PEAK CAR OWNERSHIP

THE MARKET OPPORTUNITY OF ELECTRIC AUTOMATED MOBILITY SERVICES

BY CHARLIE JOHNSON AND JONATHAN WALKER

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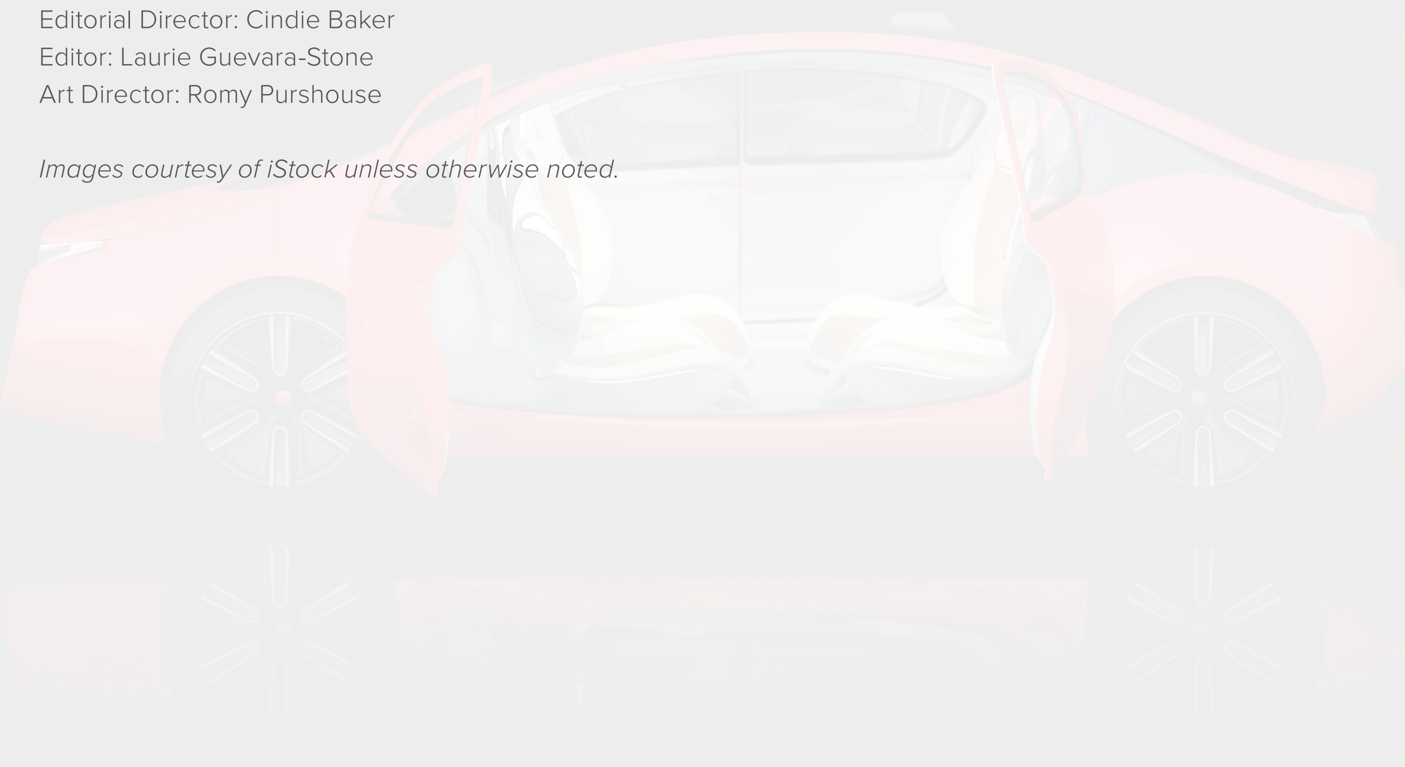


ABOUT US

ABOUT ROCKY MOUNTAIN INSTITUTE

Rocky Mountain Institute (RMI)—an independent nonprofit founded in 1982—transforms global energy use to create a clean, prosperous, and secure low-carbon future. It engages businesses, communities, institutions, and entrepreneurs to accelerate the adoption of market-based solutions that cost-effectively shift from fossil fuels to efficiency and renewables. In 2014, RMI merged with Carbon War Room (CWR), whose business-led market interventions advance a low-carbon economy. The combined organization has offices in Basalt and Boulder, Colorado; New York City; Washington, D.C.; and Beijing.

ABOUT MOBILITY TRANSFORMATION

Rocky Mountain Institute's Mobility Transformation program brings together public and private stakeholders to codevelop and implement shared, electrified, and eventually autonomous mobility solutions. Working with U.S. cities, it leverages emerging technologies and new business models to reduce congestion, decrease costs, increase convenience, enhance safety, curb emissions, and ensure economic growth.
Please visit http://www.rmi.org/mobility for more information.

GLOSSARY OF TERMS

- AV: Autonomous Vehicle
- EV: Electric Vehicle, also called Battery Electric Vehicle (BEV)
- EAV: Electric Autonomous Vehicle
- SEAV: Shared Electric Autonomous Vehicle
- VMT: Vehicle Miles Traveled
- eVMT: Electric Vehicle Miles Traveled
- EVSE: Electric Vehicle Supply Equipment
- POV: Personally Owned Vehicle
- TCO: Total Cost of Ownership
- TNC: Transportation Network Company (Uber, Lyft, etc.)
- Autonomous Vehicle: A vehicle that can drive itself with no need for human involvement
- Driverless Vehicle: A vehicle that operates with no human driver present
- Automated Mobility Service: A business model where mobility service providers dispatch autonomous vehicles to provide rides for consumers

The rise of automated mobility services could be one of the most interesting and complex disruptions of the modern era.

01. THE MOBILITY TRANSITION

The U.S. personal mobility market is worth over $1 trillion and has been relatively stable for nearly fifty years, with personal vehicles and related services dominating other options such as public transit and taxis in terms of American expenditure. As urbanization increases, infrastructure and mobility systems designed in the 1950s are reaching a breaking point, with growing congestion and pollution, and persistent injuries and fatalities. But after decades of little change in personal mobility, we are now in the formative stages of a powerful confluence of cultural, technological, and societal events. The rise of the "service economy" is transferring revenue from products to services. New vehicle technologies like electric powertrains and autonomous driving systems are entering the market and rapidly dropping in cost. When analyzed holistically, this confluence creates the possibility for a new mobility system to emerge in the next few years that is superior to our existing system in almost every way.

Analysis by leading organizations and individuals indicates the technical, logistical, and economic plausibility of a future where most mobility needs are met by mobility services, enabled by autonomous driving technology, and powered by electric powertrains.[1] This future system has the potential to reduce costs by over $1 trillion, reduce CO_2 emissions by a gigatonne, and save tens of thousands of lives per year in the U.S. alone. With so many advantages, hundreds of billions of dollars could shift away from personal vehicle products and services to new mobility services provided by transportation network companies (TNCs), technology companies, and adaptive carmakers. What is unclear is the rate and scope at which the disruption could occur and the impact this will have on determining winners and losers, both of which are highly dependent on the decisions made today by stakeholders (financial institutions, carmakers, new entrants, electrical utilities, governments, etc.).

This report provides strategic decision makers with potential market sizes and plausible rates of mobility service proliferation that could occur under reasonable circumstances, while identifying key pitfalls that could delay the envisioned system and potential resolutions to each. Key stakeholders must shift their business models and policies accordingly to benefit from this mobility transformation.

METHOD

We performed analysis to determine key economic tipping points such as when mobility services reach cost parity with personal vehicles. At each economic tipping point, we used relevant consumer-adoption data and trends to estimate market sizes and potential growth rates of automated mobility services. We then looked at the potential impacts on personal vehicle, gasoline, and electricity demand. We leveraged leading research and real-world data where possible and made informed assumptions where necessary.

02. THE ECONOMICS OF AUTOMATED MOBILITY SERVICES

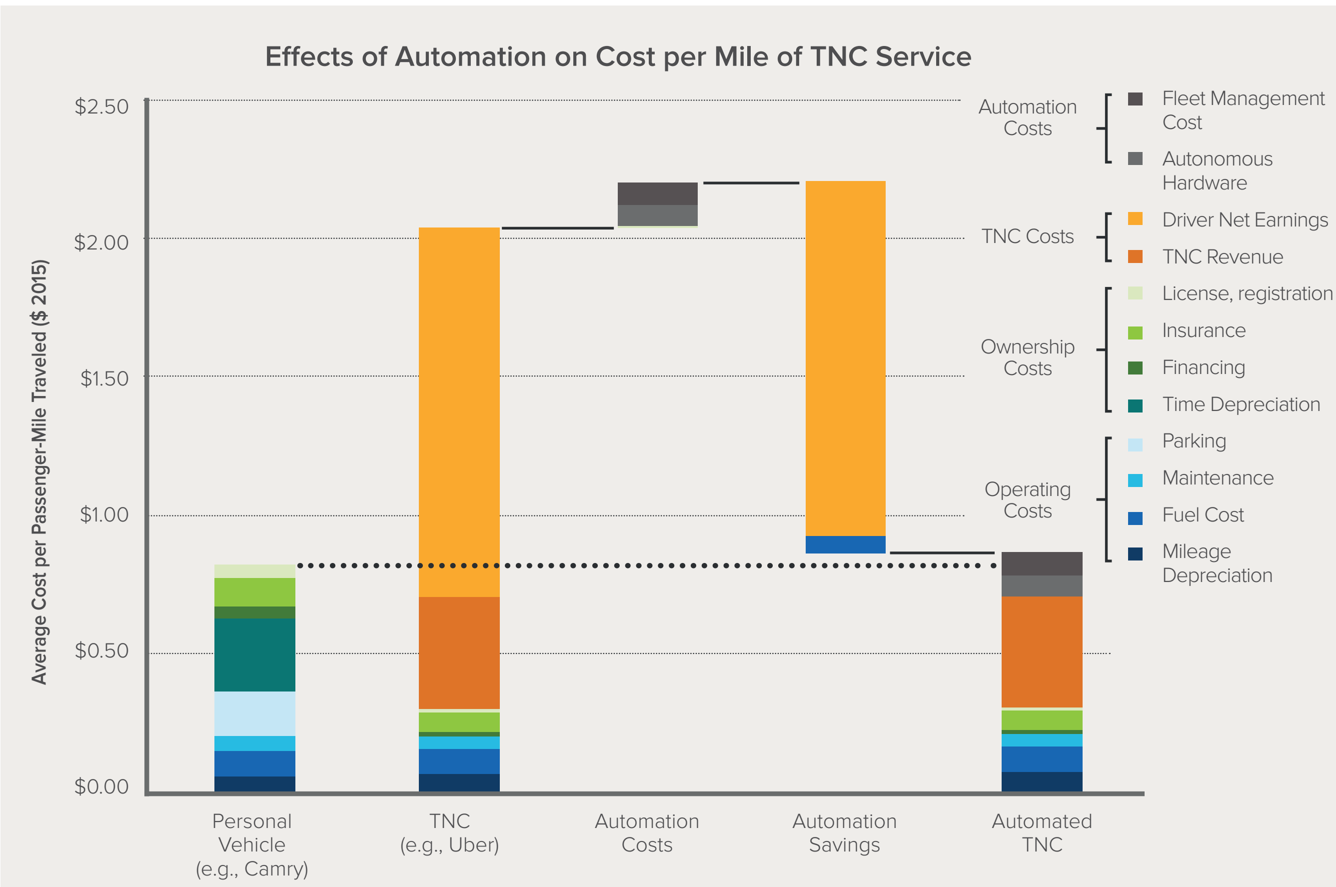
Likely debuting by 2018, mobility service performed by autonomous vehicles could enter the market at near cost parity with the total cost of owning and operating a personal vehicle—under $1.00 per mile.

On-demand, point-to-point mobility service exists today in the form of transportation network companies (TNCs) such as Uber and Lyft. TNCs are growing rapidly in popularity, but still face a major barrier in terms of cost. On a per mile or per trip basis, they cost on average two to three times as much as owning and operating a personal vehicle, which limits the amount of the mobility market that they can ultimately capture.

However, mobility service performed by autonomous vehicles could cost roughly the same as the total cost of owning and operating a sedan (see Figure 1). This means that consumers could choose automated mobility service exclusively instead of personal vehicle ownership with little increase in transportation cost or with decreased cost in many urban environments where car ownership/operation is more expensive. A recent study of consumers in Austin, Texas, found that a full 41% of residents would use an automated mobility service at least once a week if it cost less than $1.00 per mile.[2] At $2.00 per mile (about the cost of TNCs today), only 15% would use the service at least once per week. Per mile cost of less than $1.00 is a significant economic tipping point.

FIGURE 1:

EFFECTS OF AUTOMATION ON COST OF TNC SERVICE IN 2018



TECHNOLOGY READINESS

With the potential to compete economically with personal vehicles in the multitrillion-dollar mobility market, many of the world's most powerful companies are working toward fully autonomous vehicles for consumer mobility service use, several by 2018:

- **Apple** is likely working on an advanced electric autonomous vehicle and recently invested $1 billion in Chinese ride-hailing service Didi Chuxing.[3]
- **Google** has been testing electric autonomous vehicles in Mountain View, California, and Austin, Texas, for many months and recently expanded to Arizona and Washington.
- **Uber** recently began testing autonomous **Ford** Sedans and **Volvo** SUVs in Pittsburgh. CEO Travis Kalanick called autonomous vehicles providing Uber rides "existential" to the company's survival.[4]
- **GM**, which recently invested $500 million in **Lyft**, is testing autonomous electric Chevy Bolts in San Francisco.
- **Tesla** may be close to launching a mobility service. Morgan Stanley recently indicated that Tesla is in good position to launch its own electric, automated, on-demand mobility service by 2018 and modeled this insight into its relatively high valuation of the company.[5] More recently, CEO Elon Musk released his "master plan part deux," which details Tesla's plan to launch an electric automated mobility service.[6]
- **Daimler's** carshare subsidiary, Car2Go, has autonomous ambitions.[7]
- **Volkswagen's** $300 million investment in European TNC Gett signals that it too is entering the mobility services market.
- **Ford** CEO Mark Fields recently announced that Ford will mass produce autonomous vehicles (with no steering wheel) for use in ride-hailing services by 2021.

REGULATORY READINESS

With the recent pace of progress and so many of the world's leading companies hard at work, autonomous technology will likely be ready for consumer use in the next few years. But deployment of vehicles with no human driver will still require changes and additions to laws and regulations to be fully legal.

At the federal level, there have been several signs of immanent legality of driverless vehicles. The National Highway Traffic Safety Administration (NHTSA) responded to a request from Google, indicating in a letter that a computer system could be considered a "driver."[8] This is a huge point as most state and federal regulations refer to a "driver." If a computer system is a "driver," then most laws and regulations apply to a computer system as well, lowering the regulatory inertia to deploy these systems to consumers. The federal Department of Transportation (DOT) also indicated great desire for cities to deploy autonomous vehicle technology and mobility services in its Smart City Challenge Notice of Funding Opportunity. Preliminary plans were submitted by 78 cities, and seven finalist cities created detailed plans and partnerships to deploy autonomous vehicles in their municipalities by 2019.[9]

At the state level, many states appear willing to accept driverless vehicles. And although the distinction of a computer system as a "driver" removes many barriers, certain state regulations still need to be modified to accommodate driverless vehicles. Colorado DOT, for instance, is investigating how to license driverless vehicles and how to modify laws to allow consumer-facing operation. As an example, in the event of an accident, both parties must exchange insurance information. This law must be modified to allow a driverless vehicle to exchange insurance information digitally or otherwise with a human driver (or other autonomous vehicle). Texas DOT and University of Texas–Austin are investigating state-specific barriers to driverless vehicle deployment as well.

But not all states are modifying laws to accelerate deployment of driverless vehicles. The California DMV, for instance, recently proposed rules that would prohibit autonomous vehicles from operating without a licensed human driver ready to take over.[10] This regulation would essentially ban automated mobility services, relegating California to today's paradigm of "one vehicle for every person" as long as the regulation is in effect. As such, we separate California markets in our analysis.

It is clear that it will be some time before all municipalities and states explicitly allow driverless vehicles, but it is also clear that certain cities and states are taking aggressive steps to allow consumer-facing deployment of driverless vehicles as soon as technology companies demonstrate acceptable safety and performance (again, many claim they will achieve this by 2018, 2019, or 2020). Possible ways to demonstrate "readiness" would be by driverless vehicles passing special driving exams or by companies providing comprehensive road-test data showing that the vehicles are significantly statistically safer than human drivers in the conditions in which they are to be deployed.[11]

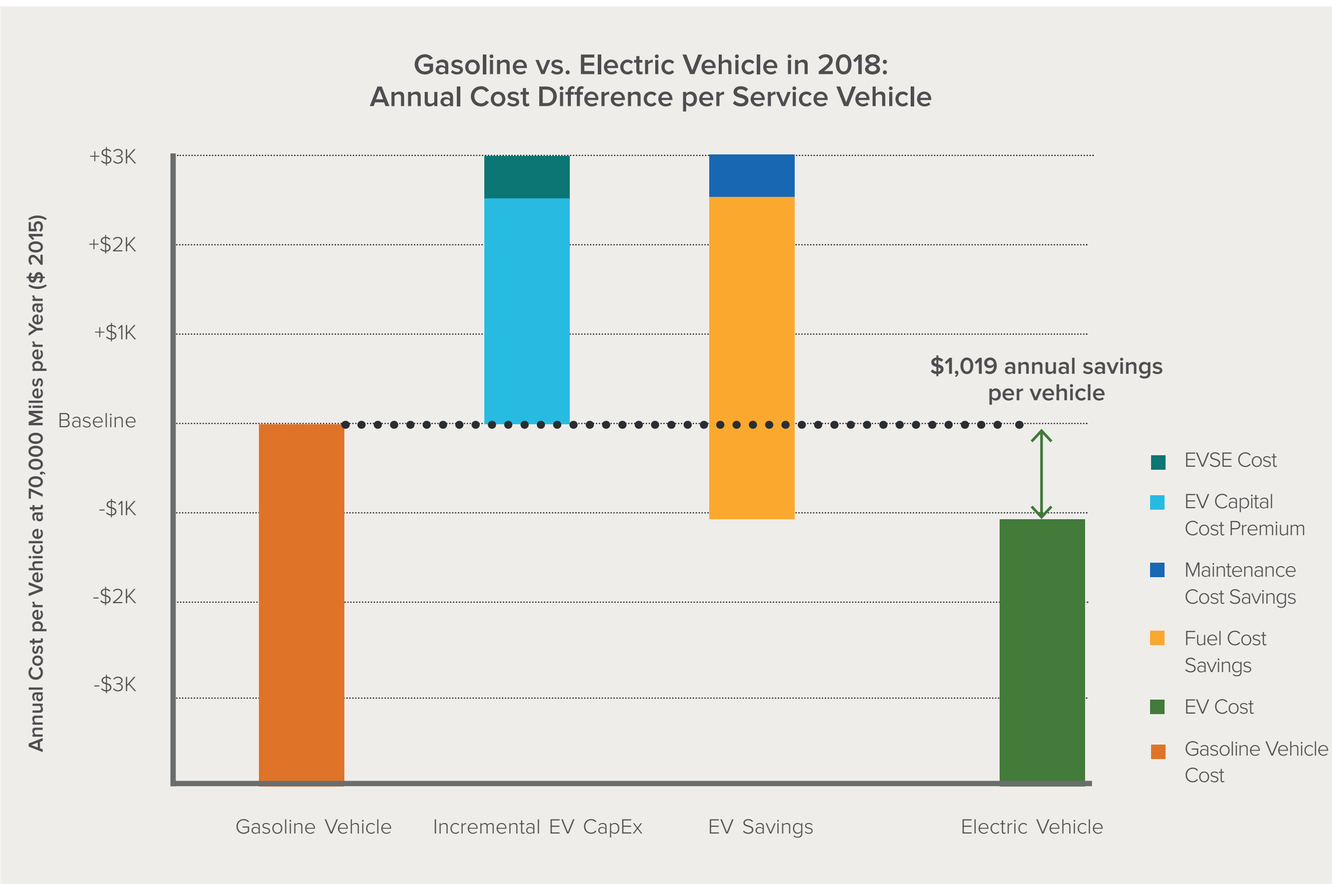
03. THE ECONOMICS OF ELECTRIC MOBILITY SERVICE VEHICLES

Model year 2018 electric vehicles will have immediate cost advantages over traditional and hybrid vehicles in mobility services that will only grow.

Electric service vehicles have economic advantages over gasoline vehicles—even hybrids—at the high mileage they are driven. Model year 2018 long-range electric vehicles (EVs) like the Chevy Bolt and Tesla 3 will have lower operating costs that more than make up for higher capital cost, potential battery replacements, and the cost of electric vehicle supply equipment (EVSE) infrastructure, thereby saving over $1,000 per vehicle, per year. This holds even with no government subsidy of any kind (see Figure 2).

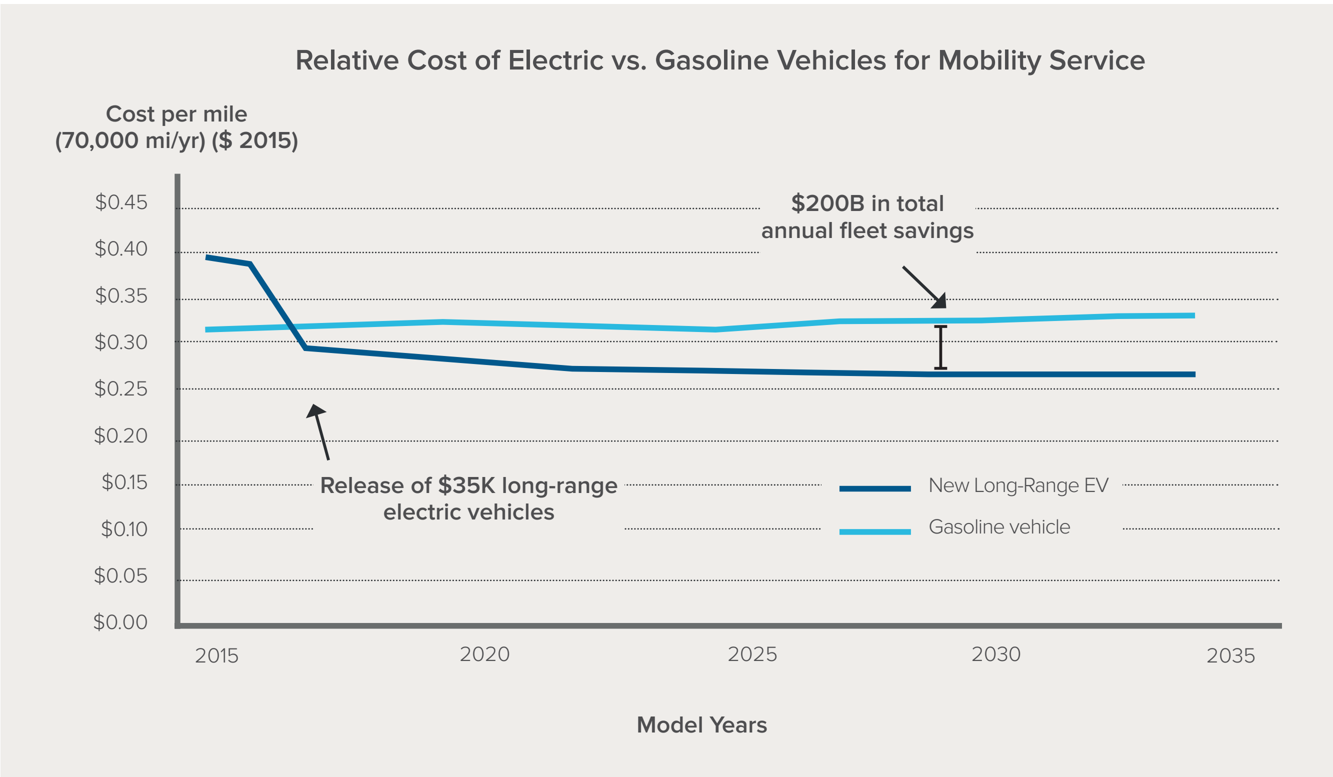
FIGURE 2:

GASOLINE VS. ELECTRIC SERVICE VEHICLE COSTS IN 2018



Furthermore, as battery costs fall, battery life improves, EVSE infrastructure matures, and vehicle production reaches full scale, the cost advantage of EVs over gasoline vehicles grows, leading to over $4,000 in annual savings per vehicle by 2030. A fleet of 50 million electric autonomous vehicles would be $200 billion less expensive to operate per year than a comparable fleet of gasoline vehicles. Therefore, economics will impel automated service providers to deploy *electric* autonomous vehicles (EAVs). The limiting factor may be EVSE ubiquity and electrical grid readiness. EVs could be a great boon to electrical utilities, serving as distributed energy resources if utilities make smart decisions today.[12]

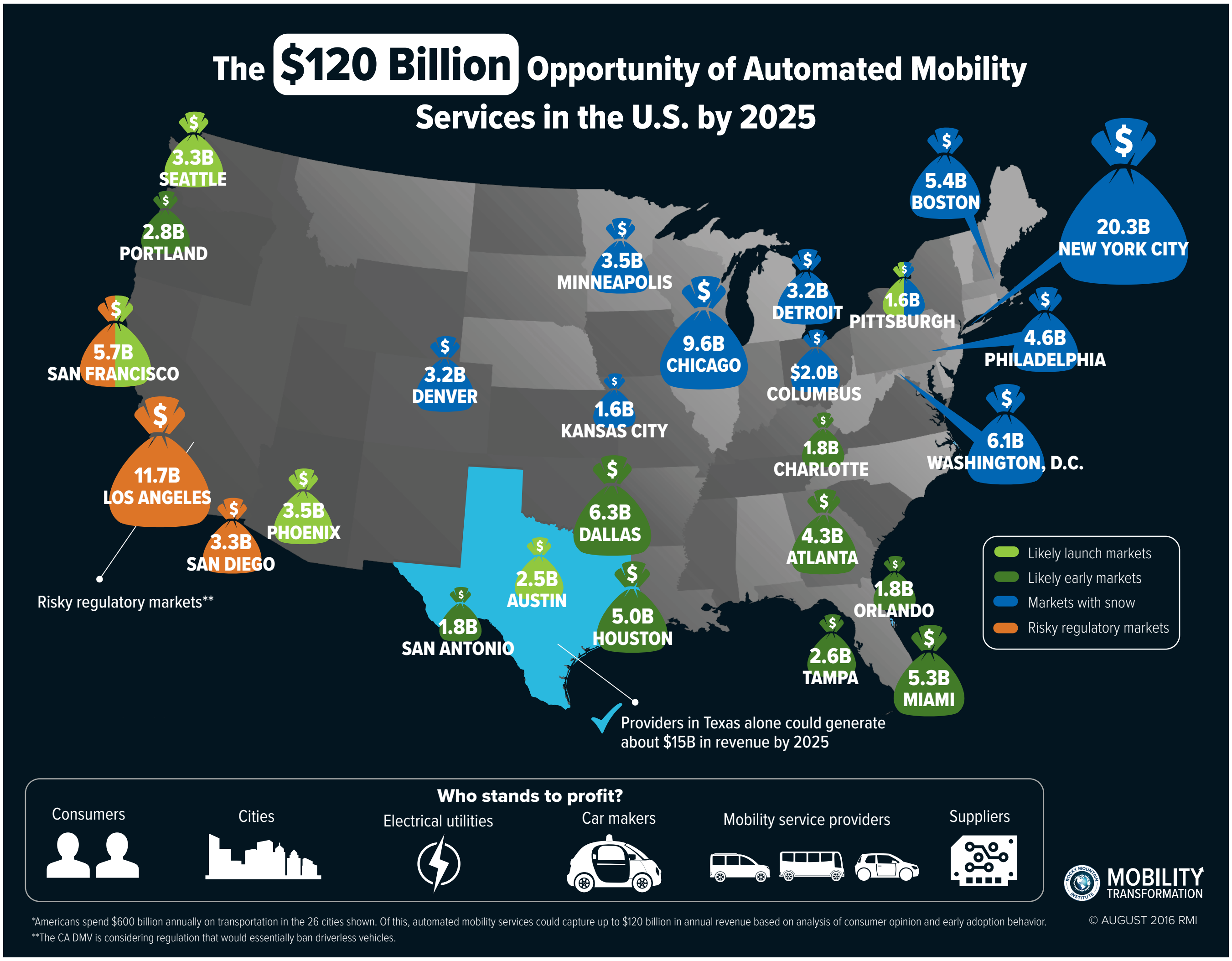
FIGURE 3:
COST PER MILE OF GASOLINE AND ELECTRIC SERVICE SEDANS



04. THE ECONOMICS OF AUTOMATED MOBILITY PROVIDERS

FIGURE 4:

RANKING THE MOBILITY MARKET OF VARIOUS U.S. CITIES



Annual revenue for $1.00 per mile automated mobility services could be more than $100 billion by 2025.

ASSESSING THE MOBILITY MARKET SIZE IN PLAY

When the technology is ready for market, automated mobility providers will likely choose their initial markets based on several key demographic, environmental, and regulatory criteria. Qualitatively, an ideal market would be a large, dense metro area with a tech-savvy populace, little or no snow (some autonomous vehicle technologies currently struggle in the snow), and a political and regulatory environment friendly to autonomous vehicles.

The total size of the mobility market of likely early deployment cities is over $200 billion. And this doesn't even include California markets due to pending regulation that would prohibit vehicles without human drivers from operating, as described in section 2 above.

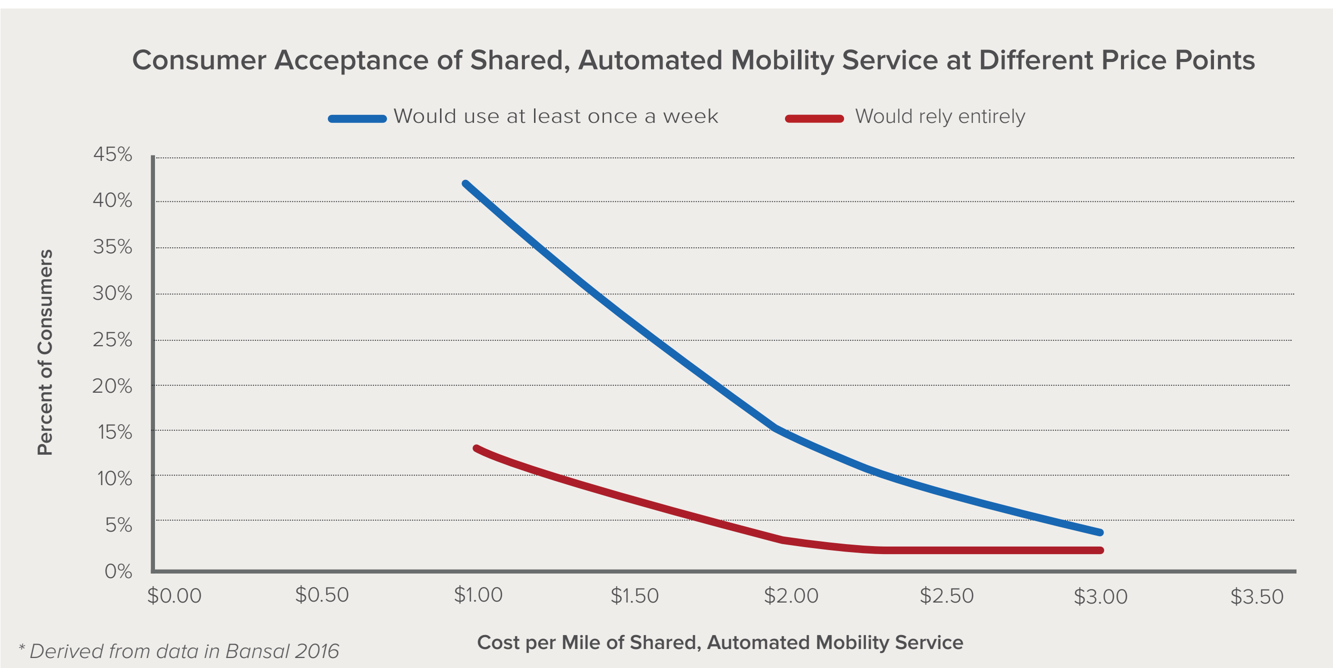
When autonomous vehicle technology is able to function in snowy environments, automated mobility services could tap into an additional ~$300 billion in mobility spend, including the coveted New York City market. This amounts to a total market of over $500 billion and over **$600 billion** if major California markets are in play.

ESTIMATING AUTOMATED MOBILITY SERVICE MARKET PENETRATION

With $600 billion in consumer spend at play in just the first 26 cities, it is clear why so many companies are developing products and services for automated mobility. But even at cost parity with a personal vehicle, automated mobility service will, of course, not capture 100% of the full mobility market. Recent studies in Austin, Texas, shed some light on potential consumer adoption size; when offered automated mobility service at near cost parity with personal vehicles ($1.00 per mile), a full 41% of Austinites would use the service at least once per week, and 13% of respondents would rely entirely on the service.

FIGURE 5:

CONSUMER DESIRE FOR SHARED AUTOMATED MOBILITY SERVICE AT DIFFERENT PRICE POINTS



Assuming that those who would use the service "at least once per week" use the service for roughly half of their transportation, automated mobility service would capture a full 27% of the Austin mobility market as soon as the service becomes available. Assuming those opting to use shared, automated mobility services spend the average amount on transportation for an urbanite (~$5,000/year), 27% of the market amounts to $2.5 billion in revenue in Austin alone, which is more than Uber's 2015 estimated total worldwide net revenue of $1.5 billion.[13]

Austin has a high percentage of early adopters compared with other U.S. cities, but even when controlling for this,[i] potential revenue from the initial deployment is still massive (see Figure 6).

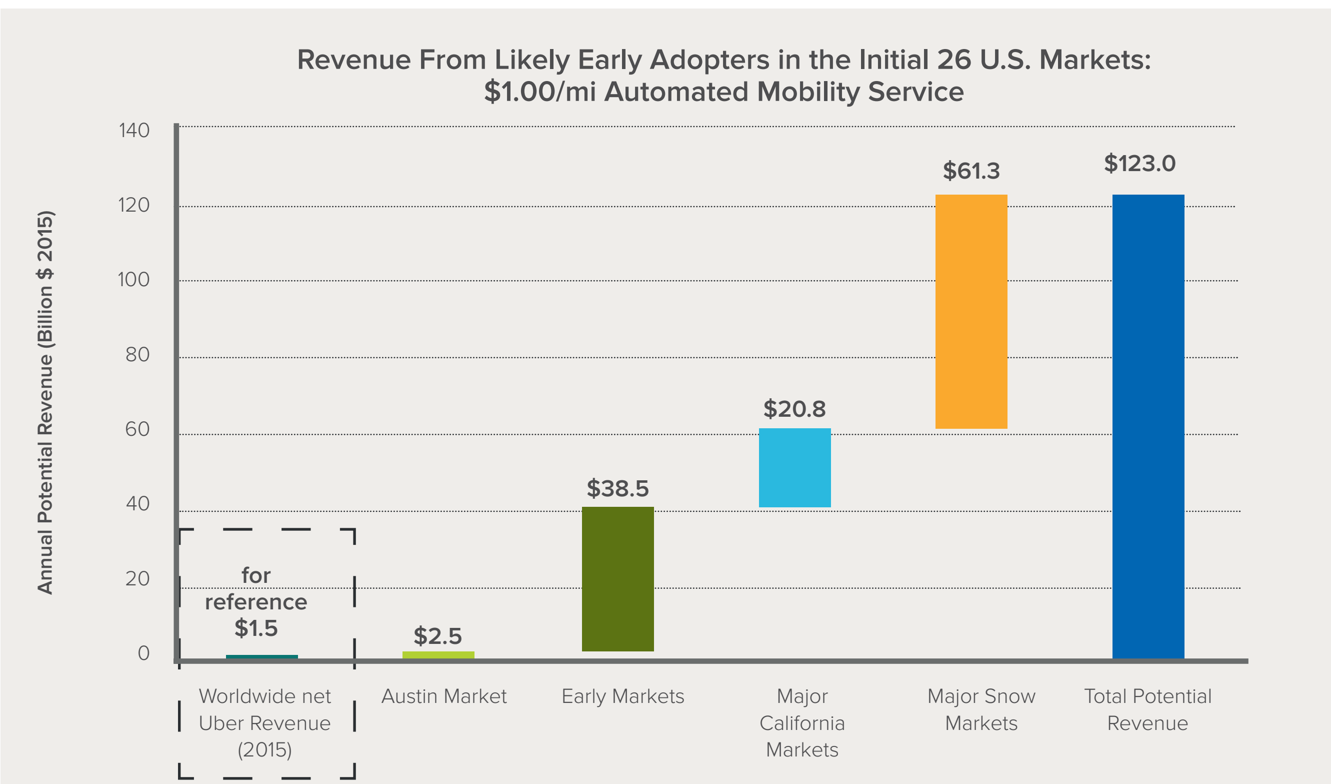
ESTIMATING GROWTH RATE IN THE FIRST 26 MARKETS

In trying to estimate the market's growth rate, two major variables will impact the speed of automated mobility proliferation: technology and regulation.

It is highly likely that some form of automated mobility service will launch in a subset of markets by the end of 2018, but how quickly the service spreads will depend on regulatory status in the other early markets and the ability for the technology to handle weather and other driving situations outside of warm urban environments. We analyzed optimistic and pessimistic assumptions for each variable to bound the speed of the rollout in the first 26 markets:

FIGURE 6:

ESTIMATED REVENUE FROM LIKELY EARLY ADOPTERS IN THE INITIAL 26 U.S. MARKETS



[i] *Average early adopter pool is 29%, according to Claritas, where Austin (Travis County) is 49%. Each metro market was normalized to its particular early adopter percentage based on Claritas research: http://usatoday30.usatoday.com/tech/graphics/tech_savvy/flash.htm*

MOBILITY TRANSFORMATION

1. Technology

a. Fast: Fast autonomous vehicle development/production, inclement weather problem solved

b. Slow: Slow autonomous vehicle development/production, inclement weather problems persist

2. Regulatory

a. Fast: National framework for regulation with commonly accepted "readiness" standards across cities and states by 2020

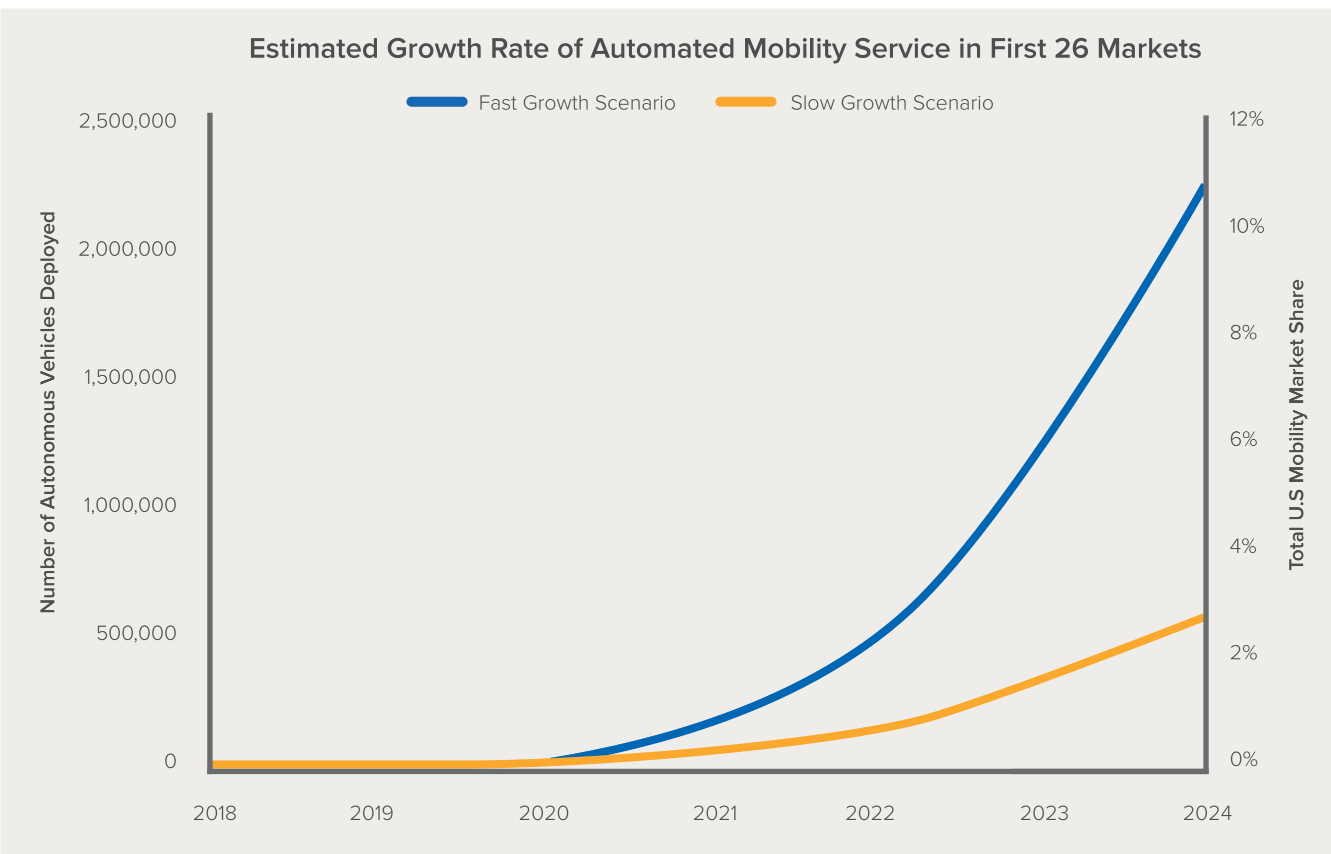
b. Slow: Patchwork regulation with various levels of regional legality persists

When both of the variables above are "fast," we have a fast growth scenario in which automated mobility service grows rapidly within all early markets. Both variables being "slow" leads to a slow growth scenario in which automated mobility service grows quickly within a percentage of "no-snow" markets with favorable regulation, but is limited in snowy markets and a percentage of "no-snow" markets with unfavorable regulation.

In the fast growth scenario, automated mobility could grow at the same rate that Uber X grew in its first ~20 markets.[14] At this rate, automated mobility could capture about 10% of the total U.S. mobility market by 2025. In the slow growth scenario, automated mobility service cannot enter snowy markets and thrives only in a subset of warm environments where regulation is favorable. But even if driverless vehicles were legal only in Texas and Florida, services could capture 3% of the total U.S. mobility market by 2025.

FIGURE 7:

ESTIMATED GROWTH RATE OF AUTOMATED MOBILITY SERVICE IN FIRST 26 MARKETS



05. THE FULL MARKET POTENTIAL FOR AUTOMATED MOBILITY SERVICES

The breadth of tailored services will grow and the cost of commodity services will drop, opening up most of the full mobility market to automated mobility services.

Automated mobility service performed by autonomous model-year 2018 vehicles could reach cost parity with personal vehicles and capture between 3–10% of the U.S. mobility market by the mid 2020s. But this is not the limit to the potential proliferation of automated mobility services.

BREADTH OF VEHICLES AND SERVICES WILL GROW

Buoyed by early success, the market will grow in breadth of services and vehicles to capture additional market share. For instance, tailored options like commuting service could transport professionals in "mobile offices," and family-focused services could transport children and run errands. Tech companies like Apple that specialize in consumer experience will have a new platform to "surprise and delight" customers. Public transit will also embrace autonomous vehicles to provide more efficient, safe, convenient, and frequent service, or use small autonomous vehicles to perform "first/last mile" service while keeping large buses focused on frequent trunk route service. Many public transit agencies proposed to employ autonomous vehicles as part of their DOT Smart City Grant proposal, for instance. The only limit to the breadth of offerings will be the creativity of the free market, transit agencies, and entrepreneurs.

COST OF COMMODITY SERVICE COULD PLUMMET

At the same time that companies launch additional services to compete in new markets, they will also compete to create the lowest-cost commodity mobility service. As electric, automated mobility services mature in the next decade, electric vehicle costs will drop, other start-up costs will fade, and remaining fixed costs will be spread over hundreds of billions of miles instead of millions. This could lead to commodity mobility service dropping below operating cost of a personal vehicle (see Figure 8), to around $0.30 per mile. This means that taking a commodity mobility service could cost less than gasoline and parking for a personal vehicle. Other studies have found a similar $0.30/mile (or less) potential for mature automated mobility service.

Mobility service dropping below personal vehicle operating cost is another major economic tipping point as it means that even those with large sunk cost in personal vehicles could now utilize automated mobility services frequently/exclusively with no economic penalty. New customers will not have to sell their car in a buyer's market and, in addition, will still have their personal vehicle as a safety net. The implications on market size of this ultra-low price point are huge. As we point out earlier, price point matters, so ultra-low-cost mobility, paired with large breadth of service options, could allow automated mobility service to grow within the entire mobility market. With the whole mobility market in play, based on the "early adopter" analysis shown in Figure 7, if automated mobility grows on a typical logistic "S" curve within the full market potential of urban Americans (~80% of Americans are "urban" according to the census), it could reach 70% market share by 2035. Figure 9 shows automated mobility service projection compared with other transformative technologies like the automobile, color TV, and smart phone.[15] Comparable technologies begin at the market introduction of the Model T, the RCA 21" CT, and the Blackberry 6200, respectively.

FIGURE 8:
COST OF AUTOMATED MOBILITY VS. PERSONAL SEDAN

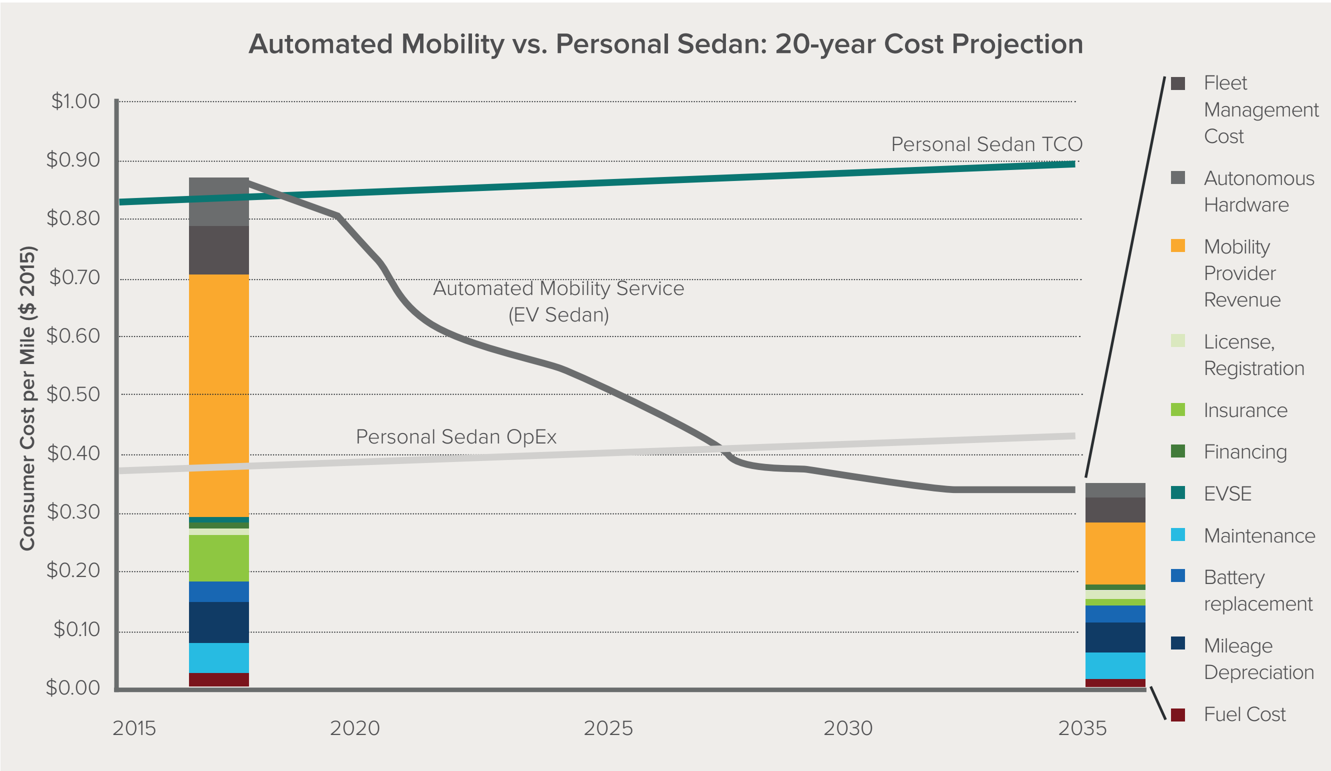
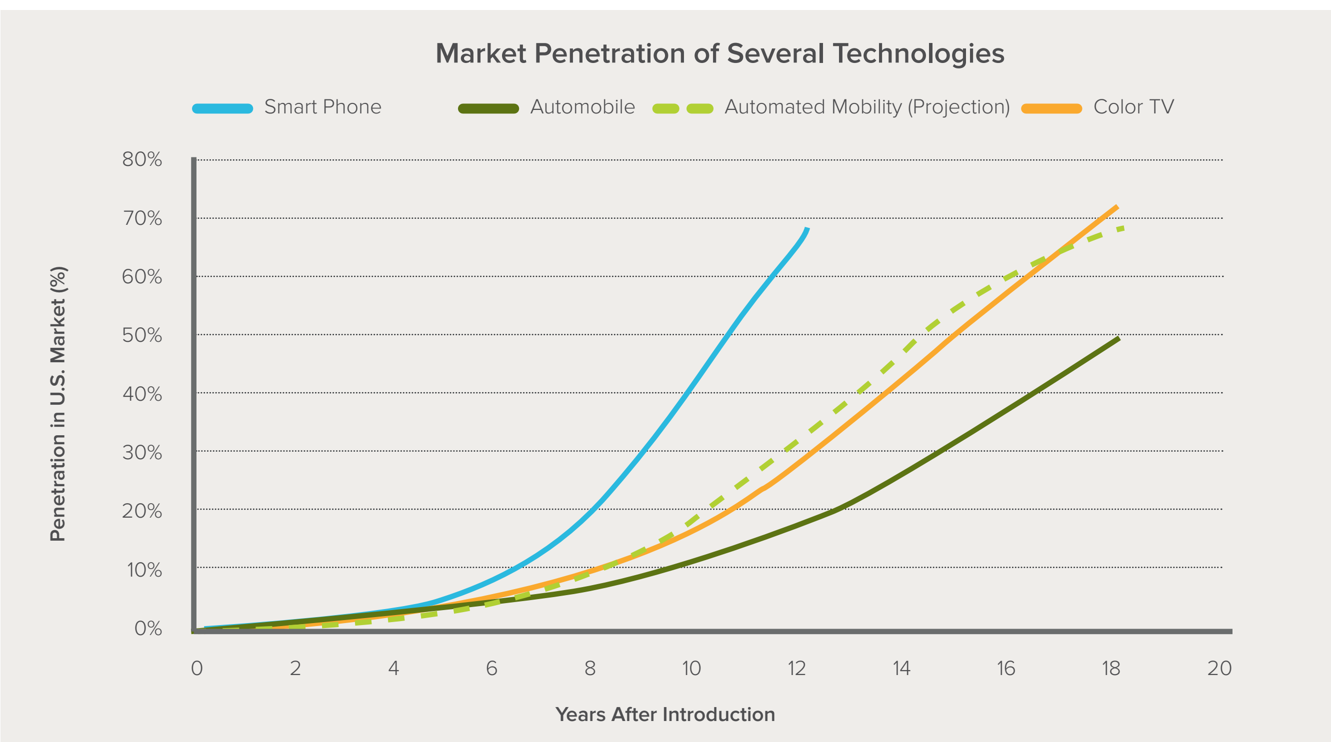


FIGURE 9:
MARKET PENETRATION OF SEVERAL TECHNOLOGIES



THE DOWNSIDE: PITFALLS COULD SET BACK AUTOMATED MOBILITY

With the combination of a large breadth of tailored services, low-cost commodity services, and potentially free public transit services, automated mobility should have access to most of the U.S. mobility market in the next fifteen to twenty years. However, potential pitfalls and threats to the rise of automated mobility service are real and cannot be ignored. *Harvard Business Review* recently outlined the following five potential threats to driverless vehicle proliferation and provided potential resolutions for each:[16]

- System meltdown
- Public panic
- Endless errands
- Car-lover revolt
- Benefit erosion

The likelihood of a potential threat delaying or derailing the rise of autonomous vehicles has no clear answer. But with hundreds of billions of dollars on the table for innovative businesses, huge potential safety benefits for cities and citizens, and the potential to reduce pollution and congestion, it is up to each strategic decision maker to weigh the likelihood of the status quo continuing to dominate in the face of a potentially revolutionary new mobility system.

06. WINNERS AND LOSERS

Oil companies will lose revenue, electrical utilities will gain, and carmakers will be split.

The initial deployment of automated mobility services at less than $1.00 per mile could capture up to $200 billion in revenue by 2025, and the mature system could own two-thirds of the total U.S. mobility market by 2035 (see Figure 10). Even if growth is slower or delayed compared with our projection, electric automated mobility will still have major impacts on the demand for gasoline, electricity, and personal vehicles in the coming decades.

GASOLINE DEMAND

Economics will impel mobility service vehicles to be electric (see Figure 3). A fleet of 500,000 electric autonomous vehicles would have a $1.5 billion annual cost advantage over a similar fleet of gasoline-powered autonomous vehicles in 2025. By 2035, a fleet of 50 million electric autonomous vehicles would have a $200 billion cost advantage over a gasoline-powered fleet. This huge competitive advantage will all but force mobility service providers to deploy electric vehicles en masse, limited only by EVSE availability and electrical grid readiness.

Each mobility service vehicle will drive five to ten times as many miles as personal vehicles,[1] and will turn over in about five years, as opposed to ten to fifteen years for a personal vehicle. This fast influx of electric vehicle miles traveled (eVMT) could reduce gasoline demand in the U.S. by up to 60% in 2035 if electric automated mobility service grows at our “fast” projected rate.

FIGURE 10:
PROJECTED U.S. GASOLINE CONSUMPTION

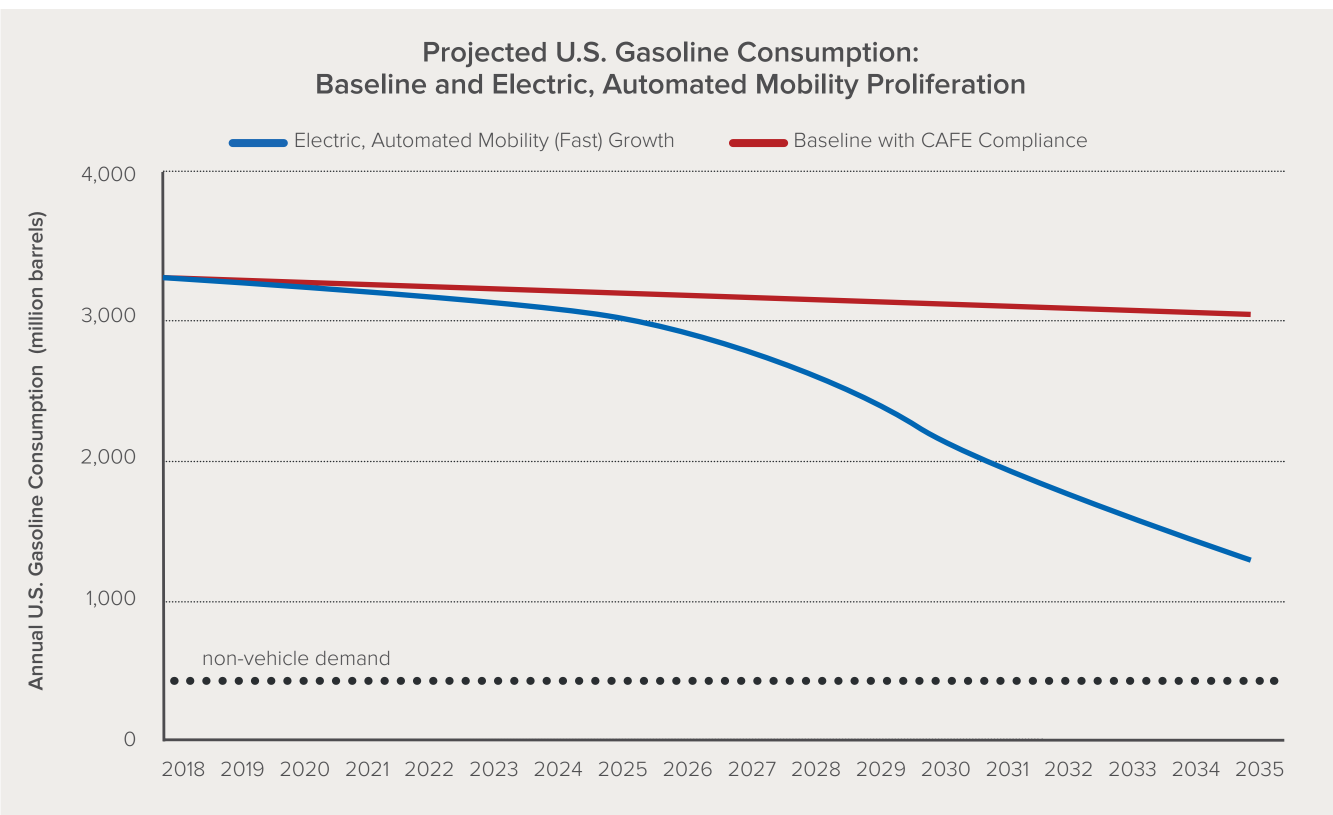
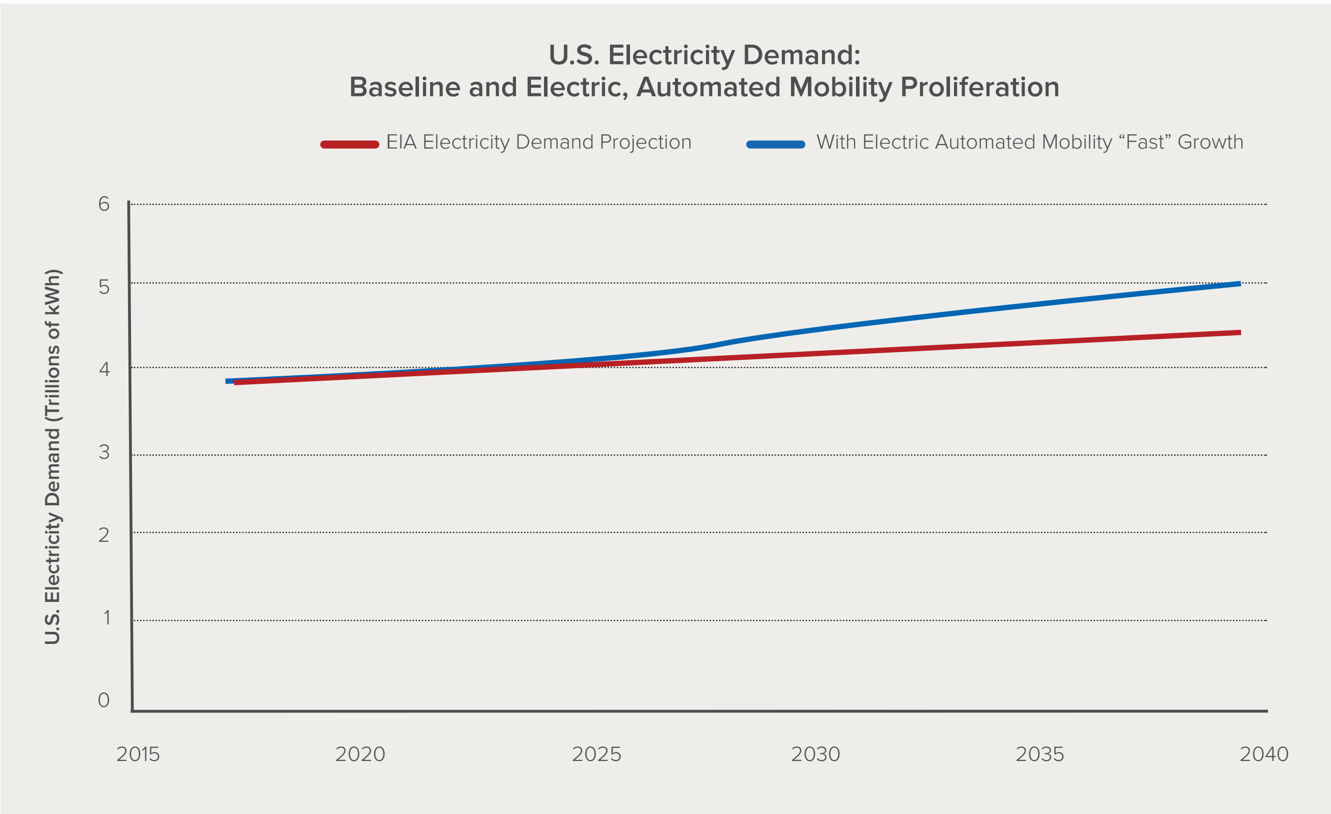


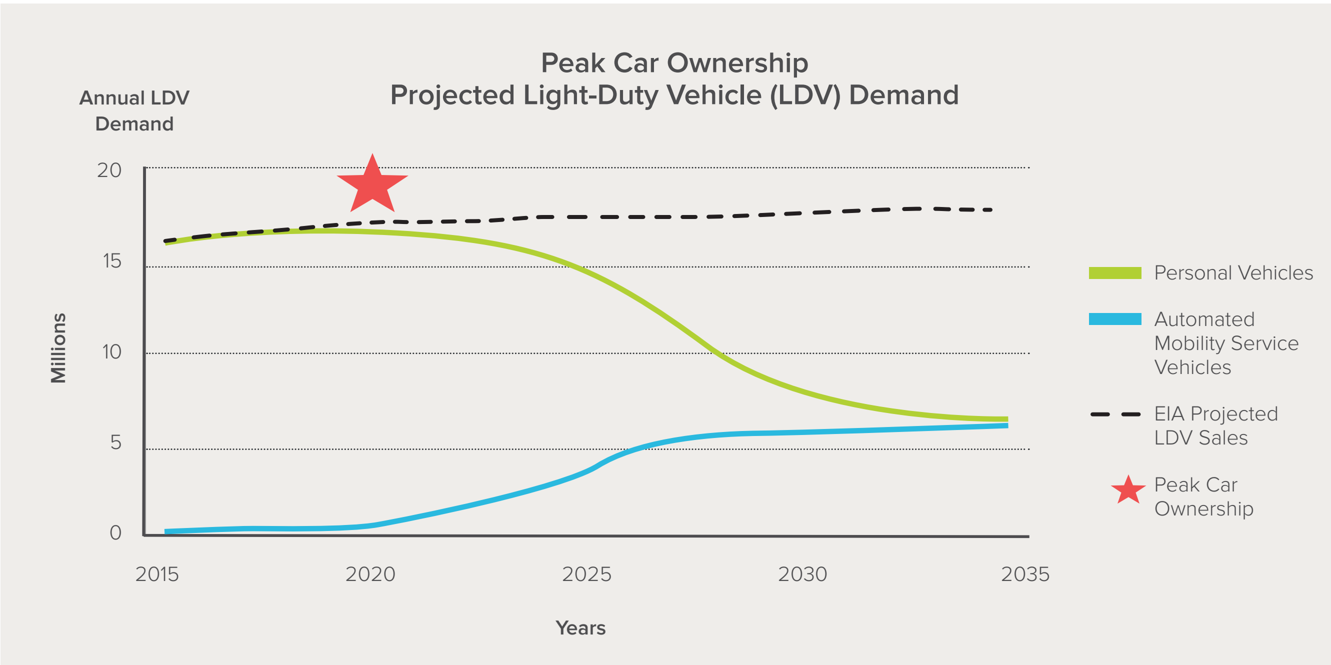
FIGURE 11:
U.S. ELECTRICITY DEMAND



ELECTRICITY DEMAND

As oil demand drops, electricity demand grows. Electrical utilities could see a 10% increase in energy demand by 2035. The extent to which additional power capacity is needed depends on how intelligently the vehicles charge. If the vehicles charge randomly, additional peak capacity would be needed. However, if vehicles charge intelligently at times of low demand, no additional power capacity may be needed. In fact, vehicles could strategically choose charging times to coincide with renewable energy production, like solar noon or windy nights. This could mitigate renewable spillage and increase the value of new renewable projects. Electric vehicles could become invaluable distributed energy resources.[17]

FIGURE 12:
PROJECTED LIGHT-DUTY VEHICLE DEMAND



VEHICLE DEMAND

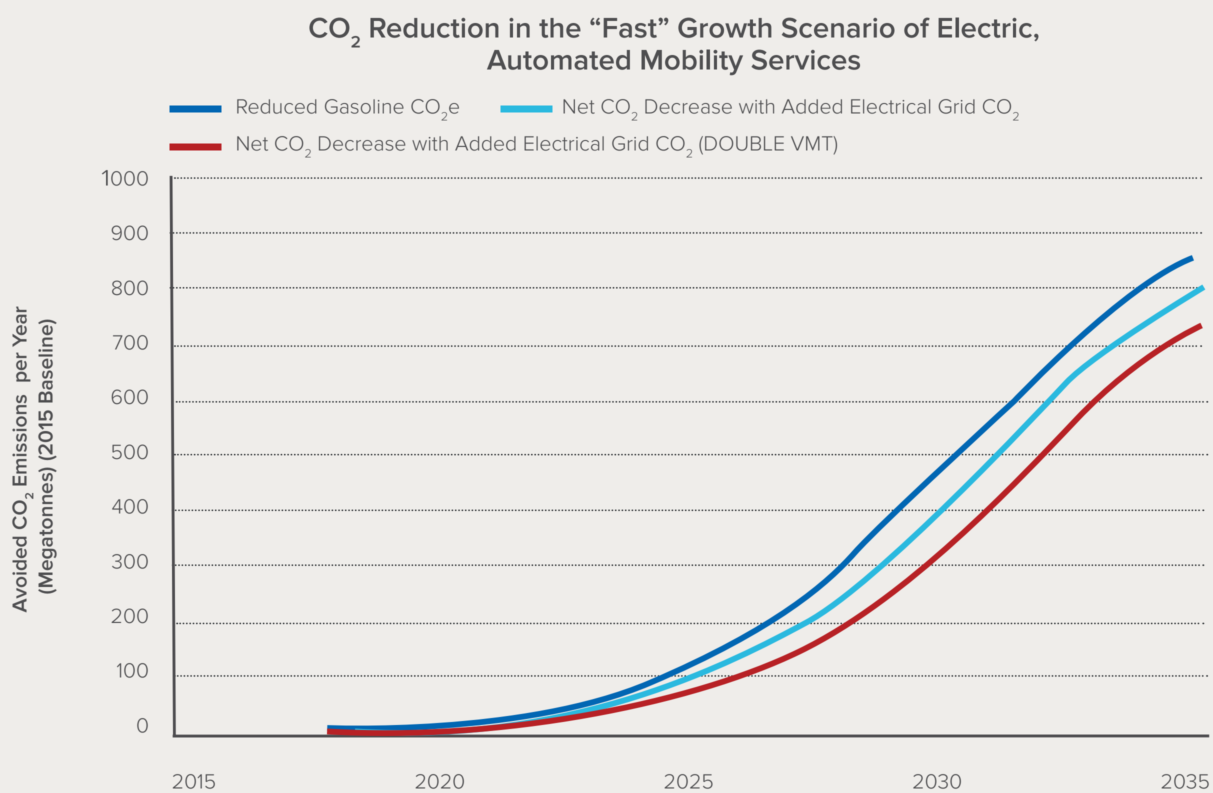
PEAK CAR OWNERSHIP

According to our modeling, peak car ownership in the United States will occur around 2020 and will drop quickly after that. This could lead to a clear delineation between winners and losers based on which auto companies capitalize on emerging business models for mobility services and which do not. In addition, the speed and complexity of this disruption could favor new entrants that are used to a rapidly changing consumer and technology landscape and fast turnover of product. New entrants also have lower risk of stranded assets that are already deployed (or planned) for a personal vehicle-centric market.

On the positive side, carmakers that excel in providing autonomous vehicles and automated mobility services stand to prosper greatly in the next two decades. As personal vehicle demand drops, demand for autonomous vehicles to perform mobility services will grow. Demand for autonomous service vehicles will compensate for lost demand for personal vehicles for several years, but ultimately the vehicle fleet will shrink considerably. But carmakers that provide mobility services and autonomous vehicles could reap substantial profit since our current system costs around $0.80 per mile, and mature electric automated mobility service could cost only $0.30 per mile. That difference of $0.50 per mile equates to over $1 trillion in total savings that will be split between society, consumers, and the mobility service providers of the future.

FIGURE 13:

WITH MASS AMOUNTS OF EVS FUELED BY A RELATIVELY CLEAN GRID, CARBON DIOXIDE FROM PERSONAL MOBILITY PLUMMETS



CO_2 EMISSIONS

As electric, autonomous vehicles rapidly displace personally owned gasoline vehicles, our primary transportation fuel switches from gasoline to electricity. In parallel, we project that the electrical grid will continue to decarbonize, reaching about 2/7 of the carbon intensity in 2035 versus 2015 (based on RMI's Reinventing Fire analysis). With mass amounts of EVs fueled by a relatively clean grid, carbon dioxide from personal mobility plummets, down almost a gigatonne per year in the late 2030s. This holds even if VMT increases by double (an additional 3 trillion vehicle miles per year), the so-called "hell scenario" in which Americans utilize more vehicle travel because autonomous mobility services are cheap and inexpensive. Studies also show that autonomous vehicles could increase vehicle throughput by at least three times, meaning even double VMT from autonomous vehicles would still have reduced congestion versus today. In terms of pollution and congestion, even the worst-case scenario is far better than today.

07. CONCLUSION

It is technologically, logistically, and economically plausible for electric automated mobility services to garner large portions of the market share currently held by personally owned vehicles by 2035. Barriers and potential pitfalls exist, but a system that is superior in terms of cost, convenience, safety, and emissions cannot be ignored or dismissed easily and should be encouraged by governments and regulators. With reasonable rates of growth within potential markets, electric automated mobility greatly reduces demand for light-duty vehicles and gasoline. It also could increase electricity demand by about 10%, the impact of which could be a great boon to utilities if integrated properly.

FUTURE ANALYSIS

The rise of automated mobility service could be one of the most interesting and complex disruptions of the modern era. This report attempts to reasonably estimate market growth and evaluate impacts. It is the first in a series of reports that dive into greater depth on the impact on specific stakeholders. Following reports will focus on:

1. The impact of automated mobility service on cities
- a. A city's role in optimizing deployment in its municipality
- b. Impacts on low-income members of the community
- c. Land codes and land use
- d. Congestion, safety, and air quality

2. The interaction of electric automated mobility service with the electrical grid
- a. Energy and power demand impacts and levers to optimize
- b. Smart charging plan for utilities and regulators
- c. EVSE infrastructure as a money maker
- d. Enabling renewables by preventing spillage

3. Consumer behavior and adoption
- a. Consumer views of autonomous vehicles by demographic
- b. Rates of change of perception
- c. More city-specific analyses of consumer attitudes

4. Smart Policy
- a. The policy levers to accelerate and optimize the disruption
- b. Policy and regulation to avoid
- c. How ZEV, CAFE, and others fit in

08. TECHNICAL APPENDIX: DATA, METHODS, AND ASSUMPTIONS

I. Figure 1 Data: Costs per Passenger-Mile Traveled

	POV [e.g., Camry]	TNC [e.g., Uber]	AUTOMATION COSTS	AUTOMATION SAVINGS	AUTOMATED TNC
Parking	$0.16	-			-
Mileage Depreciation	$0.06	$0.07			$0.07
Fuel Cost	$0.09	$0.09		-$0.01	$0.08
Maintenance	$0.05	$0.05			$0.05
Time Depreciation	$0.26	$0.00			$0.00
Financing	$0.04	$0.01			$0.01
Insurance	$0.10	$0.08			$0.08
License, Registration	$0.05	$0.01			$0.01
TNC Revenue	-	$0.40			$0.40
Driver Net Earnings	-	$1.33		-$1.33	-
Fleet Management Cost	-	-	+$0.08	-	$0.08
Autonomous Hardware	-	-	+$0.08	-	$0.08
TOTAL	$0.82	$2.04	+$0.16	-$1.34	$0.86

**Numbers in this table rounded to closest decimal point*

DATA SOURCES AND ASSUMPTIONS:

Mileage: Personal vehicle = 11,500 vehicle-miles/y. TNC (full-time driver) = 70,000 vehicle-miles/y

Parking: Average cost of parking in U.S. cities is $155/month according to FoxNews.com

Mileage Depreciation: POV based on Toyota Camry KBB.com values at same age, different mileage. TNCs based on vehicle depleting its useful life at 280,000 miles with no residual value.

Fuel Cost: $2.50 per gallon gasoline / 27 mpg average mpg = $0.09 per mile. Automated TNC saves $0.01 per mile in fuel cost due to optimal acceleration/deceleration and not exceeding speed limits based on Autonomie software modeling.

Maintenance: Oil, tires, and all other maintenance and repair is $0.05 per mile (http://exchange.aaa.com/wp-content/uploads/2015/04/Your-Driving-Costs-2015.pdf)

Time Depreciation: POV based on Toyota Camry KBB.com values at same mileage, different age. TNCs have no time depreciation since mileage depreciation completely depreciates the vehicle capital cost by end of life.

Financing: 4.3% APR for 5 years with 10% down

Insurance: Personal = $1,106 per year (AAA). Commercial = $5,608 per year (*Insurance Journal)*

License, Registration: $418 per year (AAA)

TNC Revenue: Uber, for instance, takes around 20% of total fare, which comes to about $0.40 per passenger-mile.

Driver Net Earnings: This is the difference between total revenue of $2.04 per passenger-mile and total costs. Note that this is not $1.33 net earnings per *vehicle* mile, it is net earnings per passenger mile. Non-passenger miles can be a large percentage of total miles, so TNC driver revenue can fluctuate greatly depending on customer availability.

Fleet Management Cost: When autonomous systems replace human TNC drivers, a new entity must store and manage vehicles. This entity will, of course, incur costs. We estimated that a fleet management service would spend 10 minutes per vehicle per shift (i.e., one employee could manage 50 vehicles) at an average labor rate of $15/hr = $1,667 per vehicle per year. In addition, according to Columbia Earth Institute (2013), about 10% of miles in an automated mobility service will be "empty miles" in which the vehicle moves with no revenue-generating passenger, which will cost the fleet management service $2,100 per vehicle per year. Add $155/month per parking space = $1,860 per vehicle per year for a grand total of $5,627 per year total cost per vehicle ($0.08/mi).

Autonomous Hardware Cost: Boston Consulting Group estimates that fully autonomous driving modules will cost $10,000 per unit and $2,700 per unit in 2025 and 2035 respectively. Using this, we projected early units deployed in 2018 could cost up to $28,000 per unit, which roughly doubles the capital cost of the vehicle. Therefore, cost per mile of the module is roughly the same as the total vehicle depreciation cost per mile (assuming the module has no residual value at the end of the vehicle's useful life). (https://www.bcgperspectives.com/content/articles/automotive-consumer-insight-revolution-drivers-seat-road-autonomous-vehicles/?chapter=4#chapter4)

DATA SOURCES AND ASSUMPTIONS:

Useful Life: Optimal value for Camry is 4-year, 280,000-mile useful life. After this, powertrain replacement/repair costs "total" the vehicle and are not worth it. Optimal value for EV is 7-year, 490,000-mile useful life and includes two battery/powertrain replacements that cost $12,846 each.

EV Capital Cost Premium: Base 2017 Camry is $23,840. Base 2018 Tesla Model 3 will be $35,000 without any federal or state tax incentives or rebates. Adding the two battery replacements for the EV at $12,846 each equals a total of $60,692 capital cost of EV over its life. $23,840/4 = $5,960/y for Camry vs $60,692/7 = $8,670/y for Tesla Model 3. This is a difference of $2,710/y. Incremental financing cost for the EV is $80/y for a grand total of $2,790/y capital premium for the EV.

Fuel Cost Savings: Camry SE is 28 mpg combined = $2.50/gal / 28 mi/gal x 70 kmi/y = $6,250/y. Tesla Model 3 will be ~34 kWh/100 mi x 70 kmi x $0.10/kWh = $2,380. $6,250-$3,870 = $3,870/y savings for EV.

Maintenance Cost Savings: EVs require no oil changes, which cost $0.006/mi according to *Automotive Fleet Magazine*. This saves $413/y for the EV. Qualitatively, EVs have an additional upside of no complex transmission, one moving part in the motor (ICEs have many), and regenerative braking that should improve brake life. On the downside, EVs have battery maintenance. We need more field data to weigh upside vs. downside of these additional maintenance costs, but in theory, EVs should have significantly lower overall maintenance cost than ICEs.

II. Figure 2 Data: Annual Cost Difference of Service Vehicles (70K mi/y): ICE vs. EV

	BASELINE: GASOLINE VEHICLE	TNC [e.g., Uber]	EV COSTS	NET ELECTRIC VEHICLE COST
EV Capital Cost Premium	Baseline	+$2,790	-	
Fuel Cost Savings	Baseline	-	-$3,870	
Maintenance Cost Savings	Baseline	-	-$413	
EVSE Cost	Baseline	+$474	-	
TOTAL NET	Baseline	$3,264	$-4,283	-$1,019

MOBILITY TRANSFORMATION

EVSE Cost: Each vehicle will use 32 kWh per 8-hour shift, with two shifts per day. Therefore, each vehicle will charge for 4 hours on an 8-kW L2 twice per day. We assume with "fleet intelligence," the autonomous EVs will coordinate at a fleet level, insuring an optimized balance of vehicles providing rides and vehicles charging throughout the day. Most or all vehicles will be in service during "rush hour," which is actually 4 hours (7–9 a.m. and 4–6 p.m.). This leaves many 4-hour windows when vehicle demand is lower and some or most EVs can charge. A dual-port L2 could supply 40 charge-hours during these windows, which will be sufficient for at least three EVs that require 24 charge-hours per day total. Therefore, each L2 can service at least three EVs. This comes to $193 per vehicle per year. Installation costs are based on new construction, not retrofit. The assumption is that new depots will (should) be constructed to house and charge electric, autonomous, service vehicles.

LEVEL 2 CHARGERS			
Full Annualized Cost (10-year life)	Total Cost (Cap and Install)	Total Interest Cost	Annual Maintenance
$580	$2,500	$318	$299

In addition, a fleet of long-range EVs will still need DCFC chargers to guard against demand anomalies and provide fuel security, like traditional gas stations. A DCFC can charge at 50 kW which will supply a full shift-worth of range in ~30 minutes. We estimate a DCFC could accommodate about 60 EVs for the smaller percentage (20%) of time they need fast charging. That comes to $9,475/60 = $158 per vehicle per year.

DCFC CHARGERS			
Full Annualized Cost (10-year life)	Total Cost (Cap and Install)	Total Interest Cost	Annual Maintenance
$9,475	$50,000	$6,360	$3,854

III. Figure 3 Data: EV Cost Projections

MODEL YEAR EV	2018	2020	2025	2030	2035
Powertrain cost	$3,783	$3,471	$3,055	$3,055	$3,055
Non-powertrain costs	$12,398	$12,913	$13,608	$13,608	$13,608
OEM	$7,907	$8,192	$8,609	$8,609	$8,609
Battery cost	$12,471	$10,381	$6,842	$6,562	$6,294
TOTAL COST	$36,559	$34,957	$32,114	$31,834	$31,566
Battery cost per kWh	$215	$182	$125	$125	$125
Battery capacity required (kWh)	58	57	55	52	50

Derived and projected from Bernstein Research: Stephanie Lang, et al, "Global Autos: Don't Believe the Hype – Analyzing the Costs & Potential of Fuel-Efficient Technology," *Sept 2011.*

Data For Figure 4: Ranking the Mobility Market of Various U.S. Cities

	CITY	METRO POPULATION (MILLIONS)	DAYS WITH SNOWFALL	DRIVERLESS VEHICLE REGULATORY STATUS	AVS TESTING ON PUBLIC ROADS	TEC-ENABLED MOBILITY RANK	DOT SMART CITY FINALIST	MOBILITY MARKET SIZE ($B)
Likely Launch Markets	Austin	2.0	<1	No Regulation	Yes	1	X	$9.1
	Seattle	3.7	3	No Regulation	Yes	8		$17.0
	Phoenix	4.6	<1	Exec Order	Yes	33		$20.9
	TOTAL LAUNCH MARKETS	10.3						**$47.0**
Likely Early Markets	Portland	2.4		No Regulation	No	7	X	$10.9
	Dallas	7.1		No Regulation	No	12		$32.4
	Houston	6.7		No Regulation	No	15		$30.4
	Miami	6.0		Some Regulation	No	15		$27.4
	Tampa	3.0		Some Regulation	No	15		$13.6
	Orlando	2.4		Some Regulation	No	20		$10.9
	Atlanta	5.7		No Regulation	No	21		$26.0
	Charlotte	2.4		No Regulation	No	35		$11.1
	San Antonio	2.4		No Regulation	No	42		$10.9
	TOTAL LAUNCH MARKETS	38.0						**$173.5**
Risky Regulatory Markets (CA)	San Francisco	4.7	<1	Pending Reg would ban	Yes	2	X	$21.2
	Los Angeles	13.3	<1	Pending Reg would ban	No	4		$60.8
	San Diego	3.3	<1	Pending Reg would ban	No	8		$15.0
	TOTAL CA MARKETS	21.3						**$97.1**
Markets with Snow	Pittsburgh	2.4	40	No Regulation	Yes	24	X	$10.7
	Washington, D.C.	6.1	8	Some Regulation	No	3		$27.8
	New York City	20.2	11	No Regulation	No	4		$92.0
	Boston	4.8	22	No Regulation	No	4		$21.8
	Denver	2.8	33	No Regulation	No	8	X	$12.8
	Minneapolis	3.5	37	No Regulation	No	8		$16.1
	Columbus	2.0	30	No Regulation	No	13	Winner	$9.2
	Chicago	9.6	29	No Regulation	No	14		$43.6
	Kansas City	2.1	8	No Regulation	No	24	X	$9.5
	Philadelphia	6.1	12	No Regulation	No	37		$27.7
	Detroit	4.3	36	Some Regulation	No	40		$19.6
	TOTAL SNOW MARKETS	63.8						**$290.8**
	TOTAL INITIAL MARKETS	133.4						**$608.4**

IV. Figure 5 Data: Public Interest in Automated Mobility Services:

From Prateek Bansal, "Assessing Public Opinions of and Interest in New Vehicle Technologies: An Austin Perspective," University of Texas at Austin, 2016, Page 7.

V. Figure 6/Figure 4 Method:

- Determine likely first 26 markets based on population and existing tech-enabled mobility.
- Estimate total consumer spend on transportation in those markets.
- Estimate percentage of consumers who will participate in automated mobility and for what percentage of their total travel based on public interest studies and early adopter demographics.
- Calculate the amount of money the early adopters may spend on automated mobility in the first 26 markets.

VI. Figure 7 Method: Automated Mobility Growth Rate

- Fast: The "Fast" growth projection assumes that automated mobility services launch in certain markets in 2018. The likely launch markets are Austin, San Francisco, Pittsburgh, Phoenix, and Seattle (all places where autonomous vehicles are currently testing on public roads). The Fast scenario then assumes that a national regulatory framework makes interstate expansion simple and that technology overcomes issues with weather in "snow markets." Availability of autonomous vehicles will likely not be the limiting factor as many companies should be producing full driverless vehicles in the next few years, including Ford, who just announced "mass production" of autonomous vehicles for ride hailing services by 2021.[18] Ford alone could meet our projected "Fast" growth demand if it manufactures 200,000 AVs in 2021, which is well within the spectrum of OEM "mass production." The vehicles could all be electric too. Tesla has indicated goals of mass-producing hundreds of thousands of autonomous electric vehicles by 2020 using its "gigafactory" for batteries. With these assumptions, there would be little limit to the speed at which automated mobility could expand to meet the market demand of the "early adopters" identified in Figure 6. As such, we assume that the number of autonomous vehicles providing automated mobility service could grow at the same rate that Uber X did in its first 24 markets. This leads to over 10% market share of U.S. transportation by 2025 for $1/mile automated mobility services.

- Slow: The "Slow" growth projection still assumes that automated mobility service launches in at least one market in 2018, like Austin, TX. It pessimistically assumes that technology does not solve the "snow problem" in the next 8 years and therefore cannot expand to snowy markets en masse (though testing and pilots will certainly occur in snow markets). The Slow scenario also assumes that each state has its own regulatory policy, with some embracing and some rejecting driverless vehicles. Based on current regulatory conditions, we assume that Arizona, Texas, and Florida will allow driverless vehicles, but major states like California may block them out of fear. In these conditions, automated mobility can still grow rapidly in Arizona, Texas, and Florida, capturing the "early adopters" who amount to a full 3% of the total U.S. mobility market by 2025 in these three states alone. This is still tens of billions of dollars in revenue, even given pessimistic assumptions.

VII. Figure 8 Data: Cost per Mile by Year

YEAR	2018	2025	2030	2035
Personal Sedan TCO	$0.81	$0.84	$0.85	$0.87
Personal Sedan OpEx	$0.37	$0.39	$0.41	$0.42
Automated TNC Service in Electric Sedan	$0.84	$0.51	$0.36	$0.33

DATA SOURCES AND ASSUMPTIONS:

Personal Sedan TCO: Projections from Bernstein Report, 2011.

Personal Sedan OpEx: Projections from Bernstein and EIA for gasoline price projection.

Automated TNC Service in Electric Sedan: Assumptions about EV cost reduction from Figure 3, plus decreasing costs of automated mobility services. As these services reach large scale, start-up cost will fade (reducing service provider/fleet manager costs), vehicles will be "right-sized" for specific tasks (reducing OpEx), and overhead/fixed costs will be spread over trillions of miles (reducing CapEx).

VIII. Figure 9: Method

Disruptive technologies from electricity to The Internet gain market penetration on an "S" curve defined by the logistic function. The "S" begins with early adopters (~15% of population), grows into "early majority", then "late majority," then "laggards," and never captures "hold outs" (some people won't fly in aircraft, for instance). Using the "Fast" growth rate from Figure 7, we have the shape of "early adopter" market share growth and can then use this to project the continuation of the "S" curve using the logistic function.

We then overlaid historic disruptive technologies to give a sense of relative growth compared to familiar products. Our projection lies right on top of how color TV grew, is a bit faster than how the original automobile grew, and is slower than perhaps the most recent disruption, smart phones. This seems reasonable given the assumptions in the "Fast" growth scenario. Note that even in our "Slow" scenario, at some point regulatory framework will be common and tech will solve the "snow problem," so even the "Slow" scenario will likely reach the market size projected, but just some years later.

IX. Figure 10–13: Method

With the growth projection from Figure 9, we can project how electric, automated mobility service vehicles will displace conventional vehicles. This gives insight into gasoline demand, electricity demand, light duty vehicle demand, and carbon dioxide emissions. For all four figures, we estimated that the service vehicles turn over about every five years and that each vehicle can displace about five personal vehicles due to much higher utilization (several studies indicate that each autonomous service vehicle could displace over 10 personal vehicles). We also made assumptions about the percentage of automated mobility service vehicles that will be gasoline vs. electric by year. Qualitatively, a good amount of automated services will launch with gasoline vehicles (we estimated two-thirds will be gasoline in 2018) due to issues around long-range electric vehicle availability and EVSE ubiquity. But as long-range EVs become plentiful across vehicle types (sedans, vans, SUVs, "pods," etc.) and EVSE reaches scale, the economics (Figures 2 and 3) will compel mobility service providers to deploy electric vehicles or be undercut in cost/price by those who do (we estimated 85% of automated mobility service vehicles will be electric by 2025). Continued research and work with electrical utilities is critical to ensure that the electrical grid and related infrastructure is prepared and prospers under the wave of new EV demand. On a related note, Figure 13 assumes that the grid continues to decarbonize and has two-sevenths the carbon intensity in 2035 as it did in 2015 based on RMI's analysis for its book *Reinventing Fire: Bold Business Solutions for the New Energy Era.*

09. ENDNOTES

[1] Rocky Mountain Institute, http://blog.rmi.org/blog_2015_03_12_how_the_us_transportation_system_can_save_big; Columbia Earth Institute, http://sustainablemobility.ei.columbia.edu/files/2012/12/Transforming-Personal-Mobility-Jan-27-20132.pdf; Albright Stonebridge Group, "Autonomous Vehicles, Future Mobility, And The Role Of Public Policy," April 2016; University of Texas-Austin, http://www.caee.utexas.edu/prof/kockelman/public_html/TRB14EnoAVs.pdf; Lawrence Berkeley Laboratories, http://newscenter.lbl.gov/2015/07/06/autonomous-taxis-would-deliver-significant-environmental-and-economic-benefits/; and http://www.gordianviews.com/driverless-car-revolution-buy-mobility-not-metal-a-great-read/

[2] Prateek Bansal, *Assessing Public Opinions of and Interest in New Vehicle Technologies: An Austin Perspective*, University of Texas at Austin, http://www.caee.utexas.edu/prof/kockelman/public_html/TRB16NewTechsAustin.pdf

[3] Daisuke Wakabayashi and D. MacMillan, "Apple's Latest $1 Billion Bet Is on the Future of Cars," *Wall Street Journal*, May 14, 2016. http://www.wsj.com/articles/apples-1-billion-didi-investment-revs-up-autonomous-car-push-1463154162

[4] David Curry, "Uber to Kick Off First Autonomous Car Test in Pittsburgh," Readwrite News, May 20, 2016. http://readwrite.com/2016/05/20/uber-autonomous-car-pittsburgh-tl4/

Biz Carson, "Travis Kalanick on Uber's bet on self-driving cars: 'I can't be wrong'", *Business Insider*, Aug. 18, 2016. http://www.businessinsider.com/travis-kalanick-interview-on-self-driving-cars-future-driver-jobs-2016-8

[5] Fred Lambert, "Morgan Stanley's Adam Jonas Weighs in on Elon Musk's 'Tesla Masterplan part 2', predicts 'Tesla Mobility' Again," Electrek, July 12, 2015. http://electrek.co/2016/07/12/tesla-tsla-elon-musk-masterplan-adam-jonas-tesla-mobility/

[6] Elon Musk, "Master Plan, Part Deux," July 20, 2016. https://www.tesla.com/blog/master-plan-part-deux/

[7] Matt McFarland, "CEO of car2go North America Discusses Self-Driving Cars, Electric Vehicles," *Standard Examiner*, July 23, 2015. http://www.standard.net/frontpage/2015/07/23/CEO-of-car2go-North-America-discusses-self-driving-cars-electric-vehicles

[8] David Shepardson and P. Lienert, "In Boost to Self-Driving Cars, U.S. Tells Google Computers Can Qualify As Drivers," Reuters, Feb. 10, 2016. http://www.reuters.com/article/us-alphabet-autos-selfdriving-exclusive-idUSKCN0VJ00H

[9] Smart City Challenge, https://www.transportation.gov/smartcity

[10] "Summary of Draft Autonomous Vehicles Deployment Regulations," California Department of Motor Vehicles, Dec. 16, 2015. https://www.dmv.ca.gov/portal/wcm/connect/dbcf0f21-4085-47a1-889f-3b8a64eaa1ff/AVRegulationsSummary.pdf?MOD=AJPERES

[11] Michael Sivak and B. Schoettle, "A 16-Year-Old Needs a License. Shouldn't a Self-Driving Car?" *The New York Times*, July 7, 2016. http://www.nytimes.com/2016/07/07/opinion/a-16-year-old-needs-a-license-shouldnt-a-self-driving-car.html?_r=1

[12] Chris Nelder, James Newcomb, and Garrett Fitzgerald, *Electric Vehicles as Distributed Energy Resources*, Rocky Mountain Institute, 2016, http://www.rmi.org/pdf_evs_as_DERs.

[13] Biz Carson, "Report: Uber Was on Track to Top $1.5 Billion in Revenue Last Year," *Business Insider*, Jan. 11, 2016. http://www.businessinsider.com/report-uber-15-billion-revenue-in-2015-2016-1

[14] Brian Solomon, "The Numbers Behind Uber's Exploding Driver Force," *Forbes*, May 1, 2015. http://www.forbes.com/sites/briansolomon/2015/05/01/the-numbers-behind-ubers-exploding-driver-force/#20963ef54901

[15] "How Americans Spend Their Money," *The New York Times*, Feb. 10, 2008. http://www.nytimes.com/imagepages/2008/02/10/opinion/10op.graphic.ready.html

[16] Robert Hutchinson, "Driverless Cars: What Could Possibly Go Wrong?" *Harvard Business Review*, Jan. 15, 2016. https://hbr.org/2016/01/driverless-cars-what-could-possibly-go-wrong

[17] Nelder, et al., *Electric Vehicles as Distributed Energy Resources*.

[18] "Ford Promises Fleets of Driverless Cars Within Five Years," *The New York Times*, Aug. 16, 2016. http://www.nytimes.com/2016/08/17/business/ford-promises-fleets-of-driverless-cars-within-five-years.html

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