout Europe.[507] The announcement was in addition to a previous announcement by Porsche that it is working on an 800-volt charging system that it said should be able to charge a large sedan's battery pack to 80 percent in about 15 minutes. A pilot project of four such chargers came online in July 2018, and the Porsche Taycan is projected to be the first series-production vehicle to feature the 800-volt technology when it becomes available in 2019.[508] EVgo, a leading operator of public EV charging networks in the U.S., opened its first of what it envisions will be many 350 kW public charging stations in 2017 in Baker, Calif.[509] Finally, the global DC fast charging network leader CHAdeMO, which has more than 17,700 units worldwide, released its protocol 2.0 in May 2018 to enable 400 kW, 1,000 V high-power charging, a doubling of 200 kW at 500 V enabled by its protocol 1.2.[510]

As more ultra-fast recharging stations such as these come online, and as more electric vehicles are equipped to handle such power, public confidence in EVs' abilities could increase and prompt greater deployments. Furthermore, ultra-fast networks may lead us to see electrification appear in a greater variety of vehicular platforms. For instance, vehicles that are inherently less efficient, such as pickup trucks and motorhomes, could be equipped with smaller, cheaper batteries that would allow for lower vehicle prices should a large network of ultra-fast chargers exist to quickly recharge the vehicles.

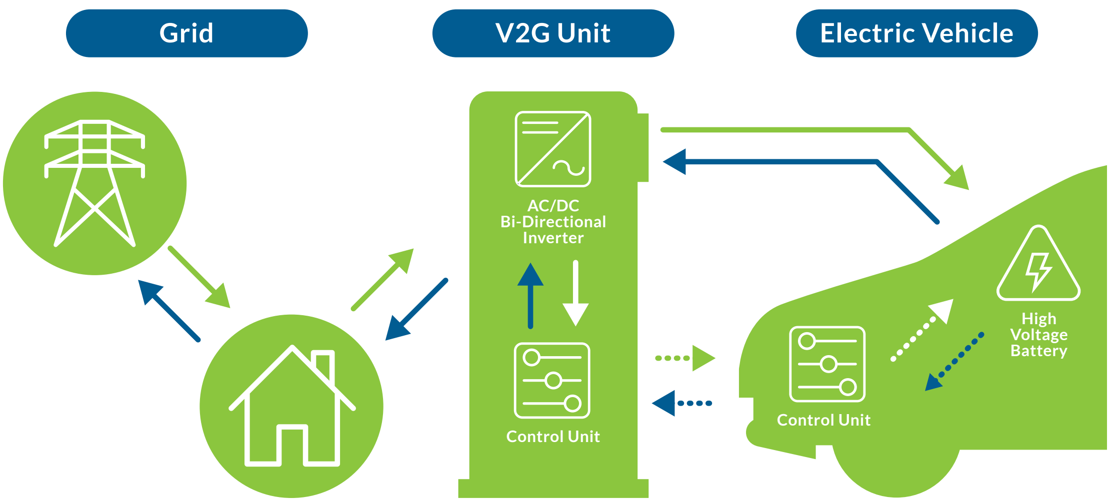
VEHICLE-TO-GRID (V2G)

The increasing availability of plug-in electric vehicles as well as their projected deployments in the coming years has the potential to add value to the greater energy paradigm that extends far beyond mobility. Namely, EVs' advancement comes at about the same time that renewable energy usage is rapidly scaling up. While good for the environment, the increase of renewable energy fed into the electric grid introduces an element of intermittency, defined by variable and uncertain output, and whose systems' output is not fully under control of the operators and not "dispatchable."[511] Studies show that at very high penetration levels, for instance when renewable energy supplies 80-100 percent of grid energy, substantial energy storage is required in order to maximize use and minimize curtailment. The buildout costs and logistics of sufficient energy storage capacity that is devoted only to electric grid stabilization could be daunting. Yet if the ever-growing amount of energy storage present in electric vehicles could be tapped to perform double-duty, the cost could be greatly reduced.

Such is the promise of V2G technologies, which allow electric vehicles not just to withdraw electricity from the grid via vehicular charging, but also to deposit stored energy back onto the grid via discharging, as illustrated in Figure 30.

While V2G has been studied since the early 2000's and proven theoretically beneficial – both to electric grid management and as a source of revenue for electric vehicle owners – recent pilot projects have done much to advance the technologies and perhaps enable

Figure 30: Vehicle-to-Grid (V2G) Operation



its commercialization. For instance, Southern California Edison (SCE) and the California Independent System Operator (CAISO) launched a two-year study in late 2015 of 34 V2G-equipped plug-in electric vehicles.[512] The project, which was funded by the U.S. Department of Defense, took place at the Los Angeles Air Force Base and demonstrated that battery storage of PEV fleets can provide energy and ancillary services to the CAISO markets to generate additional revenues, thereby reducing the cost difference between PEVs and conventional ICE.[513] SCE's final report on the project concluded that it provided many tangible benefits. It:[514]

- Maximized the use of underutilized vehicle assets by using the batteries as an energy source;
- Reduced installation energy and fleet vehicle costs were reduced;
- Reduced GHG emissions associated with liquid-fuel vehicles;
- Lowered environmental risk from petroleum processing, transportation, and spillage;
- Advanced the state of PEVs and charging stations;
- Advanced the state of V2G engineering and software applications;
- Stimulated cooperativeness with utility operators and regulators to embrace an
- alternative energy solution;
- Increased grid energy storage capacity; and
- Promoted energy security across the nation while decreasing dependence on foreign oil

Elsewhere, Nissan, Nuvve and the Italian utility Enel SpA in Denmark also conducted a yearlong V2G study. The program confirmed that V2G services could cover some costs related to charging an electric car. In fact, Nissan and OVO Energy, a United Kingdom energy supplier, began offering V2G service to Nissan Leaf buyers in 2018 via the launch of a home charger for V2G.[515]

Overall, V2G could enable consumers to save as much as $272 per year on their energy bill. It could also bring significant cost-savings and additional revenues of $2 billion to global energy suppliers in 2025, while performing the critical service of load shifting demand from peak to off-peak, according to ABI Research. The company believes that up to 21 TWh of energy could be distributed to the grid via V2G in 2025.[516] This could allow energy markets to better incorporate intermittent renewable energy sources by creating off-peak storage, allowing these renewable energy sources to run more often during off-peak hours. V2G could also provide the grid-critical additional resources for primary and secondary frequency control as well as help grid operators better manage line constraints and forecast demand.[517]

Yet for V2G to be fully realized requires overcoming key barriers. Foremost amongst these barriers is resistance from OEMs, who are concerned that using electric vehicle batteries to repeatedly store and discharge energy from and to the grid could degrade batteries, negatively impacting vehicle performance and operating range while potentially increasing warranty costs. Such concerns could be overcome via financial mechanisms: battery leases rather than ownership, modifications to vehicular warranties that reflect V2G revenues flowing to vehicle owners, and/or demonstrating the value proposition to consumers so that they're willing to pay more for V2G equipped vehicles.

Assuming that OEM support can be garnered and that other commercialization barriers can be over come, V2G could serve as a significant driver for EV adoption and vice versa. This becomes increasingly true as shared, automated fleets replace private ownership and operation, given the relative ease of V2G market entry within centrally-located fleet applications and their associated recharging depots. Such depots could even be co-located with renewable power generation facilities and/or grid and microgrid resources, thus further easing its deployment and utilization.

KEY INSIGHTS AND CONCLUSIONS

In thinking about the transition underway in transportation and mobility, it may be more apt to think of it not so much as an evolution of the automotive industry, but rather the broadening of the transportation paradigm via the increasingly rapid wholesale adoption of usage models developed by other industries.

Of particular relevance is the telecommunications industry. The industry was once slow to evolve and wholly centralized around single modes – first the telegraph then subsequently the telephone, which shortened communication from days, to hours, to seconds – and was characterized by uniform usage and pricing models. Now, the industry is defined by frequently updated iterations, is diversified, and telecommunication is ubiquitous. Users can communicate with others via in-home fixed telephone lines, mobile phones, Voice over Internet Protocol (VoIP), satellite phones, short message service (SMS), and via other means. Furthermore, they can select a wide variety of usage and pricing models that better reflect how and when they need to communicate by purchasing minutes and megabytes for an individual phone as needed, or entire communication packages comprised of bundled minutes and data that can even be accessible to a broader family. They are also afforded a plethora of different communications devices to select from for any given usage mode depending on their needs, a departure from standard telegraphs and early household telephones. It appears that mobility's evolution is following the same pathway.

KEY INSIGHT #1: TRANSPORTATION IS EVOLVING FROM PRODUCTS AND VEHICLES TO SERVICES AND MOBILITY.

While defined by the personal automobile – a modal monopoly – for much of the past century, the arrival of electrified, connected and automated, shared vehicles of different shapes, sizes, ranges, functions, and prices is rapidly evolving the paradigm. Modal ubiquity in various city centers as well as the emergence of subscription-based usage models by Uber, Lyft, and others furthers the analogy with the telecommunications industry.

Yet it's important to note that for this analogy to be appropriate, the same level of openness instituted by deregulatory measures within the telecommunications industry must be established for mobility. Until the 1980s in the United States, the term "telephone company" was synonymous with American Telephone & Telegraph (AT&T). The emergence of new technologies prompted the progressive opening of the industry, most forcefully in 1984 and 1996 as the federal government relaxed regulatory barriers that ended the industry's monopolies.[518] The automobile industry's monopoly on mobility wasn't established by the same policies, but it did benefit from policies and subsidies – such as the funding of the Interstate Highway System, as previously discussed – that helped it monopolize mobility.

KEY INSIGHT #2: SOURCES AND TARGETS OF FEDERAL, STATE, AND LOCAL TRANSPORTATION FUNDING SHOULD BE DIVERSIFIED

Remedying this situation required an immediate diversification of federal and other funding to include more micromobility, shared mobility, and other emerging technologies and systems. Furthermore, funding for transportation need not only come from traditional sources such as the Department of Transportation, the Federal Transit Administration, and general taxes, but also from a greater array of sources, including those industries such as healthcare and commerce who are poised to benefit as mobility modes emerge and blend deeper into the social fabric.

The industry itself should also adopt behaviors that do the most to solve core challenges and establish viable car ownership-free mobility options. Foremost among these is averting walled gardens by instituting open application programming interface (API) policies so that essential needs – like broad-based integration and coordination – can quickly emerge. At a minimum, averting walled gardens can provide for better user experiences, for having to toggle between multiple apps to find and book e-scooters and ridesourcing services could compel commuters to instead drive personal vehicles. More fundamentally, open APIs can ensure that more players offering the most desirable mobility options at the best prices emerge and are oriented around solving societal goals rather than simply maximizing any given provider's revenue.

KEY INSIGHT #3: OPEN DATA POLICIES CAN EXPEDITE THE ARRIVAL OF SOCIALLY-DESIRABLE MOBILITY SERVICES, MODES, AND TECHNOLOGIES.

Cities and agencies have established an open API for transit dubbed the General Transit Feed Specification (GTFS)[519] that provides real-time locations for buses and trains. JUMP and Motivate both offer an open API for bikesharing called the General Bikeshare Feed Specification (GBFS)[520] in all their markets, enabling users to see all the bikes around town regardless of brand. With open APIs like GTFS and GBFS, innovators can enter markets and promote car-free transport in creative ways.

Furthermore, the establishment and adoption of open API platforms for current modes such as transit and micromobility can help influence the direction of development for more nascent modes, such as automated vehicles. Organizations such as the DAV Foundation[521] are working to establish open source AV networks that allow vehicles to interconnect with other vehicles and operators, creating an entire ecosystem that enables vehicles to discover, communicate, and transact with each other to transport anyone – or anything – anywhere.[522] Such networks have the potential to help avert some of the previously discussed prospective consequences of modal usage – such as increased energy consumption and congestion – while lowering providers' barriers to entry and enabling broader systemic coordination as the network synthesizes with GTFS, GBFS, and other open platforms.

The work of these and other groups to establish and build support for open, inclusive networks is paramount as we enter the new "golden age" of transportation, whereby any single modal monopoly is averted in favor of mobility-as-a-system (MaaSys). A systemic approach, built upon the backbone of modern transit technologies, that leverages a "mobility menu" of domains, modes, and usage models provided by an increasing variety of suppliers operating electrified, connected, automated, and shared vehicles – *enabled by and seamlessly integrated within open, inclusive networks* – is what presents the very real opportunity to achieve full urban mobility for the 21st century and beyond.

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