February
2018

The Great Divide: What Consumers Are Buying vs. The Investments Automakers & Suppliers Are Making in Future Technologies, Products & Business Models

CAR
CENTER FOR AUTOMOTIVE RESEARCH

Carla Bailo
Kristin Dziczek
Brett Smith
Adela Spulber
Yen Chen
Michael Schultz

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Section I: Introduction

The U.S. automotive industry is in a critical period. U.S. light vehicle sales are plateauing at a high level that includes a rich mix of pickup trucks, SUVs, and CUVs. Sales of these high-priced and high-margin vehicles are producing record profits that companies are pouring into new products, processes, and technologies. Some technological developments—including automated driver assist systems (ADAS); connected and automated vehicle technologies (CAV); and advanced powertrains—have the potential to transform not only the vehicle but also the entire automobile industry. Alone or in combination, these technologies can enable new mobility paradigms and business and revenue models that could dramatically alter the way consumers purchase transportation and interact with vehicles.

Even while the industry is making substantial bets on the future of automotive technology and the automotive business more broadly, companies must continue to develop and sell vehicles to make a profit in today's market. The mixed fleet—personal ownership and shared mobility—will likely persist for decades. Developing and manufacturing a light vehicle is a costly endeavor with uncertain paybacks. Automakers must justify their platform and powertrain business cases over a multi-year time horizon to meet internal rate of return (IRR) hurdle rates or the targeted level of return on invested capital (ROIC). Capital and human resources are typically constrained, and current technology trends have tightened the constraints even further. The United States' technological leadership is at stake.

Most automakers and suppliers agree that the "three revolutions" of automated, shared, and electric vehicles will be transformative (Sperling, 2018). However, it may take decades for this idealized future to take hold, and even then, automated, connected, electric, and shared vehicles (ACES) will not make sense in every region of the country or every climate. This briefing addresses the challenges automakers and suppliers face, the tension between consumer demand and regulatory mandates on electrified powertrains, the impact of CAVs on personal vehicle ownership and mobility, and the implications for the nation's engineering and technological leadership in the world.

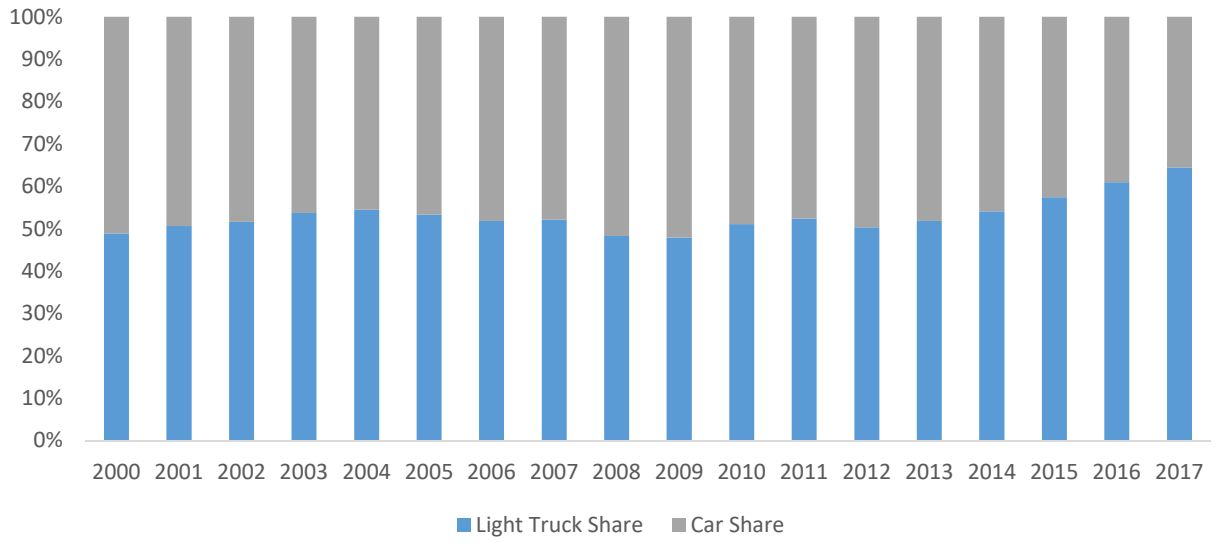
Section II: Current Market

Segments

As recently as 2000, the U.S. market was evenly split between vehicles considered "cars" and those classified as "light trucks." With relatively low fuel prices, and the corresponding popularity of vehicles in the sport-utility (SUV), crossover-utility (CUV),[1] and pickup truck segments, the light truck share has grown to nearly two-thirds of the U.S. market, as shown in Figure 1. The CUV segment alone expanded from just 5.7 percent market share in 2000 to 37.8 percent share in 2017 as manufacturers offered more vehicles in this very appealing consumer category.

[1] The CUV can be classified as either a car or a light truck, but over 97 percent of CUVs sold in the United States in 2017 were considered light trucks.

Figure 1: U.S. Car-Truck Market Share Split, 2000-2017

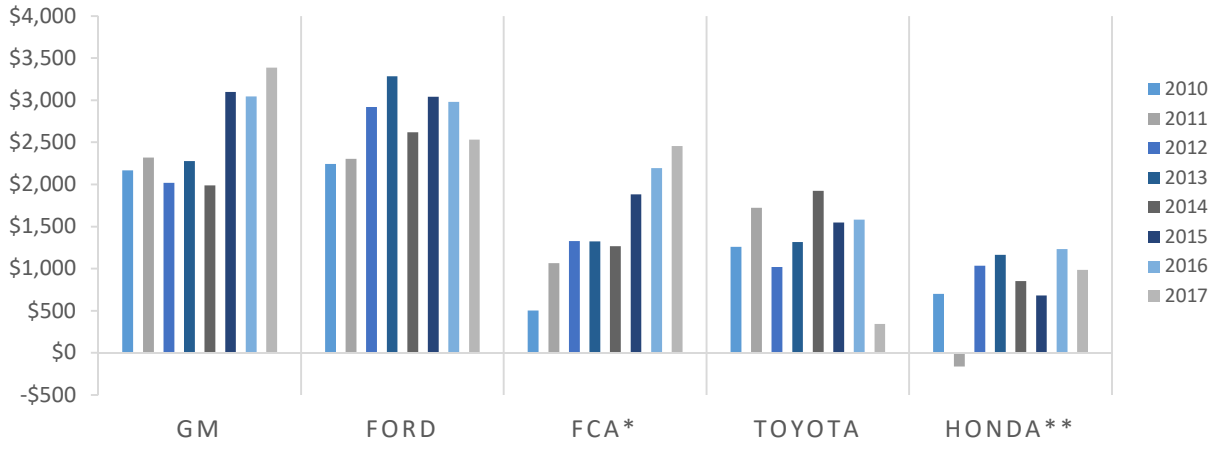


Source: IHS|Markit

Profitability

It is not a coincidence that the shift to CUVs, SUVs, and pickups coincides with a period of increased profitability for nearly every automaker that sells vehicles in the U.S. market. Figure 2 shows that after the recession, almost every automaker in the U.S. market is profitable on a per-unit basis on their U.S. sales. The exceptions at Toyota and Honda are a result of currency and other factors, and not the vehicle profit margins per se. Profit margins also vary by segment, with profits in the hundreds of dollars on some cars and $10,000 per vehicle or more for larger CUVs, SUVs, and trucks. The more the market moves toward these vehicles, the greater the opportunity to increase margins.

Figure 2: Operating Profit Per Vehicle, 2010-2017 for Five Largest Automakers in U.S. Market

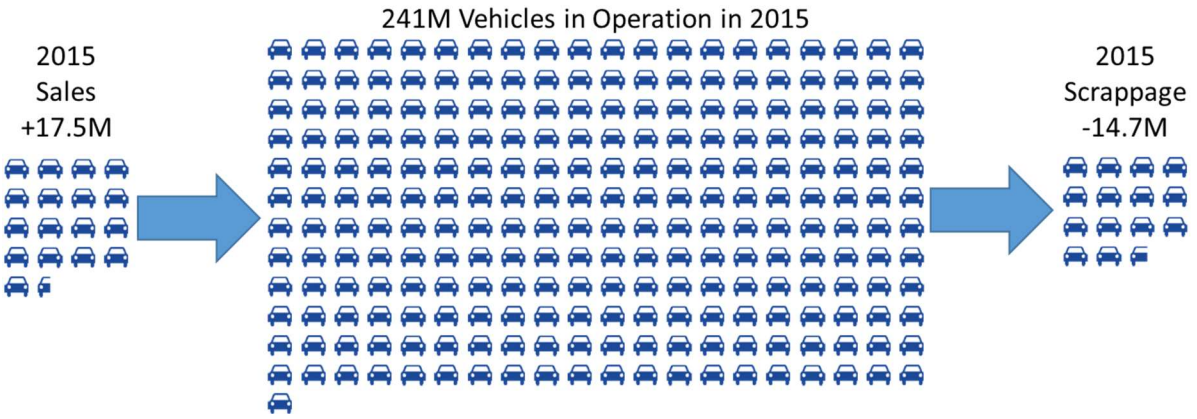


**2013 and earlier: Chrysler Group LLC; 2014 and 2015: FCA US LLC; 2016 and on: FCA NAFTA*
***Honda also excludes motorcycle, finance, and power products*
Source: CAR research based on companies' financial reports.

Average Vehicle Age and Vehicle Turnover

The average vehicle on the road in the United States in 2016 was 11.6 years old (IHS|Markit, 2017). The market turnover is relatively slow. On a base of 241 million light vehicles registered in the United States in 2015, new vehicle sales added 17.5 million to the in-use fleet, and 14.7 million vehicles were scrapped that year, as shown in Figure 3.

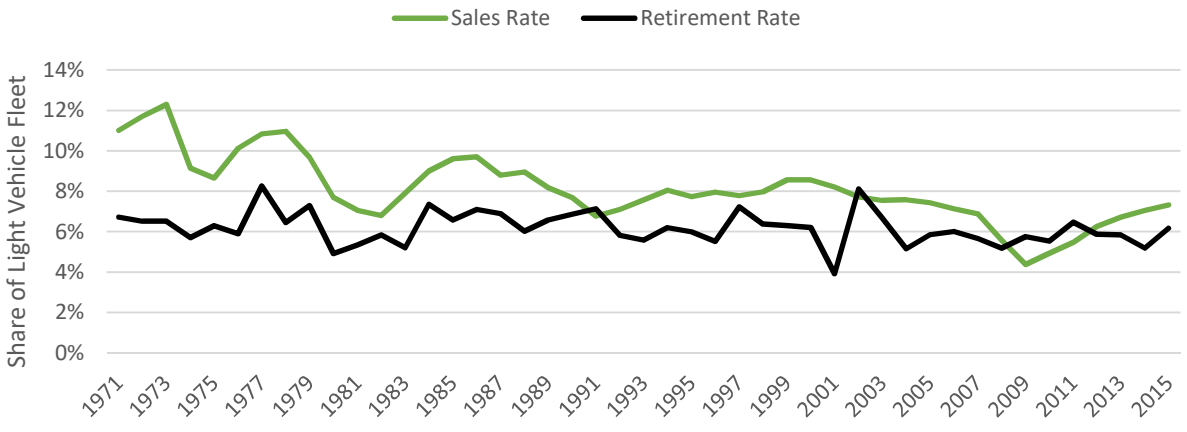
Figure 3: Illustration of 2015 U.S. Light Vehicle Fleet Dynamics



Source: CAR analysis; Automotive News; Oak Ridge National Laboratory Transportation Energy Data Book

Remarkably, vehicle sales and retirement rates have remained relatively constant over a period of more than 30 years, as shown in Figure 4. U.S. sales rates average roughly 8 percent, and retirements around 6 percent annually, which means the overall fleet is growing at a rate of 2 percent a year.

Figure 4: Dynamics of the U.S. Light Vehicle Fleet: Sales and Retirement Rates, 1971-2015



Source: CAR calculations using data from Oak Ridge National Laboratory and Automotive News

Vehicle Miles Traveled

The relatively high average vehicle age does not mean that it would take nearly 12 years for new technologies to proliferate. While fleet installations might take that long, the fact that the newer vehicles comprise a majority of the vehicle miles traveled (VMT) in a given year means that it would only

take about seven years before a new technology installed on every vehicle sold is in use for half of the annual U.S. VMT.[2]

Many of the new and emerging automotive trends have prioritized dense, urban areas for deployment. For ridesharing and ridehailing services, this reflects the relative ease of finding customers in denser areas. New technologies, such as automated driving, require detailed three-dimensional maps of roadways for system reliability. With an extreme cost to develop these maps, urban areas, representing the majority of the population and thus potential customers, are prioritized. For vehicle electrification, the charging infrastructure build-out is a critical factor.

Even with a significant delay before mobility and charging systems and services are available in rural areas, near all of their potential benefits, whether to motor vehicle safety from avoided and mitigated collisions or improved convenience of travel, will have been realized before rural area technology deployment takes place. Driving on rural roads constitutes only 30 percent of all VMT each year, as shown in Table 1. Excluding rural travel on the interstate highway system, which transportation providers may prioritize above urban surface roads for vehicle autonomy, the rural share of VMT is significantly smaller at 22.5 percent of vehicle travel (United States Department of Transportation-Federal Highway Administration, Various Years).

Table 1: 2016 Share of U.S. Vehicle Miles Traveled by Type of Route

	Percent of Total
Rural Interstate	8%
Rural Other Arterial	12%
Other Rural	11%
Urban Interstate	18%
Urban Other Arterial	36%
Other Urban	17%
All Systems	100%

Source: U.S. Department of Transportation, Federal Highway Administration

Section III: Powertrain & Propulsion

Powertrain Market and Consumer Acceptance

The internal combustion engine (ICE) has been the dominant power source for a light-duty vehicle for over a century. U.S. light vehicle sales were over 17.2 million in 2017, and over 98 percent of the vehicles sold in this country last year had an ICE. However, automakers are investing heavily and making significant commitments to advanced propulsion and vehicle electrification (Reuters, 2017):

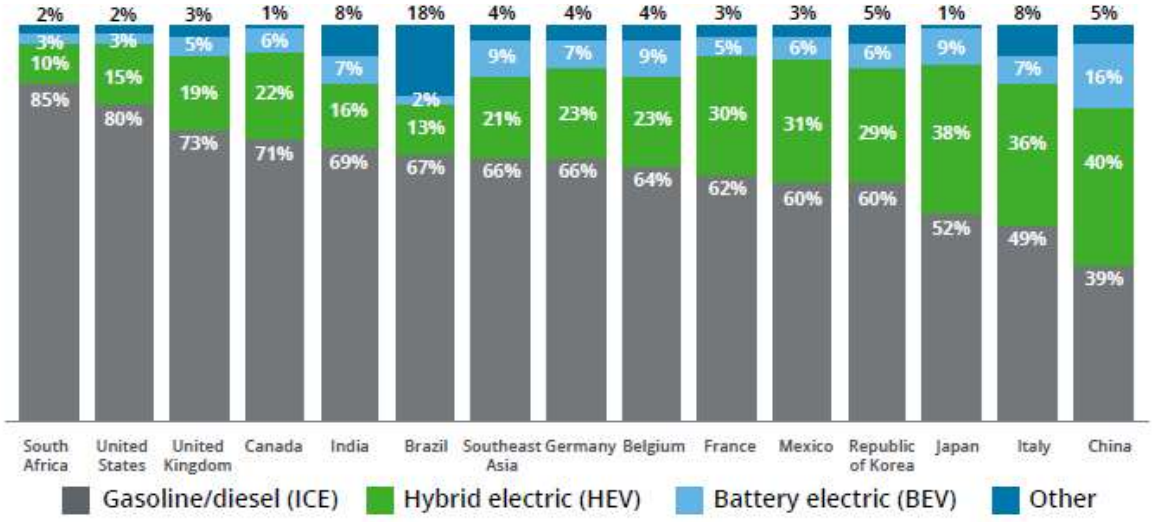
- BMW plans to offer 12 fully-electric vehicles by 2025 (Preisinger & Taylor, 2017).
- Daimler plans to sell 100,000 electrified vehicles by 2020.
- FCA is planning to offer half of all Maseratis as EVs by 2022.

[2] CAR bases its VMT by age schedule on data from available travel surveys. According to the most recent available data in the 2009 National Household Travel Survey, the average vehicle on the road has an annual mileage of approximately 11,200, while the newest vehicles travel 14,400 miles per year (Federal Highway Administration, n.d.).

- Ford is spending $11B and plans to offer 40 electrified vehicles by 2022 (White & Carey, 2018).
- GM will offer 20 all-electric models by 2023 (Welch, 2017).
- Honda announced two electric vehicles in 2017 and planned to have two-thirds of its lineup electrified by 2030 (Tajitsu, 2017).
- Mercedes is planning an electrified version of every model it sells.
- Renault-Nissan has sold nearly 500,000 Leafs globally—the highest volume of EVs of any automaker—and expects to have zero-emission vehicles make up 20 percent of its sales by 2020.
- Tesla is planning to build 500,000 all-electric Model 3s annually by 2020—which would be six times the total number of EVs sold in 2016.
- Toyota plans to offer all zero-emission vehicles by 2050.
- VW is investing $11.8B to roll-out 80 new electric models across all of its brands by 2025.
- Volvo announced it would only launch electrified vehicles after 2019.

Consumers' stated preferences for powertrain technology vary widely across global markets, and there are also vast differences between what consumers say they want and what they buy. Consumer interest in alternative powertrain technology is a critical first step to increased sales, but consumer surveys on future purchase intentions are often hard to interpret. Figure 5 shows results from a consumer "engine preference" survey for selected countries. The data suggest that globally, consumers have a solid interest in hybrid-electric (HEV) and battery-electric (BEV) vehicles. While 18 percent of U.S. respondents indicate a preference for HEVs and BEVs, European respondents express an even higher preference for the technology (30 percent in Germany, 25 percent in France). Chinese consumers top the list with a reported 56 percent preference for HEV and BEVs. The current market share of BEVs and HEVs is 3.3 percent in the United States (2017), 0.7 percent in Germany (2016), 1.5 percent in France (2016); and 1.4 percent in China (2016) (OICA, 2016). There is a disconnect between consumers' expressed intent and their actions.

Figure 5: Consumer Preference for Type of Next Vehicle (2018)



Note: 'Other' category includes ethanol, compressed natural gas, and hydrogen fuel cell.

Source: 2018 Deloitte global automotive consumer study

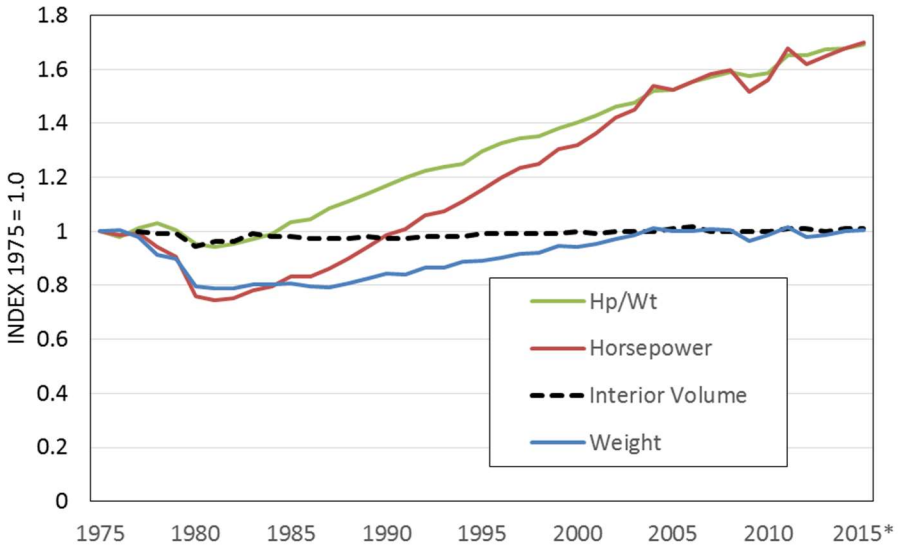
Another survey suggests a lack of consumer awareness is a barrier to increased EV sales. The share of car-owning households in California who have already considered buying a BEV, plug-in electric vehicle (PEV), or plug-in hybrid electric vehicle (PHEV) is no higher in 2017 than it was in 2014 (Kurani & Hardman, n.d.). Greater public awareness could help, but it is also essential that these vehicles meet *all* of the consumers' expectations. Even with the broader availability of BEV and PEV makes and models, most consumers continue to be unaware or uninterested in buying one. The reasons behind consumers' choices to not buy a BEV or PEV could include purchase price, technology limitations, or other performance challenges that current electrics may not be capable of meeting.

The U.S. market has long been unique amongst major global markets. Low, relatively stable, energy prices and higher levels of suburban driving have encouraged U.S. consumers to value different vehicle characteristics than do vehicle owners in many other markets. Current and upcoming global regulatory pressures, combined with technological advancements, may lead the composition of vehicles sold in the U.S. market to further deviate from much of the rest of the global automotive world.

The U.S. automotive market has shifted from passenger cars to body-on-frame based SUVs, and more recently toward unibody CUVs. Throughout these vehicle preference shifts, the U.S. consumer has shown a penchant for increased performance, and the industry has responded with ever more refined and powerful ICEs.

Figure 6 shows three often measured vehicle characteristics for the U.S. market: horsepower, weight, and interior space. Consumers define vehicle performance in many ways, but the relationship between horsepower and weight is a critical performance factor for many U.S. consumers. Material selection and vehicle size influence vehicle weight, and average vehicle weight steadily increased between the mid-1980'and 2005. Since 2005 vehicle weight has remained relatively stable, and over the same period, vehicle horsepower has risen steadily leading to a remarkable increase in the horsepower-to-weight ratio. The U.S. customer has shown an appreciation for performance as defined by horsepower. In many ways, the refinement of the ICE has been an enabler for satiating this demand.

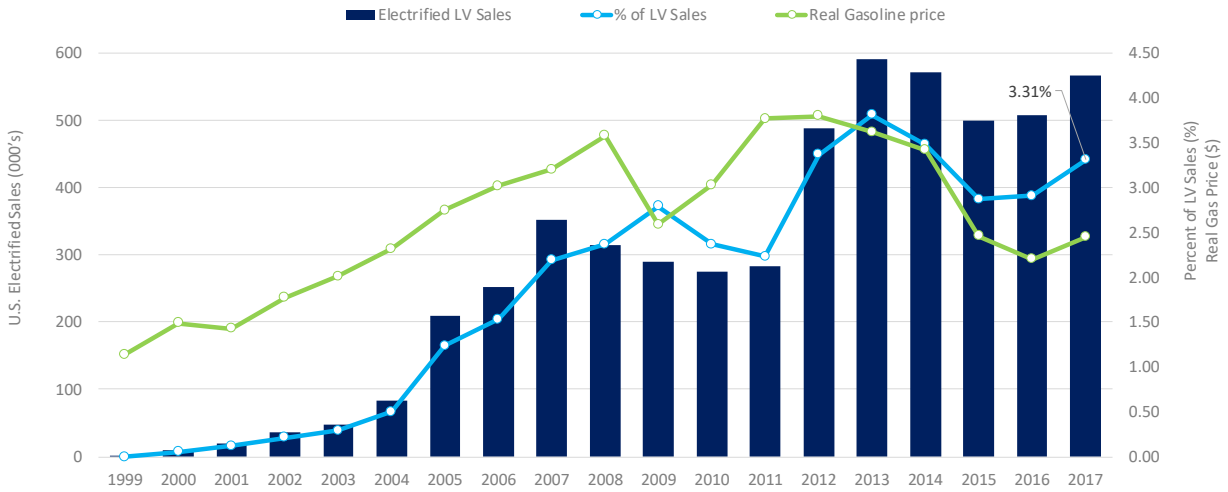
Figure 6: Selected Attributes of Passenger Cars: 1975-2015



Source: U.S. Environmental Protection Agency CO_2 and Fuel Economy Trends Report

In the United States, electrified vehicle (HEV, PEV, and BEV) sales and market share are highly correlated with gasoline prices. The vertical bars in Figure 7 represent annual electrified vehicle sales (on the left axis), the blue line represents electrified vehicle market share, and the green line represents the inflation-adjusted gasoline price (both lines on the right axis). In 2013, the U.S. market achieved record high electrified vehicle sales (nearly 600,000 vehicles or 3.8 percent of market share) during a period of relatively high gasoline prices. In 2017, after a three-year dip in sales and a concomitant drop in gasoline prices, electrified vehicle sales and gasoline prices rebounded, and the U.S. market share for electrified vehicles reached 3.3 percent.

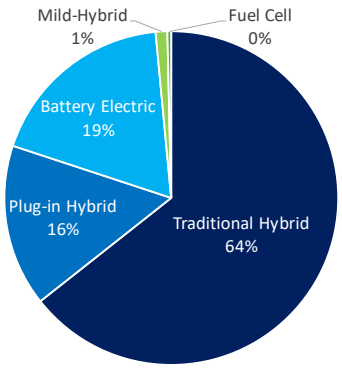
Figure 7: The U.S. Electrified Light Vehicle Sales and Take Rate 1999 – 2017



Source: Ward's Automotive Reports; Hybridcars.com; U.S. Energy Information Administration

Among the 567,000 electrified vehicles sold in 2017, near two-thirds were traditional HEVs such as the Toyota Prius and the Ford Fusion Hybrid, as shown in Figure 8. PHEVs such as the Chevrolet Volt and the Ford Fusion Energi accounted for only 16 percent of U.S. electric vehicle sales in 2017. BEVs such as the Chevrolet Bolt, the Tesla Model S, and the Nissan Leaf, accounted for 19 percent of the electrified vehicle market. In 2017, BEVs held 0.6 percent of total U.S. market share, PHEVs comprised 0.5 percent share, and traditional HEVs accounted for 2.1 percent of the overall U.S. light-vehicle market.

Figure 8: Market Share: Electrified Vehicles 2017: 1/3 of electrified vehicles are BEVs and PHEVs



Source: Hybridcars.com

Investment in Advance Powertrain Technology

In the last decade, governments have rapidly instituted stricter regulations to lower tailpipe carbon dioxide emissions and, in some cases, governments have mandated the implementation of specific vehicle technologies. With rare exceptions, U.S. consumer powertrain preferences tend to shift only in relation to the price of fuel.

Regulatory efforts to limit global climate change and improve energy security have driven the automotive industry to develop and produce ever more efficient vehicles. Automakers and suppliers have made significant investments in both research, development, and engineering to refine ICE powertrains further and develop viable alternative energy systems. To keep pace with future regulations, the auto industry will need to make even more investments in advanced powertrain research and development.

BEV and fuel cell vehicles (FCVs) may gain broader market acceptance at some point in the future, but for the coming decade, the ICE powertrain will likely remain dominant in the U.S. market. While powertrain development-specific investment data are not available for individual companies, many companies have announced their projected expenditures. According to Reuters, the automotive industry has announced investments to develop EVs totaling as much as $90 billion globally (Lienert, 2018). While these announcements may include both product and powertrain development, the spending represents a substantial investment in a technology that has not yet gained mass market acceptance.

Even without a precise estimate of automakers' powertrain expenditure, investments in production facilities can shed some light on the scale of the industry's spending. Since 2009, automakers have announced investments in North America exceeding $9.2 billion for the production of advanced, efficient, ICE powertrain systems. These investments are split evenly between high-speed transmissions (8+ gears and CVTs) and new, smaller engines (4 or fewer cylinders). Electrified vehicle technologies remain in development, and electrified vehicle sales levels have grown slowly, and therefore related capital outlays in North America have been relatively small, totaling just $9.8 billion between 2009 and 2017. The majority of this sum, $6.1 billion, has been to establish or expand manufacturing operations for electrified vehicles (HEV, PHEV, BEV, FCEV) and their components. North American battery production is limited in scale, and automakers often source this work to a supplier company. Automakers have directly invested less than $3.7 billion in battery production to date, with nearly $3 billion of this investment from one company (Center for Automotive Research, 2018).

Historically, automakers have built powertrain business cases over at least a ten-year time horizon, straddling two or more vehicle programs. The need to introduce new technology coupled with the substantial levels of capital investments required to design, engineer, test, and validate engine and transmission programs drives this long time horizon. In addition to the engine and transmission, automakers must invest in machining and assembly lines for drivetrain components and assemblies.

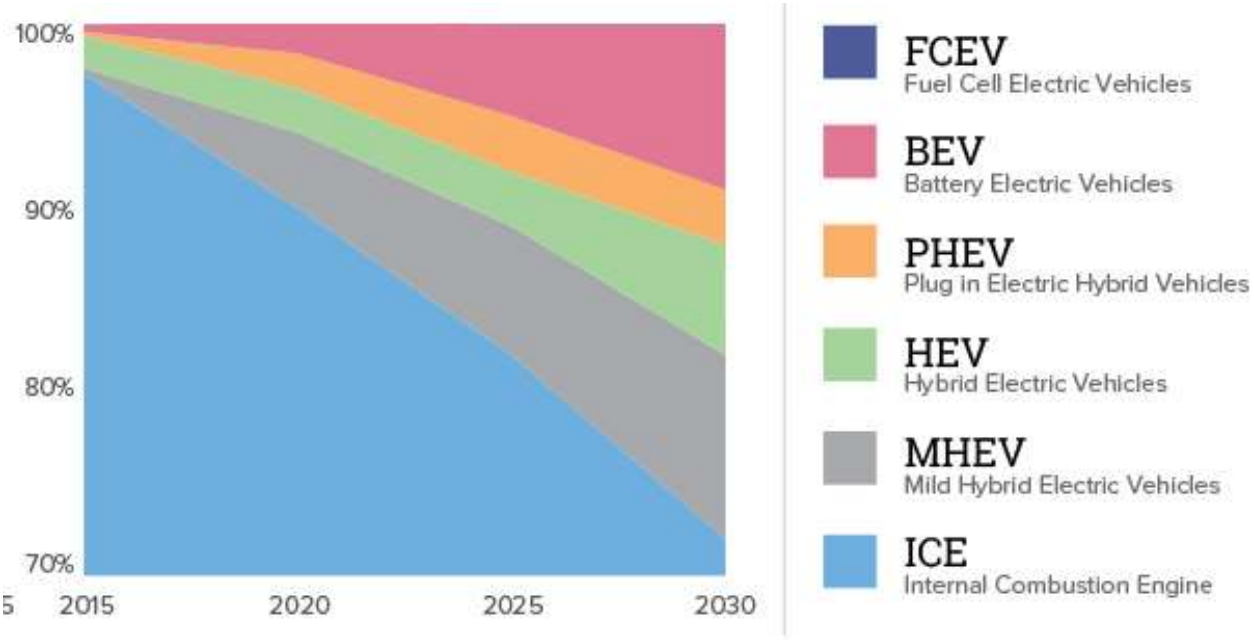
Vehicle programs, in turn, take on the cost of these powertrain programs as automakers allocate the spending over the total unit volumes, and incorporate the costs into the vehicle platform business cases. Auto manufacturers design and engineer engine and transmission families for use across as many vehicle platforms and nameplates as possible to spread the powertrain costs and market risks across as many units, market segments, and vehicle designs as possible. Companies that offer a variety of powertrain options per platform or nameplate increase the probability that their vehicles will be in demand month-to-month, quarter-to-quarter, and year-to-year through fuel price changes, competitor

new vehicle introductions, regulatory requirements, consumer lending availability, and other factors that drive market volatility.

Technology Readiness Roadmap

There is some consensus on the general direction of powertrain technological advancement in the coming decade; however, there remains a significant degree of uncertainty as to specific implementation timeframes. Light duty vehicle propulsion systems have rapidly progressed over the years due to several factors, but most importantly due to increasingly stringent global emissions and fuel economy regulations. Manufacturers are investing in a broad portfolio of different propulsion technologies for the next several years including advanced ICE, BEV, HEV, PHEV, and FCVs. For over a century, ICEs have been the primary propulsion for light-duty vehicles throughout the world. With additional advanced technology upgrades, ICEs will continue to dominate the market with approximately 80 percent market share, including 48-volt mild hybrids (MHEV), through 2030, as shown in Figure 9 (Smith, Spulber, Modi, & Fiorelli, 2017).

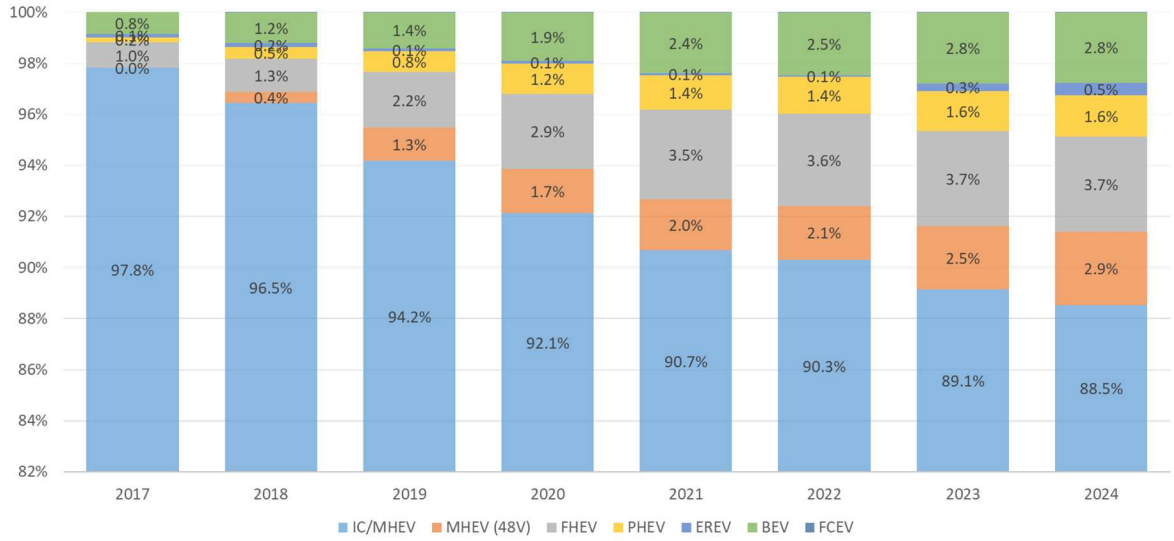
Figure 9: Global Powertrain Market Share 2015-2030



Source: Center for Automotive Research

North American production may lag this global market shift. Figure 10 shows the LMC Automotive forecast for a powertrain product mix of 91.4 percent ICE and MHEV share in 2025 (LMC Automotive, Q4 2017). The production forecast may be indicative of the difficulty of selling advanced electrified powertrains in the U.S. market.

Figure 10: North American Powertrain Production Share 2017-2024



Source: LMC Automotive

Global vehicle manufacturers are committed to developing electrified vehicle technology, and their recent announcements are a strong indication that vehicle electrification is nearing a tipping point. The Chinese government's commitment to creating an electric vehicle market will be critical to automakers, as China is now the largest new vehicle market both regarding units sold and total market value. China also has the policy tools to shape market acceptance, thus creating markets for the technology.

Regulations may drive propulsion technology implementation, but the consumer determines the market success of these technologies. Consumers tend to be cautious when presented with new technologies. Therefore automakers need to address their concerns about safety, reliability, and high costs. The ICE, even with additional technology and content, remains a formidable cost, performance, and utility target to beat—especially in low-cost energy regions.

Development of advanced batteries for tractive power is a critical enabler for the successful adoption of PEVs. Lithium-ion is the current technology for electrified vehicles, and the cost of lithium-ion batteries has been decreasing rapidly for over a decade. Cost-per-kilowatt-hour estimates for lithium-ion batteries vary but are thought to be approximately $200/kW currently. Lithium-ion battery costs could be below $100/kW by 2025 (Smith, Spulber, Modi, & Fiorelli, 2017). Such cost reductions would make BEVs much more purchase-price competitive with ICE vehicles.

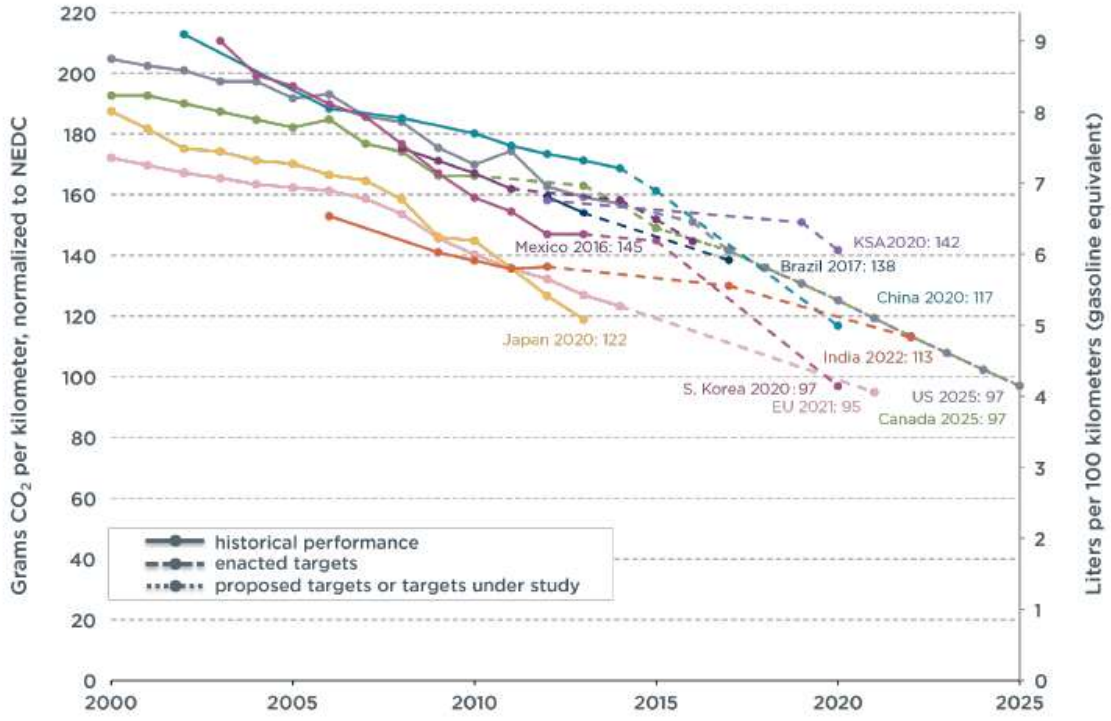
Emissions and Fuel Economy Regulatory Climate

Vehicle emissions and fuel economy regulation are frequently done on a national level but often have global environmental and industrial implications. There are many reasons governments may regulate emissions and fuel economy, but the reduction of CO_2 and local pollutants is usually a primary goal. While emissions regulation in certain markets can drive technology development, the consumer may or may not immediately embrace the new technology. These policies can potentially create a position of industrial leadership in those markets that mandate specific technology use, such as China.

For decades, governments have relied mainly on laws of such as the U.S. Corporate Average Fuel Economy (CAFE) standards or Europe's New European Drive Cycle (NEDC) to regulate motor vehicle

emissions. The International Coalition for Clean Transportation has tracked these past, current, and future standards, as shown in Figure 11. While there are some differences in the slope, globally, these standards are rapidly becoming more restrictive, which will lead to lower emissions and reduced fuel consumption.

Figure 11: ICCT Passenger Car CO_2 Emissions and Fuel Consumption, Normalized NEDC



Source: International Coalition for Clean Transportation

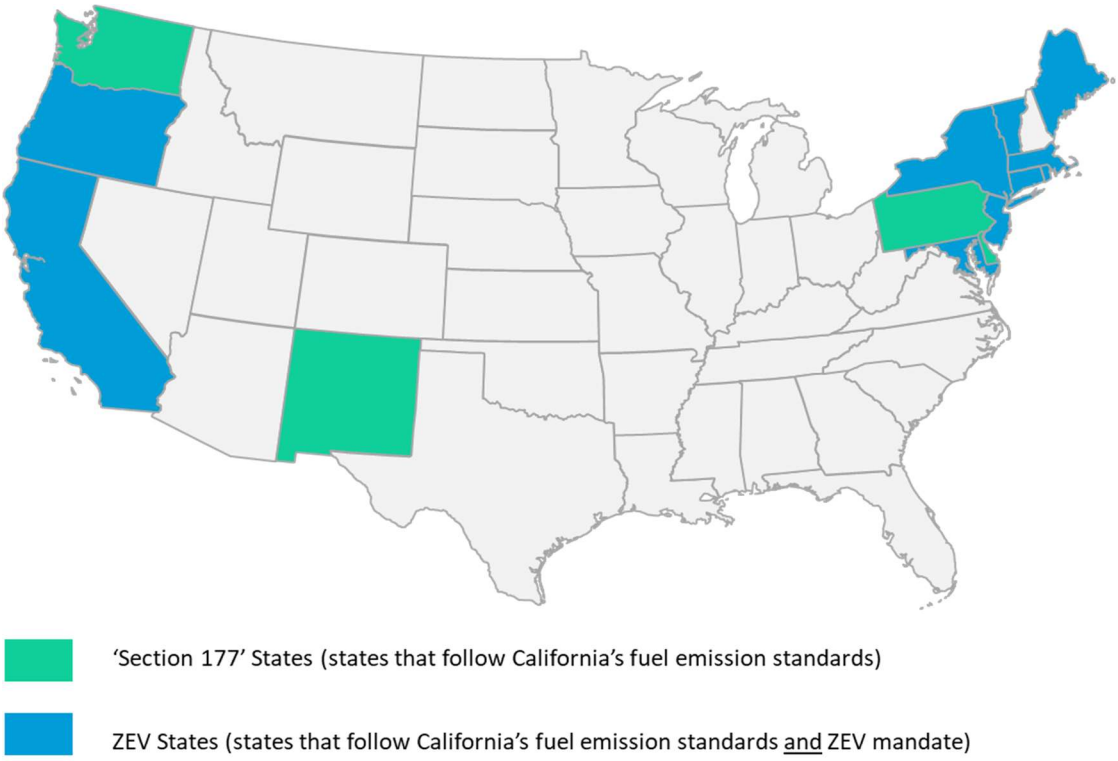
Regulators in the United States are currently reviewing future CAFE and CO_2 standards. Their decisions will have significant implications for the U.S. market, and likely also the technological competitiveness of the U.S automotive industry. Early indications are that NHTSA may reduce the stringency of regulation starting in 2021 (Lippert & Beene, 2018).

As noted earlier, a majority of U.S. consumers seem to place a higher importance on attributes other than fuel efficiency in their new vehicle purchase decision. The most fuel-efficient vehicles available enjoy considerable subsidies from governmental entities and direct from manufacturers. Subsidization from manufacturers comes in two forms: purchase or lease incentives and base pricing which does not reflect fixed costs. An example of the latter is when FCA CEO Sergio Marchionne famously revealed that the Fiat 500e sold at a $14,000 loss per unit (Marchionne, 2014). Additionally, consumers do not weigh vehicle attributes for only the new purchase – they select a vehicle attribute portfolio across all of the vehicles within their household, as is documented in a wide range of studies including recent research sponsored by the California Air Resources Board (Rapson, Gillingham, & Knittel, 2017).

A reduction in fuel economy standards will likely offer many consumers continued opportunity to purchase vehicles with the attributes they most desire. It may also encourage manufacturers from around the world to continue to partake in what is a highly competitive, but also very profitable U.S. market. However, it will create a fragmented U.S. market; state regulators in California and the other 14

Section 177 states will continue to regulate CO_2 and mandate zero emissions vehicles (ZEVs) regardless of the direction national regulation (see Figure 12).

Figure 12: States that have adopted California Emissions Regulations



Source: Center for Automotive Research

Government regulators across the globe are increasingly shifting toward regulating a technology-based solution. Vehicle electrification, long the domain of the California Air Resource Board (CARB), has become a favored technology for many government regulators throughout the world. Many countries and even cities have taken actions develop zero-emission vehicle mandates, with a specific interest in BEV technology. Countries including China, France, Germany, Great Britain, India, Norway have announced plans to phase out gasoline and diesel-powered engines. Also, Austria, Denmark, Ireland, Japan, the Netherlands, Portugal, Korea and Spain have set government targets for EV sales (Petroff, 2017). Several cities are also looking to move to limit or ban ICE-powered vehicles, including Paris, London, and Copenhagen.

Norway has been famously aggressive in its commitment to PEV technology; the country has implemented a "green" tax system for vehicles, where the government taxes vehicles sold according to their emissions. The Norwegian strategy has been effective; in 2017, PEVs accounted for 39.2 percent (20.8 percent for BEV and 18.4 percent PHEV) of new vehicle sales in the country (NPRA, 2017). Norway has supported this effort with a set of broad financial incentives, and the development of charging infrastructure (Lorentzen, Haugneland, Bu, & Hauge, 2017) (Milne, 2017). Norway's monetary incentives are the equivalent of 45 percent of the total price for a midsize EV. At the end of 2017, Norway had more than 10,330 charging stations, and, over 2,000 of those were high powered (European Alternative

Fuels Observatory, 2017). While this strategy has gained much acclaim, it may not serve as a model for countries with larger vehicle markets due to its high costs.

Although Norwegian regulatory activities have helped the country achieve the highest penetration of PEVs, China's New Energy Vehicle (NEV) credit system may be more important for global automakers. Modeled after California's ZEV mandates, China has put in place the foundation to what might be a viable market for electric vehicles. China's strategy is a partial response to local, and maybe even global, emissions concerns. However, the opportunity to become the global leader in the development and manufacture of EVs and components also drives the country's regulatory approach to create an electric vehicle market.

Section IV: Innovative Mobility Services and Connected and Automated Vehicles

Advances in connectivity, automation, and new mobility services are potent agents of change affecting the automotive industry, the broader transportation sector, and beyond.

The growth of innovative mobility services (IMS) around the world and in the United States has many implications for the automotive industry, and these impacts will become even more significant after the deployment of automated vehicles (AVs). Increased use of IMS (including those that will use AVs) could reduce car ownership for people that do not use a private vehicle as their primary mode of transportation, and instead use public transit, bike or walk. The shift towards IMS and away from the private vehicle may cause some losses in sales of new and used vehicles. However, higher vehicle turnover and a shorter life expectancy of vehicles used by mobility services will offset some of those losses.

The most important impact that innovative mobility services (IMS), driving automation, and vehicle connectivity will have on the automotive industry will be on how customers interact with vehicles, their expectations for vehicles, and their uses of these vehicles. Mobility, connectivity, and automation will change the way people use, value, and relate to personal vehicles. They will alter people's expectations about vehicles, and that may be more important in the long term than the net loss in vehicle sales. IMS will likely contribute to a change in preferences away from vehicle ownership and towards "vehicle usership," exploring new business models that do not involve the user owning a vehicle and having all the inconveniences and costs associated with that ownership (Spulber, Dennis, Wallace, & Schultz, 2016).

Innovative Mobility Services Market and Consumers

The origin of IMS can be placed roughly in the 1990s, though substantial growth occurred in the 2010s when the number of different concepts (or business models) and companies increased. IMS are growing in areas with specific characteristics, and many of their first adopters share a set of distinctive demographic traits.

Overall, consumer attitudes toward IMS are improving. However, fewer Americans consider ridehailing and carsharing an alternative to the personal vehicle (56 percent and 47 percent, respectively) than they do buses (58 percent) and subways (86 percent). In 2016, 35 percent of U.S. residents reported having used ridehailing, and 8 percent of Americans had used carsharing in the past year (Abraham, et al., 2016). It is important to place these low usage shares in context; these services are still relatively recent

developments and have limited geographic availability. The first ridehailing service, Uber, launched in 2009, and small carsharing programs started appearing in the 1990s.

Overall, IMS are available in denser and walkable urban areas that also have good public transportation networks. Few people use IMS as a sole means of transportation, but instead, riders use these services in combination with other modes, especially public transit. IMS are occasionally used in areas with little or no public transit, and in these areas, IMS might serve specific purposes, such as travel to or from an airport. In areas with sparse public transit coverage, a personal vehicle remains the dominant mode of transportation, thereby limiting the demand for hailing an Uber or renting a Zipcar, for example (Spulber, Dennis, Wallace, & Schultz, 2016).

Table 2: Guidelines for Where Carsharing Succeed

Demographics	
One-person households	minimum 30%
Work Commute Mode	
Drive alone	maximum 55%
Walk	minimum 5%
Vehicle Ownership	
Households with 0 vehicle	10% - 15%
Households with 0 or 1 vehicle	60% or more
Neighborhood Characteristics	
Housing units per acre	5 or more

Source: (Millard-Ball, Murray, Ter Schure, Fox, & Burkhardt, 2005)

Carsharing works in areas with dense housing units, a number of single-person households, where vehicle ownership is low, and people either drive to work alone or walk, as shown in Table 2. Likewise, IMS users are mostly urban dwellers and have higher income and educational attainment levels than average (83 percent of carsharing members hold at least a Bachelor's degree) (Millard-Ball, Murray, Ter Schure, Fox, & Burkhardt, 2005). They are also less likely to own a vehicle and rely more heavily on public transportation, especially for the work commute. The average IMS users own 1.05 cars per household (Shared-Use Mobility Center, 2016), compared to the national average of 2.06 (Federal Highway Administration, 2013). For instance, the target demographic for carsharing programs are younger than average, with a median age of 35 years (Millard-Ball, Murray, Ter Schure, Fox, & Burkhardt, 2005). College students and faculty frequently rely on IMS.

Connected and Automated Vehicles Market and Consumers

Consumer attitudes concerning AVs have been evolving rapidly in the past few years. One survey compared consumers' trust that fully automated vehicles would be safe and found that in 2017, 53 percent of U.S. residents deemed self-driving cars safe, up from 26 percent in 2017 (Giffi, Vitale, Schiller, & Robinson, 2018). Another survey from 2017 found that only 44 percent of Americans would want to ride in a self-driving vehicle (Smith & Anderson, 2017).

While a growing number of drivers have experienced ADAS features and SAE Driving Automation Levels 1 or 2, vehicles with Levels 3 to 5 are not yet available to the general public beyond a few limited pilot projects (Waymo, Uber, Navya, among others). It is therefore still a challenge to measure attitudes to products that consumers have not yet experienced. Nevertheless, a growing number of surveys on attitudes toward AVs reveal a generation divide. Table 3 shows that younger adults are more comfortable with the idea of automated driving compared to older adults. According to one survey from 2016, 40 percent of respondents aged 25 to 34 are comfortable with full autonomy—significantly more than any other age category. On the other hand, older adults over 45 years old were more comfortable with ADAS features such as collision avoidance and lane keeping (Abraham, et al., 2016).

Table 3: Age Differences in Willingness to Use Automation in Vehicles – Maximum Level of Automation With Which Respondents Would Be Comfortable

	Age						
Level of Automation	**16-24**	**25-34**	**35-44**	**45-54**	**55-64**	**65-74**	**75+**
No Automation	12.4%	8.0%	9.7%	6.1%	5.0%	3.8%	3.1%
Emergency Only	18.3%	11.3%	15.7%	16.0%	14.7%	12.2%	16.7%
Help Driver	26.7%	25.4%	21.1%	41.2%	44.4%	56.0%	52.2%
Partial Automation	16.3%	15.3%	19.0%	13.2%	17.0%	13.9%	15.4%
Full Automation	26.2%	40.0%	34.4%	23.4%	18.9%	14.2%	12.7%
Source: (Abraham, et al., 2016)							

Acquisitions and Investments

The growth of IMS and the development of CAV technologies are prompting vehicle manufacturers to rethink their existing business models and explore new approaches to the market. The mainstreaming of IMS is more of an opportunity than a threat for automakers. As transportation preferences slowly evolve, the automotive industry is trying to show customers that it understands the shift toward on-demand shared mobility and that it has relevant new products and services to offer. Some of the opportunities for the automotive industry include:

- Partnerships with new mobility and technology firms
- Investments and venture capital in mobility startups
- R&D and experiments on mobility solutions
- In-house mobility services
- Fleet sales to mobility providers
- New vehicle financing models

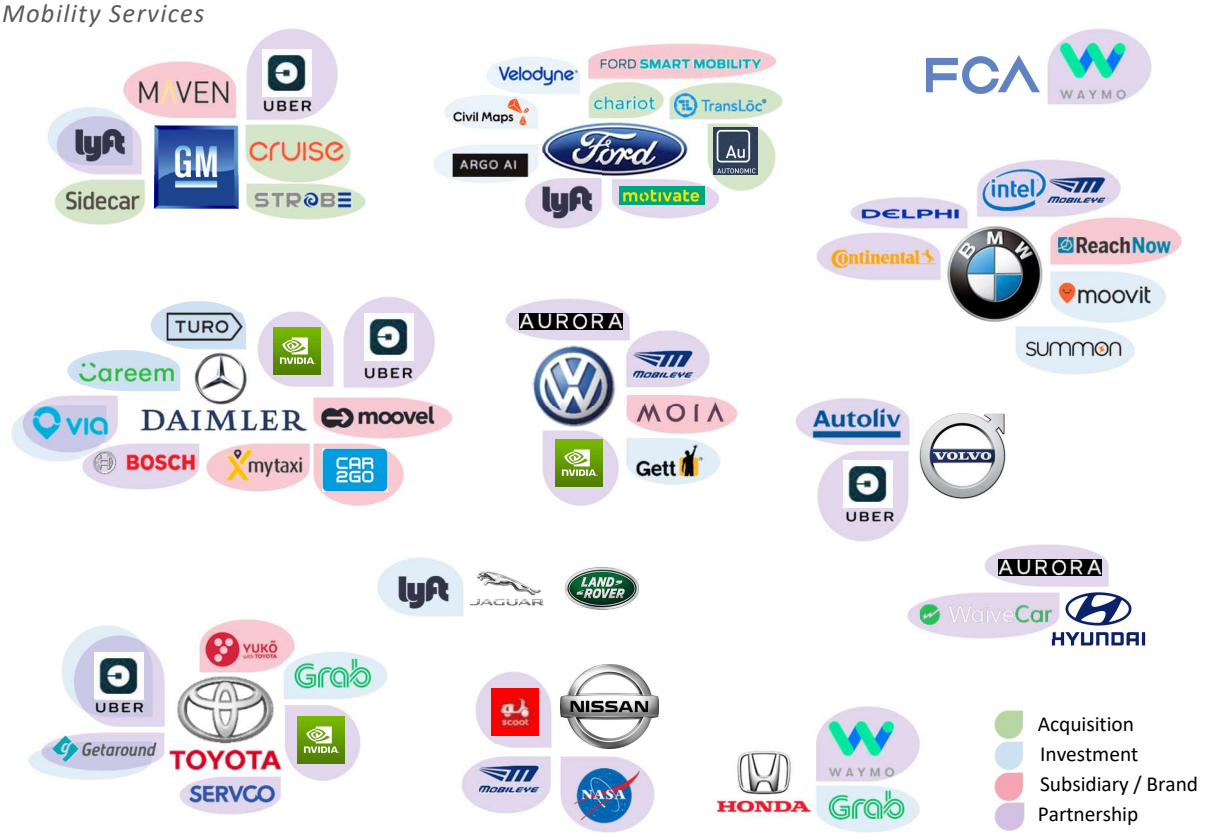
Beyond presenting a challenge to the vehicle ownership mode, the expansion of IMS could influence other aspects of the automotive industry and related sectors such as the automotive value chain, supply chain, logistics, automotive insurance, and vehicle maintenance and repair.

The success of IMS is encouraging automakers to create mobility services of their own, and those can become new revenue sources. Vehicle manufacturers such as Ford and Volkswagen have announced their intention to become mobility companies that offer different services alongside their established core business of manufacturing vehicles. On-demand mobility services are a way to generate ongoing income and to engage more with customers more frequently than just through a vehicle sale or lease every few years.

In the past several years, automakers have started investing in, partnering with, and acquiring mobility and tech companies, as well as creating mobility subsidiaries (see Figure 13). Building customer relationships through IMS is an opportunity for vehicle manufacturers to diversify their activities and to strengthen their market share in urban areas and with the younger generations. Partnerships with IMS companies give automakers increased visibility to mobility users (who might one day become car buyers), as well as access to valuable consumer data and analysis. Innovative mobility companies also have an interest in these deals that come with access to auto industry engineers or discounts on vehicles.

Tech companies and startups are disrupting traditional supply chains by developing software, chipsets, and sensors for connected and automated vehicles. In turn, many automakers are developing driving automation technologies in-house to assure their companies remain relevant and profitable in a future in which software, data, and connectivity are more valuable than the mechanical elements of a vehicle. However, investing or acquiring startups that are developing CAV technologies is another primary way in which established automotive companies can advance in the race to developing self-driving cars.

Figure 13: Automakers' Partnerships Related to Connected and Automated Vehicles and Innovative Mobility Services



Source: Center for Automotive Research

Noteworthy Investments and Acquisitions

1. December 2015 – Audi, BMW, and Mercedes acquired mapping company Here for $2.8 billion (Krauskopf, 2018). Intel announced the purchase of a 15 percent stake in the company in January 2017 and in January 2018 Bosch and Continental announced the acquisition of 5 percent of Here each (Krok, 2018).
2. January 2016 – General Motors paid $500 million for a minority stake (9 percent) and a board position in ridehailing company Lyft (Trousdale, 2016).
3. March 2016 - General Motors acquired automated driving startup Cruise Automation for $581 million (DeBord, 2016). In April 2017, GM announced plans to invest $14 million in Cruise, adding an estimated 1,100 full-time employees by 2021 (Wayland, 2017).
4. May 2016 - Volkswagen invested $300 million in ridehailing company Gett (Lunden, VW invests $300M in Uber rival Gett in new ride-sharing partnership, 2016).
5. May 2016 - Toyota has invested an undisclosed amount in ridehailing firm Uber (Buhr, Uber and Toyota confirm strategic investment and auto leasing deal, 2016). In August 2017, Toyota also invested in Uber rival Grab (Meyer, 2017).
6. August 2016 - Uber acquired Otto, a truck automation company for $680 million (Buhiyan, 2016).
7. February 2017 - Ford Motor announced it would invest $1 billion over the next five years in Argo AI, an artificial intelligence start-up focused on developing autonomous vehicle technology (Ford Motor Company, 2017). Ford did not acquire Argo AI, but is the majority stakeholder and has two seats on a five-seat board (Korosec K. , An inside look at Ford's $1 billion bet on Argo AI, 2017). Since September 2016, Ford Smart Mobility LLC, Ford's mobility subsidiary, acquired Chariot, TransLoc, and Autonomic, and invested in Velodyne, SAIPS, Nirenburg Neuroscience, Civil Maps, and Swiftly (Ford Motor Company, 2018).
8. March 2017 - Intel acquired Mobileye, an Israeli company that makes sensors and cameras for driverless vehicles for $15.3 billion, making it one of the most significant CAV acquisitions so far (Lunden, Intel buys Mobileye in $15.3B deal, moves its automotive unit to Israel, 2017).
9. April 2017 - Delphi made minority investments in Otonomo and Valens, two Israel-based connected vehicle companies (Irwin, 2017).
10. June 2017 - Bosch announced it would build a $1.1 billion semiconductor plant in Germany, the largest single investment in the company's history (Behrmann, 2017).
11. October 2017 - GM announced it would acquire lidar company Strobe (Vogt, 2017).
12. October 2017 - Delphi acquired startup NuTonomy for $400 million (Burns, 2017).
13. December 2017 - Denso invested an undisclosed amount in Ridecell, a leading platform for carsharing and ridesharing operators (Denso, 2017).

Noteworthy Partnerships

1. Alliance led by BMW includes Intel, Mobileye, Delphi, Continental and FCA (Reuters, 2017).
2. Lyft's Open Self-Driving Platform includes GM, Ford, NuTonomy, JLR (Newcomer, Lyft Enlists Ford to Help Get Self-Driving Cars on the Road, 2017).
3. Waymo has partnerships with Lyft since May 2017 (Isaac, 2017) , FCA since May 2016 (Burke, 2018), Honda since December 2017 (Byford, 2017).
4. Uber has partnerships with Volvo since August 2016 (Volvo, 2016), Daimler since January 2017 (Newcomer, Uber, Daimler Strike Partnership for Self-Driving Vehicles, 2017) , and Toyota since May 2016 (Buhr, Uber and Toyota confirm strategic investment and auto leasing deal, 2016).
5. Aurora (Chris Urmson's new automated driving startup) has partnerships with Moia (Volkswagen's mobility subsidiary) and Hyundai since January 2018 (Korosec K. , Meet Aurora, the Ambitious (and Spunky) Self-Driving Car Startup, 2018).
6. Delphi and Quanergy since October 2015 (Delphi, Quanergy team up on low-cost lidar, 2015).
7. Daimler – Bosch since April 2017 (Taylor, 2017).
8. Volvo – Autoliv since September 2016 (Volvo, 2016).
9. Nvidia has partnerships with many automakers including Toyota, Audi, Tesla, Daimler, Toyota, and Volvo (Hawkins, 2017).

Technology Readiness

Vehicle automation, connectivity, and mobility encompass trends in technology and business models that have been in motion for decades, but these technologies and strategies have accelerated in the past five to ten years. Between 2000 and 2010, automakers and suppliers introduced numerous ADAS that warn, aid, and assist drivers. Automakers mainly installed these automated and safety systems on higher-end vehicles where consumers could pay for the additional features. ADAS features will be increasingly standard across the new vehicle fleet in the coming decades. Some features may be mandated or included in safety-rating systems, such as the EU's New Car Assessment Program (NCAP). Customers have demanded some automated vehicle systems such as automated park assist, adaptive cruise control, and automated emergency braking, and these systems are now available on an increasing number of new vehicles.

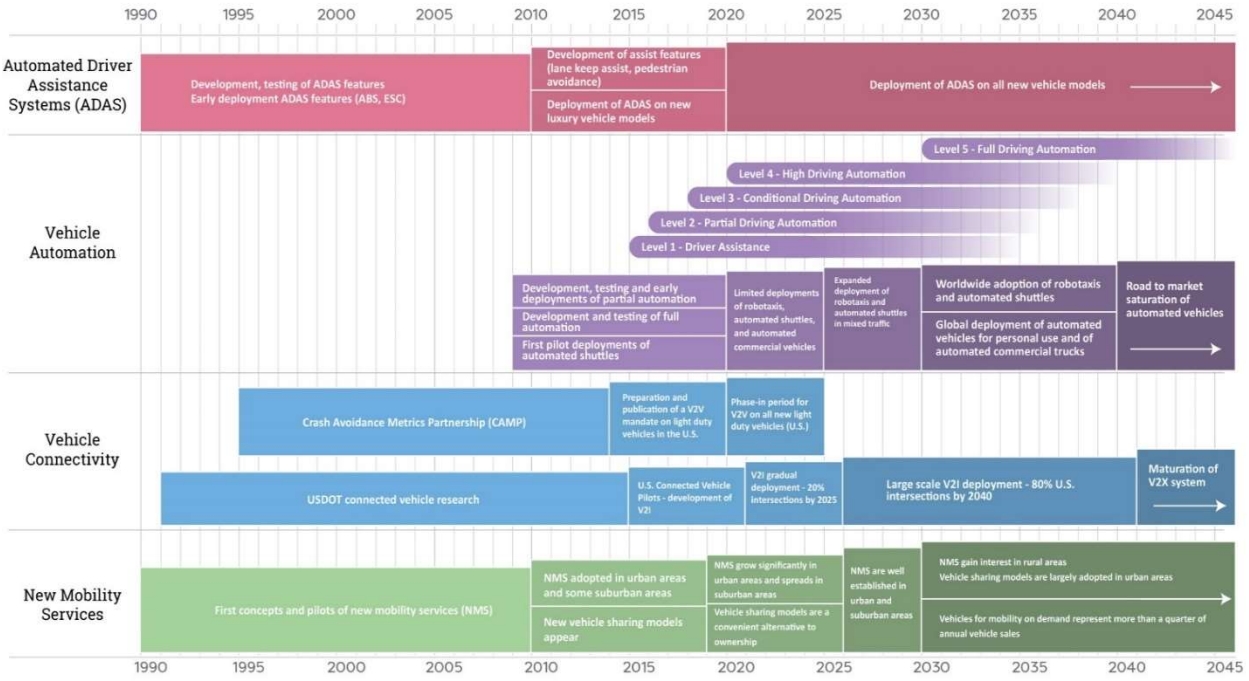
Automotive manufacturers, suppliers, and tech companies are in a race to develop and test automated driving and connectivity technologies. Increasingly, these companies are testing their self-driving prototypes in a variety of urban and suburban environments and weather conditions, even opening their pilots to the general public as Waymo and Uber have done.

Testing Automated Vehicles on Public Roads

1. Waymo – currently in Mountain View, CA (since 2009), Austin, TX (since July 2015), Phoenix, AZ (since April 2016), and Kirkland, WA (since February 2016)
2. Uber – Pittsburgh, PA (since September 2016) and Tempe, AZ (since February 2017)
3. General Motors/ Cruise – San Francisco, CA (since May 2016), Scottsdale, AZ (since August 2016), and metro Detroit, MI (since 2016)
4. Ford – metro Detroit, MI (since November 2015), California (since December 2015), and Arizona (Since 2016)
5. Apple – California (since April 2017)
6. Lyft/NuTonomy – Boston, MA (since December 2017)

Most automakers and tech companies agree they will first launch AVs in the form of low-speed automated shuttles. Pilot tests for such automated shuttles and taxis are already in progress. For example, in November 2017, Waymo took its Early Rider Program to the next level by beginning to give people in the Phoenix area rides in their driverless taxis without a human test driver (Korosec K. , 2017). In January 2018, Uber CEO Dara Khosrowshahi said his company would use AVs as part of their services within the next 18 months (Etherington, Uber CEO hopes to have self-driving cars in service in 18 months, 2018). The same month, General Motors asked NHTSA for an exemption on 16 FMVSS to deploy vehicles without steering wheels or brake pedals in a ridehailing program expected to be in place by 2019 (Bhuiyan, 2018). In June 2017, Lyft set the target of providing at minimum 1 billion rides per year via electric AVs by 2025 (Etherington, Lyft sets goal of 1 billion autonomous electric rides per year by 2025, 2017). While driverless taxi services (SAE Level 4) will be available in select urban areas as soon as 2020, AVs for personal use will be available in 2030 or later. Fully AVs (SAE Level 5)—capable of operating anywhere and in all situations—are also expected to be available after 2030, although there are still considerable uncertainties related to full driving autonomy (see Figure 14) (Smith, Spulber, Modi, & Fiorelli, 2017).

Figure 14: Roadmap for CAV Technology and Innovative Mobility Services Deployment



Source: Center for Automotive Research

In recent years, the industry has made considerable progress in developing and testing vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication equipment and applications. Connectivity will play an increasing role in the auto and mobility sectors in the coming years, but it is less clear what specific communication technologies will be most pertinent and prevalent. While the U.S. mandate for V2V-capability on light-duty vehicles that the federal government initially proposed in December 2016 has moved to the long-term regulatory agenda, large-scale Dedicated Short-Range Communication (DSRC) investments seem unlikely now. On the other hand, progress on the development of 5G seems steady, with the launches of first 5G mobile networks expected around 2020. These 5G networks will enable a variety of commercial- and convenience-oriented applications, but it remains an open question whether or not 5G can support cooperative active safety.

Finally, IMS are expected to diversify and grow significantly in cities and to spread beyond urban areas in the 2020s and 2030s, benefitting from the convergence with vehicle automation (see Figure 14). In the 2020s, sharing models will become a convenient alternative to vehicle ownership for an increasing share of the world's population. After 2030, cities will see large-scale adoption of vehicle-sharing models and rural areas will begin to see viable IMS models.

Legal and Regulatory Framework of Connected and Automated Vehicles

As the technology for CAVs continues to develop, federal and state governments have begun to address the implications of the deployment of CAVs with new legislation and regulations. Each year, the number of states considering and passing legislation related to CAVs has gradually increased. In 2012, six states introduced legislation, in 2013 there were 9 plus the District of Columbia, in 2014 there were 12, in 2015 there were 16, in 2016 there were 20, and in 2017 there were 33 states considering such legislation.

Nevada was the very first state to pass a CAV law in 2011. At the end of 2017, 26 states plus the District of Columbia had formally addressed CAVs in some way.

The regulatory approaches to CAVs can vary widely, causing many to be concerned about an emerging 'regulatory patchwork' that will prevent efficient deployment. Despite the variation, there are several trends in the enacted state laws or executive orders as shown in Table 4. First, many states have introduced definitions of driving into their vehicle code, which is an important initial step. Secondly, states are regulating testing, deployment, or both. Thirdly, addressing liability is a common regulatory concern. Although these liability provisions often merely restate existing law, some have required additional insurance for CAVs. Fourthly, requesting a study or convening a committee is a popular state response and, in some cases, these steps are the only measure states had passed so far. Finally, many states have instituted some preemptive restriction on local control and ordinances.

Table 4: Items Addressed in State Automated Vehicle Legislation and Executive Orders

	Introduce Definitions	Regulate Testing	Regulate Deployment	Address Liability	Call for Study	Permit Platooning	Local Preemption
Alabama					X		
Arizona*		X			X		
Arkansas						X	
California	X	X	X	X			
Colorado	X			X	X		X
Connecticut	X	X		X	X		X
Delaware*					X		
Florida	X	X		X			
Georgia	X		X	X		X	X
Illinois	X						X
Louisiana	X						
Michigan	X	X	X	X	X	X	X
Nevada	X	X	X	X			
New York	X	X			X		
North Carolina	X		X		X	X	X
North Dakota					X		
Pennsylvania							
South Carolina						X	
Tennessee	X		X	X		X	X
Texas	X		X	X		X	X
Utah	X				X	X	
Virginia							
Vermont						X	
Washington*		X			X		
Washington DC	X		X	X			
Wisconsin*					X		

* Executive Order

Source: Information gathered on the National Conference of State Legislatures online Autonomous Vehicles Legislative Database *http://www.ncsl.org/research/transportation/autonomous-vehicles-legislative-database.aspx*

At the federal level, the most meaningful evolution is the House of Representatives passage of the SELF Drive Act (H.R. 3388) on September 6, 2017. The bill aims to expand federal preemption of state legislation on vehicle design, construction, and performance. The states would retain their powers to register and license vehicles and drivers, and regulate motor vehicle dealers that sell highly automated vehicles (SAE driving automation levels 3 to 5). The bill also expands the number of vehicles allowed an exemption from FMVSS to 25,000 in year one, up to 100,000 in year three and four of production. Finally, the bill establishes a new timeline for NHTSA developing rules and standards for highly automated vehicles. The Senate Commerce, Science, and Transportation Committee sent a similar bill called AV START Act (S. 1885) to the Senate floor on September 28, 2017. The bill was amended and reported to the full Senate on November 28, 2017, and has yet to be discussed by the full Senate.

On September 12, 2017, NHTSA released the second version of its federal guidance for Automated Driving Systems (ADS), A Vision for Safety 2.0. The new guidance focuses on SAE driving automation levels 3-5, revises elements of the safety self-assessment, and clarifies the role of federal and state governments. The 2017 document reinforces the voluntary nature of the guidelines and does not contain a compliance requirement or enforcement mechanism.

In Europe, there is also a two-tiered effort to provide a legal framework for CAVs—both at the national and European Union level. The approach of European countries, such as Germany that passed a law in May 2017 is more cautious than the U.S. stance. Germany's new law allows the operation of automated vehicles on public roads as long as a driver is sitting behind the wheel at all times ready to take back control if prompted to do so by the AV.

China is gradually opening up its roads to self-driving cars. The government announced in December 2017 that companies registered in China would be able to obtain temporary approval to test AVs on certain roads and under certain conditions. This action comes after in 2016 Chinese authorities banned self-driving vehicles from the country's highways pending new regulations that have yet to be released. Similarly, Japanese authorities began to allow testing of CAVs on public roads only in May 2017. Previously, Japanese regulatory action in 2016 only allowed testing of CAVs on public roads with a person in the driver's seat.

Infrastructure

Innovative mobility services have already impacted cities in transformational ways and CAVs will contribute to substantial changes in urban, suburban, and rural areas. These new services and technologies will transform how people move, and where they work and live. There will be significant changes in travel patterns, land use decisions, and environmental sustainability in the coming decades, and public agencies and planners will need to plan for and adapt quickly to many of these changes.

Human-driven vehicles will share the road network with CAVs for decades as the transportation system is in transition. In the long term, widespread CAV adoption, and to a lesser extent IMS, may render some infrastructure projects currently in the pipeline obsolete, such as roadway capacity expansion, corridor upgrades, or new roadways. Conversely, IMS and CAV adoption may increase the need for ITS and other infrastructure deployments, traffic signal updates, bicycle and pedestrian improvements, and transit investments.

Increasingly, municipalities are considering whether to give access to IMS with high-occupancy in transit-only lanes or to allocate specific parking or bike docking space. In the medium- to long-term, communities can convert some on-street parking, turn lanes, or service roads into loading zones for

ridehailing and CAVs, or designate waiting areas near office buildings, commercial areas, cultural and sports venues, and apartment buildings. In the long term, cities and regions also need to decide whether CAVs should get exclusive or privileged access to the roadway (e.g., dedicated highways, dedicated lanes, access to transit lanes or HOV lanes, and signal priority). Nevertheless, allocation of public right-of-way to specific modes or operators can be controversial. For example, CAV-only lanes could raise debates about fairness and cost efficiency.

To date, road infrastructure has been designed to suit the needs of human drivers, but CAV proliferation may make human drivers less of a consideration in the future. Thus, wide-scale deployment of computer-driven vehicles might require changes to road markings, signage and signalization, lane width, and access management. The timing and nature of these modifications will depend on the level of adoption of self-driving cars, and these CAVs will co-exist on the road with conventional vehicles for many decades to come.

Companies are developing AV technologies able to function reliably on today's roads, even with their imperfections and specificities. Nevertheless, maintaining and improving road infrastructure (lane markings, signs, and work zone signage in particular), could speed up CAV deployment and especially increase the reliability and safe operation of AVs. More infrastructure investment is needed to enable vehicle connectivity—V2I communication in particular. The implementation of these infrastructure changes will be voluntary, and will take place over the next few decades. The infrastructure needed to support DSRC-based V2I communication includes both road structures like roadside units (RSU), traffic signal controllers, traffic management centers, and user or vehicle-related equipment such as onboard equipment and nomadic devices. Deployment costs are likely to drop over time, both on the infrastructure and the vehicle side. Nevertheless, the broad-scale adoption of CAVs will have an impact on public budgets at all levels of government, with potential revenue losses from parking, moving violations, vehicle registrations, or transit (Spulber, Brugeman, Dennis, & Fard, 2017).

Section V: Convergence of Electrified Powertrains and Connected and Automated Vehicles

For over 100 years, automakers have built steel cars with gasoline engines that consumers buy and then keep for a few years before buying a new model. All of that could change, and one element that could catalyze future mobility growth is when automakers design vehicles specifically to take advantage of the new powertrain and autonomous driving technologies. A purpose-built mobility vehicle will likely be electric, and starting from scratch will allow automakers to re-imagine the vehicle as a passenger conveyance without a need to prioritize elements of the driving experience.

CAV technologies demand substantial electrical power—current prototypes consume 2-3 kW for peak power (Continental AG, 2018). These demands are likely more than the current 12-volt architecture can provide, and maybe more than a 48-volt system is capable of delivering. EVs offer the energy to power automated and connected technologies and will produce the zero (local) emissions required to meet future ICE restrictions. A decade or two from now, it is very possible automated, connected and electrified will be seen as technologies that combined to change an industry and grow the shared mobility market.

From a market positioning opportunity, many companies are attempting to garner some of the excitement and have made ACES vehicles the vision for market success.

- Tesla is seen as a leader in the deployment of electric vehicles and is also one of the most aggressive companies in implementing conditional automated driving technologies. This combination of real and perceived technology leadership has given Tesla a unique marketing position, and unmatched real-world learning from its fleet of vehicles that are capable of conditional automated driving. The company has also been upfront about conditional automated driving as a step toward automated vehicles, and even put forth the idea of the Tesla Network of shared, automated vehicles.
- Volkswagen is proactively positioning the VW Buzz—their re-imagining of the VW microbus—as an automated, connected, and electric game-changer for the company. It serves as the company's star candidate for testing how the consumer might react to ACES technology innovations.
- General Motors recently built 130 Chevrolet Bolts with AV technology for on-road testing. GM has also placed the (non-automated) Bolt into service for Maven, the automaker's car-sharing program. The Cadillac brand is GM's point for SuperCruise, the company's conditional automated driving technology brand, the fully-electric Bolt is serving as their showcase for testing fully-automated driving and new mobility paradigms.
- Smart CEO Annette Winkler may have summed it up best during her introduction of the Smart Vision EQ Fortwo concept vehicle. "The smart vision EQ Fortwo is our vision of future urban mobility; it is the most radical car sharing concept car of all: fully autonomous, with maximum communication capabilities, friendly, comprehensively personalizable, and, of course, electric." When CAVs and EVs become one, that will enable the growth of the shared mobility economy.

For new mobility companies such as Lyft, Uber, and Waymo, the opportunity for real cost savings may come from eliminating the driver through the use of AV technologies. Once the need for a driver is gone, it will be simpler for the vehicle to charge itself instead of refueling was gasoline. Companies such as Qualcomm, Plugless Power, and others are working to develop and deliver inductive charging which may enable cars to refuel (recharge) without driver intervention, and that innovation could allow further growth mobility services using an ACES vehicle fleet.

Section VI: Conclusion

ACES mobility will eventually transform the automotive industry and the transportation of people and goods, but these changes are not going to happen overnight. CAR's research shows that full SAE Level 5 autonomy is currently projected to be commercially available by 2030, and IHS|Markit projects that just 3.8 percent of vehicles sold in that year will be capable of Level 4 or Level 5 autonomy. The share of autonomous-capable vehicles sold increases steadily throughout the 2030s and comprises over half of all new vehicles sold by 2040 (Table 5).

Table 5: Projected Market Share of Level 4 and Level 5 Autonomous-Capable Vehicles 2030-2040

	L4 and L5 Vehicles Share of Sales
2030	3.8%
2032	7.0%
2034	12.6%
2036	21.9%
2038	35.9%
2040	54.9%

Source: IHS|Markit

Also in 2030, more than 90 percent of global new vehicles sold will still have an ICE, and BEVs and FCEVs will comprise roughly 8 percent of new vehicle sales (Smith, Spulber, Modi, & Fiorelli, 2017).

Since ACES vehicles are expected to travel more VMT per year—some estimate as many as 100,000 VMT a year—the technology penetration rate on shared vehicles would be faster than a conventional personal vehicle that, on the current trend, travels roughly 15,000 VMT in the first year of use. Given the higher costs and higher utilization of the ACES model, these vehicles make sense in a robo-taxi or robo-delivery application. Given current projections for battery and technology costs, the initial purchase price and the total costs of ownership for AV/EVs will remain out-of-reach for most personally-owned vehicles, which means most ACES miles will be traveled by fleet vehicles.

The period where conventional personal vehicles and ACES vehicles will coexist on U.S. roadways will last decades. The technology gap between the traditional personally-owned vehicles that are slow to turnover and the highly-utilized shared fleet vehicle will become wider as the fleet vehicles will have the latest technology and operators may need to replace the shared fleet vehicles more frequently than a household would replace an owned vehicle. Society will realize a vast majority of the safety and convenience benefits of ACES vehicles in urban and suburban area deployments.

While the technology to electrify and automate vehicles will take decades to proliferate, automakers and suppliers must invest now to have a stake in the future of the transformed automotive industry. Profits have been steady, and investments have continued throughout the economic expansion. The challenge will come when sales begin to soften further and profitability lags. Will the auto industry continue to spend at the current pace through a downturn in the business cycle? If recent history is any guide, they will not—at least not at the current speed and scale of investment. Automotive investments in new products, new technology, new processes, and advanced R&D all suffer during an economic contraction. A prolonged market slump, or a steep market correction, could delay the full implementation of EVs and AVs by as long as 5-10 years.

Automakers and suppliers are investing in technology and hoping to amortize those investments over millions of units at a global scale. Investing in advanced technologies is not only costly but also brings considerable risk. In all things related to automotive technology, consumer acceptance is critical. The auto industry also operates in many different regulatory environments and must meet many different sets of targets. Even while the National Highway Traffic Safety Administration (NHTSA) and the Environmental Protection Agency (EPA) are completing work on the Mid-Term Evaluation, automakers and suppliers are aggressively pursuing electrification to meet requirements and CO_2 emissions reduction targets set across Europe, Asia, and South America. In North America, Canada and Mexico have signed agreements to align their regulatory frameworks with that of the California Air Resources Board (Government of Canada, 2014). All of this means that automakers and suppliers—nearly all of which are large multi-national companies—must keep up with the most aggressive regulatory environments if they wish to remain globally competitive.

The automotive world is inching ever closer to an electrification tipping point, and the development and deployment of automation technologies are rapidly advancing. Automakers and suppliers will develop these technologies for—and in—those markets and countries where consumers demand them, and where infrastructure, incentives, and regulatory mandates are aligned. Automotive R&D investment and advanced manufacturing will be located in or near to those markets where ACES vehicles are sold and deployed. If the U.S. market is not a leader in adopting EVs, AVs, and Mobility as a Service, there will be

implications for U.S. engineering and skilled talent development institutions and the overall technological leadership of the United States.

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