Impact of Automated, Connected, Electric, and Shared (ACES) Vehicles on Design, Materials, Manufacturing, and Business Models

CENTER FOR AUTOMOTIVE RESEARCH

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CALM is a collaboration of more than forty industry-leading organizations working to support the cost-effective integration of mixed materials to achieve significant vehicle mass reductions through the joint efforts of the material sectors and the auto manufacturers. Supporting organizations participate in the CALM working group through an ongoing, annual financial commitment.

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CAR's mission is to conduct independent research and analysis to educate, inform and advise stakeholders, policymakers, and the general public on critical issues facing the automotive industry, and the industry's impact on the U.S. economy and society.

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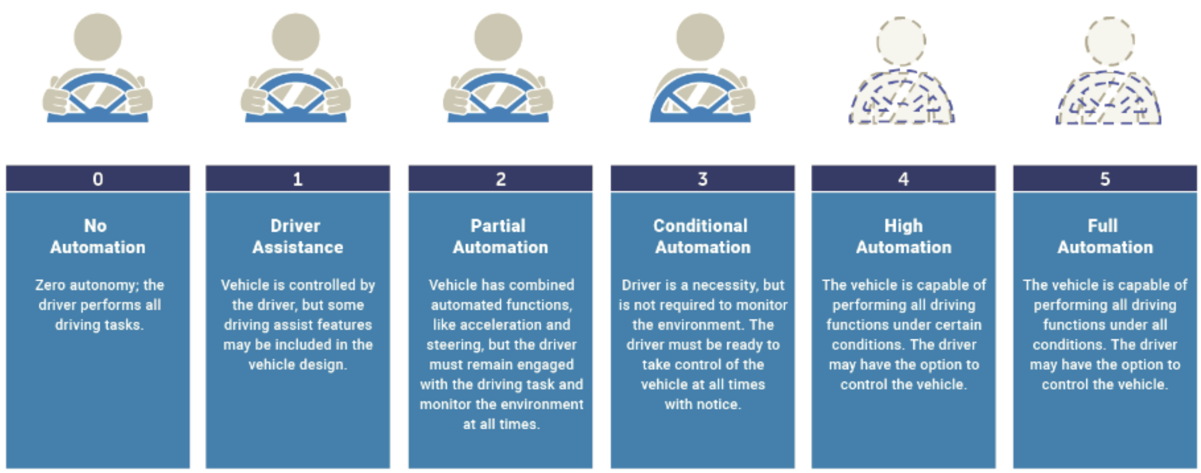
OBJECTIVE

The automotive industry is undergoing a period of extraordinary change, including advancements associated with powertrain, electronics, software, changing consumer preferences, and new materials. The investments by automotive and software industry in research and development of sensors (for example, RADAR, LiDAR), batteries, software, advanced materials, and artificial intelligence are now yielding tangible benefits. Within ten years, urban transportation likely will be dominated by automated, connected, electric, and shared (ACES) vehicles.

ACES vehicles are defined as:

- Automated vehicles with SAE Level 4 or Level 5 capability (see Figure 1);[1]
- Vehicles with connectivity capabilities for vehicle-to-everything (V2X) communication, over-the-air (OTA) updates, in-vehicle customer services, etc.,
- Battery electric vehicles, including hybrid vehicles; and
- Shared vehicles that are managed by service providers that offer short-term access to vehicles on demand—could be driven by the customer (e.g., like ZipCar today), a third party (such as current Lyft services), or by a computer.

FIGURE 1: SOCIETY OF AUTOMOTIVE ENGINEERS (SAE) DRIVING AUTOMATION LEVELS



Source: SAE, National Highway Transportation Safety Administration (NHTSA)

To help the industry better understand the implications of ACES, the Center for Automotive Research (CAR) launched an initiative to research the impacts of ACES vehicles on design, materials,

[1] SAE (2016). *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles J3016_201609*

manufacturing, and business models. This white paper focuses on ACES passenger vehicles, defined as vehicles with a maximum occupancy of nine.[2]

METHOD

CAR researchers interviewed multiple experts at vehicle manufacturers, tier-1 suppliers, and new mobility companies. Automakers interviewed include BMW, FCA, Ford, GM, Nissan, and Toyota. CAR team interviewed 12 suppliers, which are all part of the Coalition for Lightweighting Materials (CALM). Experts were asked to share their opinions on the potential impact of ACES on durability, safety, lightweighting, recyclability, manufacturing, business models, and cost of ownership. The companies interviewed are listed in Table 1. The interview questionnaire is attached in Appendix 1.

CAR also organized a workshop on this topic. The participants (total 34 people) at the workshop were materials and manufacturing experts from automakers and suppliers.[3] The CAR team conducted extensive literature review to supplement the information collected during the interviews and the workshop. This paper is a consolidation of expert opinions.

TABLE 1: LIST OF COMPANIES INTERVIWED

Vehicle Manufacturers	Suppliers	New Mobility Companies
BMW Fiat Chrysler Automobiles Ford General Motors Nissan Toyota	AP&T AK Steel Faurecia Aisin Seiki Henkel BASF Kobe Steel Vitro SABIC Shiloh Industries Solvay U.S. Steel	Ridecell

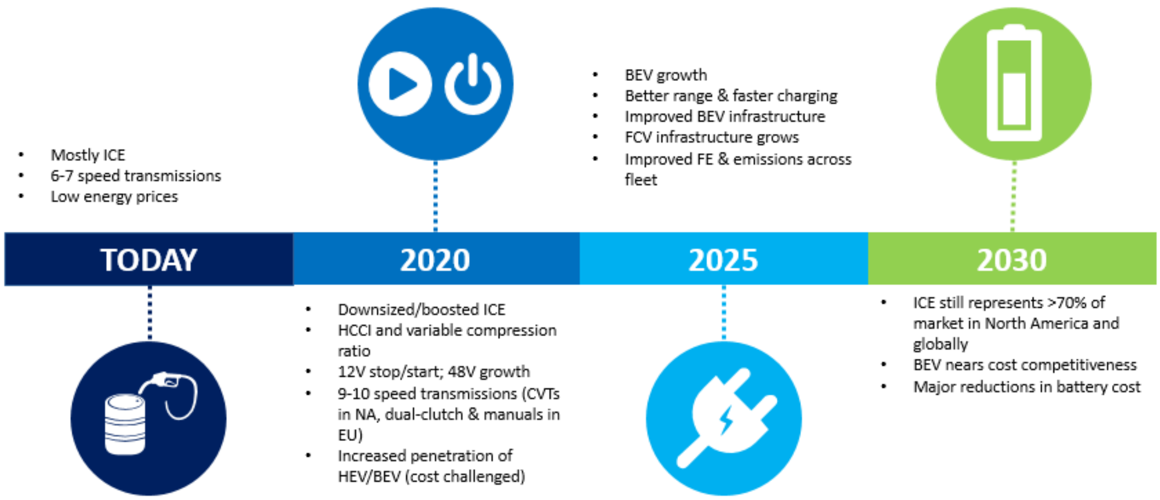
[2] *Glossary for Transport Statistics*, prepared by the Intersecretariat Working Group on Transport Statistics – Eurostat, European Conference of Ministers of Transport (ECMT), United Nations Economic Commission for Europe (UNECE).

[3] The participants included five automakers and members of the CALM group.

Market Assumptions for ACES Vehicles

It is crucial to start an evaluation of the potential of ACES vehicles by setting assumptions for future market size and a timeline for development of these vehicles. Figure 2 shows CAR's roadmap for Battery Electric Vehicle (BEV) growth. CAR expects that BEVs will represent less than 30 percent of the global automotive market by 2030.[4] Electric vehicle market growth will occur most dramatically in China, followed by the European market, with North American growth trailing those two. In Europe, France, England, and the Scandinavian countries will be the first to implement BEVs on a large scale. This forecast is expected to be driven primarily by government regulations favoring electric vehicles over internal combustion engine (ICE) vehicles.

FIGURE 2: ELECTRIC VEHICLE ROADMAP



Source: CAR Research

The automakers and other companies that are developing automated driving technology have released varying estimates regarding when they expect to start deploying SAE Level 4 and Level 5 automated vehicles, with the most aggressive estimates targeting 2020. Most of these companies have stated they will deploy Level 4 and Level 5 vehicles in shared fleets first. Private ownership of fully-automated vehicles is still a possibility, even if that option is not readily available in the early years of this technology.[5]

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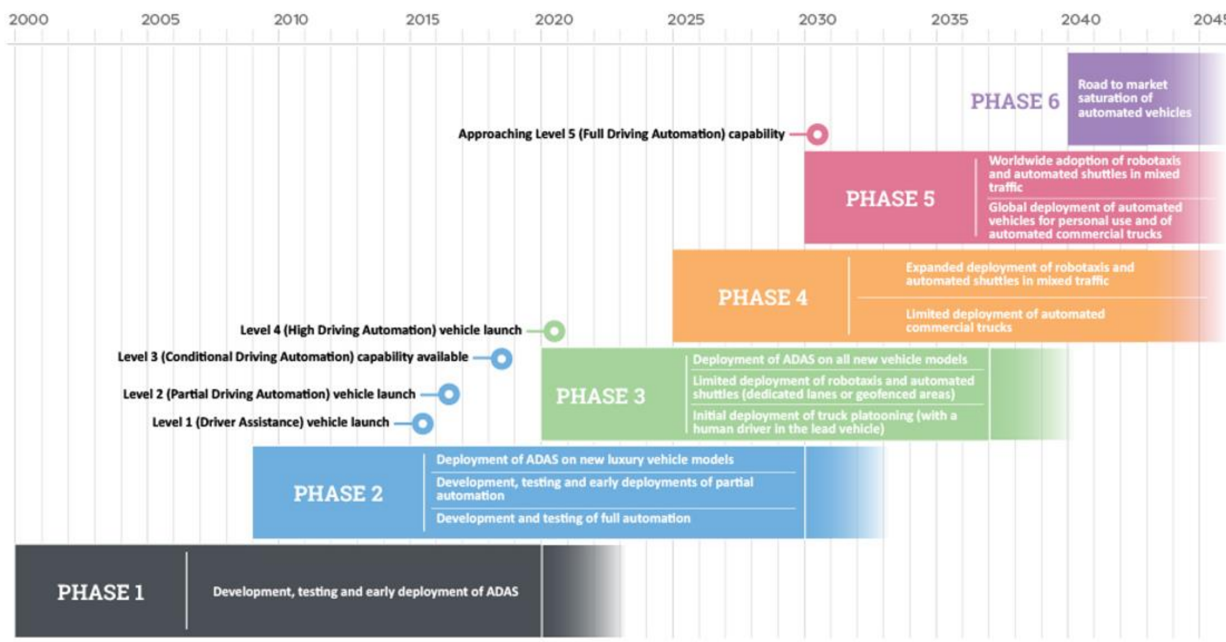
[4] Smith, B., Spulber, A., Modi, S. Fiorelli, T. (2017), *Technology Roadmaps: Intelligent Mobility Technology; Materials and Manufacturing Processes; and Light Duty Vehicle Propulsion*, CAR

[5] The Economist (2018), *Self-Driving Cars Will Require New Business Models*, https://www.economist.com/special-report/2018/03/01/self-driving-cars-will-require-new-business-models

According to CAR research (see Figure 3), fleet deployments of Level 4 automated vehicles will happen in select areas in most regions of the world by 2025.[6] CAR projects that it will be possible for private individuals to own Level 4 vehicles after 2030 and that these vehicles will approach SAE Level 5 capabilities; however, it will take at least 30 years for almost all vehicles on the road to have level 4 and level 5 automation considering the current trend in fleet turn-over (see Table 2). These projections were based on official company announcements, an overall assessment of technology readiness, and an assessment of the market penetration speeds in various regions and driving environments.

FIGURE 3: DRIVING AUTOMATION ROADMAP



Source: CAR Research

It is difficult to estimate the market penetration of automated vehicles in a given year, and even more difficult to estimate market penetration for ACES vehicles. One prudent approach for estimating the potential speed of market penetration involves examining historical data on fleet renewal speeds. Based on historical data and the EPA and NHTSA vehicle survival figures, it takes about 16 years to permanently remove half of a given vehicle age cohort from use, and it takes 31 years to renew 98 percent of a vehicle cohort (see Table 2). For example, in 2030, we can expect that 76 million of the vehicles on the road today (2018) will still be in active use; these 76 million will represent a bit more than 25 percent of all vehicles on the road in 2030.

[6] Smith, B., Spulber, A., Modi, S. Fiorelli, T. (2017), *Technology Roadmaps: Intelligent Mobility Technology; Materials and Manufacturing Processes; and Light Duty Vehicle Propulsion*, CAR

TABLE 2: PERCENTAGE OF VEHICLE RETIRED BY VEHICLE AGE

Vehicle Age, Years	Percent Retired
12	25
16	50
20	75
31	98

Source: CAR Research

Another useful approach is to examine fleet renewal rates based on vehicle miles traveled (VMT), because it provides an estimate rooted in vehicle use. The typical light vehicle travels 30 percent of its total lifetime mileage in its first three years of operation (see Table 3).[7] Therefore, based on historic trends, CAR researchers project that vehicles existing today will account for just more than 10 percent of fleet VMT in 2030.

TABLE 3: PERCENT OF LIFETIME MILES WITH VEHICLE AGE

Vehicle Age, Years	Percent of Lifetime Miles Traveled
3	29.7
7	74.6
26	99.1

Source: CAR Research

CAR researchers have observed synergies in the development and deployment of automated vehicle technology and electric propulsion. Therefore, we expect that many automated vehicles will have either full electric propulsion or at least hybrid propulsion. CAR researchers also have assumed that ACES vehicles will be available in several segments, because consumers use different types of vehicles for different use cases. Also, we assumed that there could be new markets for one- or two-seat vehicles, especially in urban areas.

While a growing number of drivers have experienced advanced driver assistance systems (ADAS) 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 (e.g., those being conducted by Waymo, Uber, and Navya). Therefore, it remains a challenge to measure attitudes to products that consumers have not yet experienced. Consumer surveys have found that attitudes concerning automated vehicles have been evolving rapidly in the past few years. One Deloitte survey to measure consumers' trust on fully automated vehicles safety found 53 percent of U.S. residents deemed self-driving cars safe in 2018, up from 26 percent in 2017.[8] Attitudes towards automated vehicles also seem to be sensitive to major events such as the fatal Uber crash in March 2018. Surveys commissioned by AAA have confirmed this trend, revealing that the percentage of U.S. drivers that would be afraid to ride in a fully automated

[7] CAR calculations based upon data from Oak Ridge National Laboratory, U.S. Environmental Protection Agency, U.S. Department of Transportation Federal Highway Administration, and IHS Markit.
[8] Giffi, C. A., Vitale, J., Schiller, T., & Robinson, R. (2018), *A Reality Check on Advanced Vehicle Technologies Evaluating the Big Bets Being Made on Autonomous and Electric Vehicles, Deloitte Insights*

vehicle rose after the Uber crash incident in Tempe, Arizona.[9] For this discussion, we assumed that consumers trust will not be a major impediment to deployment as the technology improves over time.

Users of mobility services powered by ACES vehicles will have different requirements related to these vehicles than those of owners of manually-driven vehicles, and many of these requirements are similar to those regarding carsharing, ridesourcing, and use of taxis. Some of the most significant differences in requirements from the user's point of view include:

- Price per ride (e.g., by distance, duration, or both) or per subscription (e.g., weekly, monthly, yearly);
- Reliability of the service (e.g., wait times, accuracy of time of arrival estimates);
- Secure access to the vehicle (e.g., accurate customer identification);
- Privacy;
- Vehicle cleanliness;
- Vehicle personalization and ability to use the vehicle for working, relaxing, and other alternatives (with an emphasis on interiors);
- Vehicle comfort (with an emphasis on interiors); and
- Accessibility for persons with disabilities, older adults, children, and other groups with physical, mental, or other barriers to access

While some new considerations might arise, conversely, customers of mobility services using ACES vehicles might not care about other issues that currently are important for owners of private vehicles, for example, vehicle performance (i.e., acceleration, cornering, etc.), exterior design, color, etc.

VEHICLE UTILIZATION

In the United States, privately owned vehicles sit unused on average for more than 23 hours per day.[10] In other words, they are used only five percent of the typical day. The individuals who own these vehicles drive an average of 13,436 miles per year.[11] Experts suggest that, when fleet owners rather than individuals control the vehicles, it makes good business sense to keep vehicles on the road throughout the day. Therefore, ACES vehicles are expected to operate "more or less around the clock."[12] After accounting for downtime to charge, clean, maintain, and repair ACES vehicles, CAR estimates that some of these vehicles could be in operation for up to 20 hours a day; however, reliable estimates for usage rates for these future vehicles are not available. Also, the demand varies considerably over the course of the day. Because of high vehicle utilization in shared mobility, average age of vehicles on the road might reduce from 11.6 years today to 4-5 years.[13]

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[9] AAA (2018, May). *Vehicle Technology Survey*. Retrieved from AAA Newsroom

[10] Based on the fact that the average one-way work commute was 25.5 minutes in 2013. Data source: 2013– U.S. Bureau of the Census, 2009-2013 American Community Survey, 5-Year

[11] Federal Highway Administration, U.S. DOT, March 2018, https://www.fhwa.dot.gov/ohim/onh00/bar8.htm

[12] car2go (2017). *White paper - The five conditions essential to successfully operate automated carsharing fleets in the future*

[13] IHS Markit (2016)

CAR researchers used taxi services, ridesourcing, and carsharing as partial proxies for the utilization rates of ACES vehicles. Ridesourcing, or Transportation Network Company (TNC) services, uses smartphone apps to bring passengers in contact with drivers who typically drive part-time and use their own car (for example, Uber, Lyft, Ola). Carsharing is a model of car rental whereby people rent cars for short periods of time, often by the hour (for example, Zipcar, Maven). Taxi services are a satisfactory proxy for duty cycles of future ACES vehicles, except that most taxi companies do not use fleet management tools that allow them to rebalance vehicles and minimize miles driven without a passenger at the fleet level. This is even more relevant for ridesourcing, because a large proportion of ridesourcing drivers are part-time; these services have a different business model than what is expected for fleets of ACES vehicles for which maximizing utilization of vehicles will be a priority. Carsharing operators have similar asset utilization goals as do future automated mobility services but have lower market penetration rates than ridesourcing currently. Finally, traditional car rental operations are an even less relevant proxy for the utilization of ACES vehicles, because the rental duration tends to far exceed the amount of time that the rental vehicle is actually driven.

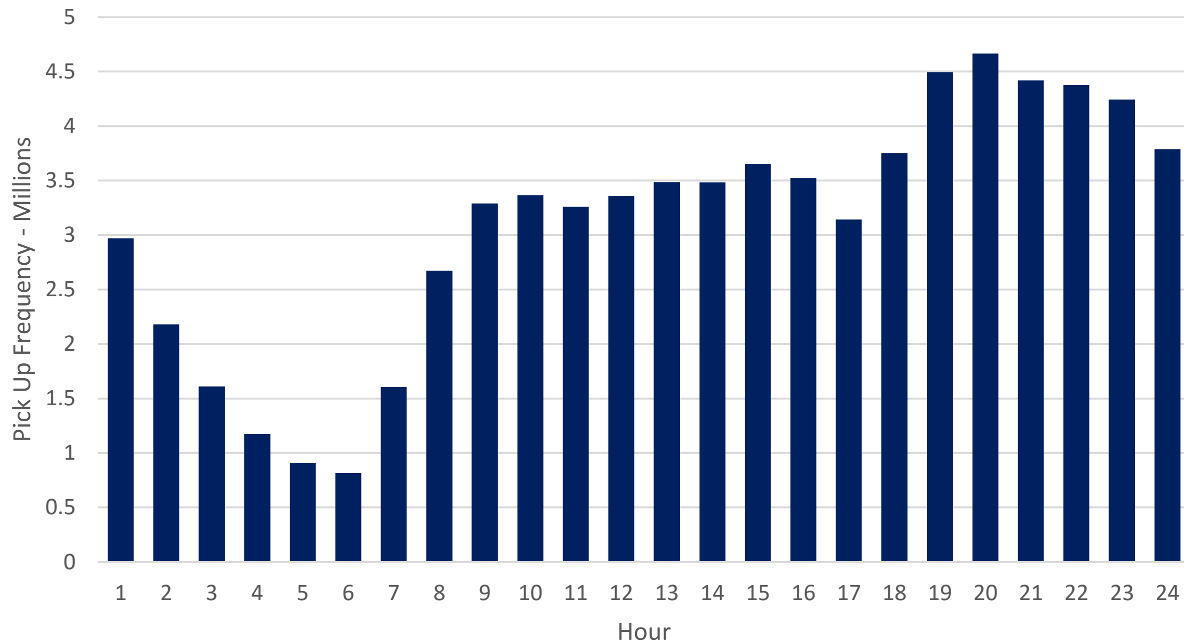
Taxi Example

For-hire taxi services provide prearranged and on-demand vehicle services for compensation through a negotiated price, zone pricing, or taximeter (either traditional or GPS-based). Passengers can schedule trips in advance (booked through a phone dispatch, website, or smartphone app), street hail (by raising a hand on the street or standing at a taxi stand or specified loading zone), or e-Hail (by dispatching a driver on-demand using a smartphone app).

The average New York City medallion taxi traveled 70,000 miles in 2014.[14] Each NYC taxi provided an average of 36 rides a day, with the average trip distance at 2.6 miles. The average age of taxi vehicles was 3.3 years. Taxi demand fluctuates throughout the day and is highest around 7 PM (see Figure 4). Generally, trip numbers increase during the morning hours when people go to work, and when they go out to run errands or travel for leisure purposes, and decrease during the late hours of the night. The New York city taxi network is not necessarily representative of taxis at the national level, and an accurate assessment of taxi duty cycles would require an in-depth analysis that is more representative of national averages. Nonetheless, the NYC examples suggests some trends: automated and shared vehicles might experience peak demand during commuting hours and mostly sit idle for the remainder of the day. Generally, ACES vehicles will have increased duty-cycles compared to human-driven, personal vehicles. During the interviews, experts suggested that taxis are a good proxy for studying ACES demand in urban areas.

[14] de Blasio, Bill and Yassky, David (2014). *2014 TLC Factbook.* New York City Taxi & Limousine Commission

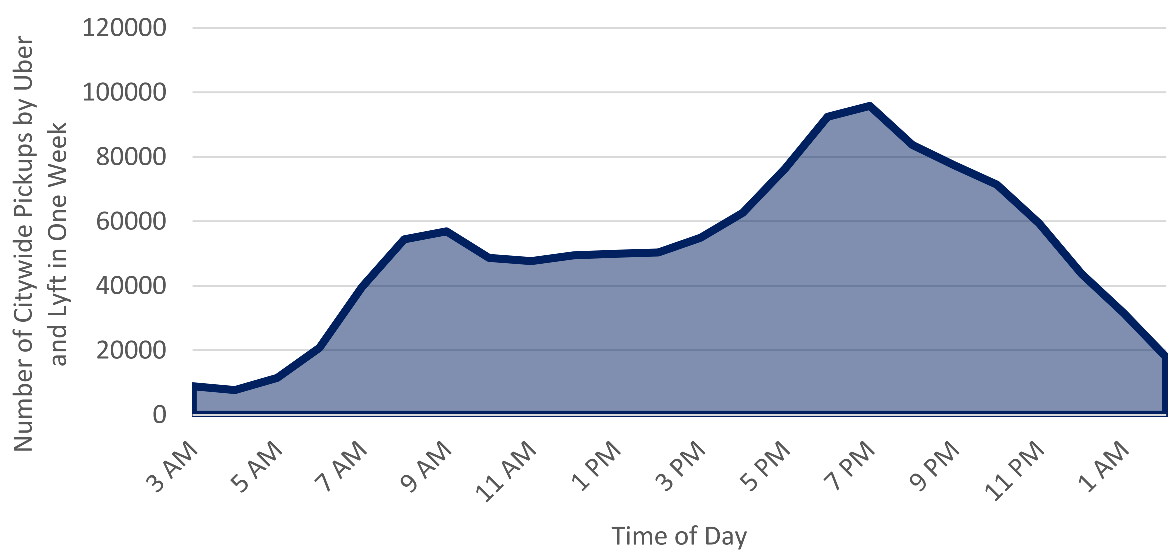
FIGURE 4: TAXI DEMAND BY HOUR IN NEW YORK CITY, 2010



Source: NYC Data Science

Data on Uber and Lyft pickups in San Francisco shows a pattern similar to NYC taxi demand (see Figure 5). Demand is low at night, increase in the morning as commuters to go work, and peaks around 7 PM.

FIGURE 5: AVERAGE NUMBER OF CITYWIDE PICKUPS BY UBER AND LYFT IN ONE WEEK IN SAN FRANCISCO



Source: San Francisco Transportation Authority, Data is an average from several weeks in Fall 2016

Ridesourcing Example

Ridesourcing services (also known as ride-hailing, transportation network companies, or TNCs) provide prearranged and on-demand transportation services for compensation, connecting drivers with passengers. Drivers and passengers rely on smartphone applications for booking, electronic payment, and ratings. CAR found very little reliable data on the number of miles driven by ridesourcing vehicles or the number of customers each driver has. Most of the data are self-reported by ridesourcing companies in media interviews or company reports.

In the available date, for 2017, Lyft reported more than 1.4 million drivers serving 23 million passengers who took 375 million rides in the United States.[15] Based on those numbers, the average Lyft driver provided 267 rides per year – or 0.73 rides per day. Similarly, in 2017, three million Uber drivers provided four billion rides worldwide.[16] Therefore, the average Uber driver provided 1,333 rides in 2017 – or 3.65 rides per day.

It is important to note that many drivers are currently working in the ridesourcing business on a part-time basis. In 2017, 93 percent of Lyft drivers (1.3 million) drove fewer than 20 hours per week – or an average of 2.85 hours a day.[17] Similarly, in 2014, 55 percent of Uber drivers worked fewer than 15 hours a week, and only 5 percent drove more than 50 hours a week.[18] Because of the high turnover rate of ridesourcing drivers[19] and because most of them drive fewer than 15 or 20 hours a week, current driver-user rates are not directly applicable to mobility services using ACES.

A 2016 report based on ridesourcing trip data from Chicago; Washington, D.C.; Los Angeles; Nashville; and Seattle found that the median trip length varied between 2.2 and 3.1 miles. Average ridesourcing trips were between 4.4 and 5.4 miles. Maximum ridesourcing trip lengths ranged between about 20.4 and 30.7 miles depending on the regions.[20] Trip data, however, do not include miles from dead-heading – the distance traveled by drivers to pick up their next customer. While sufficient aggregate data on dead-heading are available, ridesourcing drivers are known to complain that dead-heading represents a significant amount of their miles driven. Current ridesourcing companies have little interest in helping their drivers reduce dead-heading, because the companies do not own the vehicles; however, ACES vehicles fleet owners will have a strong incentive to do so, because that would increase the utilization of their assets.

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[15] Lyft (2018). *Economic Impact Report*.

[16] Bhuiyan, Johana (2018). *Uber powered four billion rides in 2017. It wants to do more — and cheaper — in 2018*. Recode. Published on Jan 5, 2018

[17] Lyft (2018). *Economic Impact Report*.

[18] Hall, Jonathan and Krueger, Alan (2015). *An Analysis of the Labor Market for Uber's Driver-Partners in the*

[19] Lomas, Natasha (2017). *Uber has seen a sharp drop in new driver retention this year: Apptopia*, Techcrunch, published Jun 23, 2017

[20] Feigon, S. and C. Murphy (2018). *Broadening Understanding of the Interplay Between Public Transit, Shared Mobility, and Personal Automobiles*. Pre-publication draft of TCRP Research Report 195. Transportation Research Board, Washington, D.C.

Carsharing Example

Carsharing offers members access to vehicles by joining an organization that provides and maintains a fleet of cars and light trucks. The carsharing organization typically provides insurance, gasoline, parking, and maintenance. Members who join a carsharing organization usually pay a fee each time they use a vehicle.

A carsharing vehicle in a free-floating system, such as car2go, has a utilization rate five to six times higher than privately-owned cars, or five to six hours a day.[21] In addition, car2go has the goal of 16 rentals per day per vehicle. Other carsharing programs average between five and ten users per day, depending on city demographics and population density.[22]

The average ratios of carsharing members-to-vehicles[23] have increased significantly in the past years as shown in Table 4. In North America, the numbers have doubled since 2006. This increase, in large part, is due to a significant increase in membership of one-way carsharing programs, coupled with a more modest increase in fleet size.

TABLE 4: AVERAGE CARSHARING MEMBER-TO-VEHICLE RATIOS BY YEAR AND REGION

Region/Year	2006	2008	2010	2012	2014	2016
North America	35.3	42.5	49.5	57.5	67.1	68.9
Asia	25.8	15.5	19.0	26.1	47.0	129.5
Europe	28.3	30.8	32.9	33.8	38.1	75.6
South America[24]	0.0	0.0	13.8	60.0	100.0	120.0
Oceania	17.4	20.4	29.0	23.6	33.3	19.2
Global	30.1	34.6	36.4	41.0	46.5	95.6

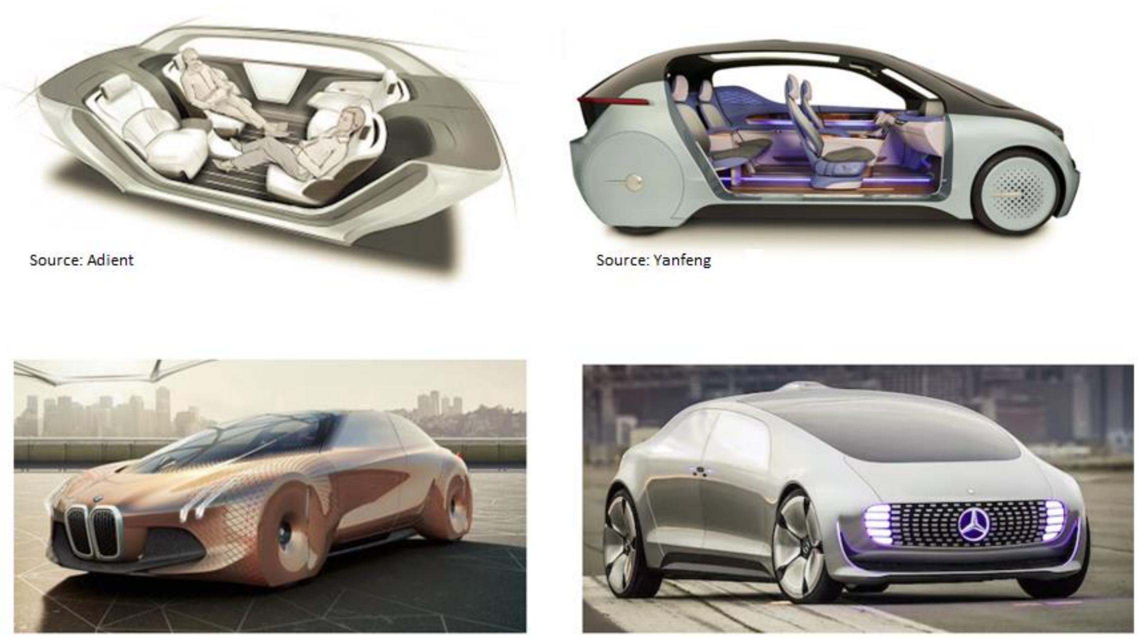
Source: Innovative Mobility: Carsharing Outlook, UC Berkeley

[21] car2go (2017). White paper - *The five conditions essential to successfully operate automated carsharing fleets in the future*, November 7, 2017
[22] Interview with a carsharing company.
[23] Member-to-vehicle ratio = total number of members of a carsharing program / number of vehicles in that program
[24] According to Shaheen, Cohen and Jaffee research, there were no carsharing programs in South America in 2006 and 2008.

IMPACT OF ACES ON VEHCILE DESIGN

The automobile as we know it today has gone through multiple iterations in design since the Ford Model-T. In 1909, Henry Ford remarked about the Model T that “Any customer can have a car painted any color that he wants so long as it is black.” That mindset has evolved due to mass adoption of the automobile, advancements in technology, and creative thinking. As the automotive industry transitions into automated, connected, electric, and shared mobility world, new opportunities will open up for vehicle design studios. The internet is full of futuristic vehicle design ideas (see Figure 6 for examples). Some of these design ideas are quite radical and might not make it to production vehicles, but some of their design aspects might get applied in the real world.

FIGURE 6: FULLY AUTOMATED VEHICLE DESIGN CONCEPTS



Source: Adient

Source: Yanfeng

Source: BMW

Source: Mercedes

Vehicle designers consider many factors, but the two factors of interest for this paper are function and aesthetics. Because functionality plays a significant role in governing design, ACES vehicle design will depend on the intended use of the vehicle. For example, for urban, low-mile trips, the vehicles might look like pods. Long-haul vehicles will be larger than short-haul vehicles – with greater cabin space, more comfort features, and improved aerodynamics to support high speeds.

For this study, vehicle design can be categorized into four broad categories – powertrain, structural, exterior, and interior. The following paragraphs will discuss each of these in detail.

Powertrain Design

For ACES vehicles, most of the powertrain components could become a commodity. When individuals will not be driving the vehicle, unique brand identity could shift from powertrain performance to other components or service experience in case of shared fleets. In this scenario, differentiation in powertrain would not matter as much as it does today for personally owned, human-driven vehicles. Moreover, fewer opportunities for differentiation exist in an electric powertrain. Thus, automakers could share powertrains across the industry to save cost and then invest more in interior customization. Interviews with automakers and suppliers have revealed that out of all the powertrain components, only the control unit and software will remain a core competency of the automakers and rest may become a commodity (see Table 5). This would be a major change for the automotive industry that has, in the past, believed that the design, development, calibration, and manufacturing of powertrains, perticularly the engine, must be kept in-house. This anticipated change bolster the argument that the definition of performance might shift from acceleration, top-speed, and handling, to passenger comfort, infotrainment and productivity features, acoustic profile, and service experience.

TABLE 5: POWERTRAIN COMPONENTS COMMODITY OR CORE COMPETENCY: 2018 AND 2030

Component	2018	2030
Battery Pack / Engine	5	2
Control Unit (Hardware)	5	5
Software	4	5
Transmission	4	2

Scale: 1 = Commodity to 5 = Core Competency, Source: CAR Research

Structural Design

The impact of ACES on structural design will come mostly due to change in vehicle powertrains from internal combustion engines with gasoline (or diesel) fuel tanks to electric motors with batteries and future safety regulations. While the batteries add weight to the vehicle, batteries also provide a unique packaging opportunity. The battery pack is structured similar to objects built from Lego® building blocks whereby the individual parts (the Legos) are the battery cells. Depending on the assembly, the battery pack can take many shapes. Observed in modern pure electric vehicles, distributing the battery cells on the vehicle's floor helps in lowering and positioning the vehicle's center of gravity. Since there is no engine, the front compartment becomes available. Tesla has advertised the front space in the Model S as an extra trunk, which they refer to as the "frunk." Depending on the crash requirements, the front space could also be used to expand the occupant cabin. Furthermore, if someday automation and safety laws allow for removal of the steering wheel and pedals, then the removal of the engine and these other components will give greater freedom to vehicle designers and packaging engineers.

Battery cell packaging and occupant protection from thermal hazards will drive significant changes in structural design and materials. The battery packs used in today's electric vehicles often are made up of small Lithium-ion (Li-ion) cells. Li-ion batteries can pose unique safety hazards, because they contain a flammable electrolyte.

Exterior Design

A typical car buyer selects a vehicle based on a variety of factors that vary by the purchaser, but these factors include performance (horsepower, acceleration, and similar characteristics), aesthetics, comfort, and infotainment features. The vehicle's exterior aesthetics also are an essential criterion in many buyers' decision matrix. Indeed, research from San Francisco State University shows consumers' loyalty and passion for an automobile brand are driven more by appearance than any other factor. These researchers found that aesthetics that resonate on an emotional level are more responsible for brand loyalty than factors such as functionality and price.[25] The social and emotional values that a vehicle's design provides to consumers have a more significant effect on brand affection than purely transactional values such as functionality or economic value; however, this criterion might change with widespread deployment of automated and shared vehicles.

CAR research revealed that external aesthetics might not be an essential criterion for shared vehicles.[26] The primary reason being people, in general, don't value the aesthetics of things they do not own. For example, all taxi cabs in New York City are painted yellow and have similar dimensions, yet no one complains. On the other hand, consumers try to differentiate their owned vehicles from the rest of the crowd as much as possible. This human behavior might decrease the importance of a vehicle's external aesthetics in a shared economy.

Functions such as aerodynamics might drive exterior design in ACES vehicles. Design criteria such as A-pillar visibility, the rear field of view, and other factors will become less critical, because ACES vehicles likely will not have a human driver most of the time. Nonetheless, vehicle designers will need to keep sensor integration in mind when designing exteriors of the future.

Interviews with experts indicated that all automobiles in a sharing economy probably will not converge to one form of design like cell phones today, which are mostly touchscreen in developed nations. There will be several segments in ACES vehicles. It has been proven time and again that people, in general, like differentiation in the vehicles they use for work commute and leisure.

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[25] Kumar, M. , Townsend, J. D. and Vorhies, D. W. (2015), *Enhancing Consumers' Affection for a Brand Using Product Design.* J Prod Innov Manag, 32: 716-730. doi:10.1111/jpim.12245

[26] Interviews with automakers and suppliers conducted for this report

Interior Design

While vehicle interiors have always been an important focus of vehicle designers, future automated and shared vehicle technologies will bring interiors more central to design thinking. As the industry prepares to eliminate the steering wheel, vehicle interior suppliers are investing heavily in innovative solutions for future mobility. Below are broad categories of innovations and few examples:

1. **Biometrics** – The automotive industry is gearing up to measure biological and physiological traits to grant vehicle access to an individual. Biometrics can be used to measure the physiological and behavioral characteristics that differentiate one individual from another. Companies that are developing biometrics for automotive applications have been focusing on design considerations such as vehicular access, the ignition switch, vehicle immobilizer, rationalization, and health monitoring. For example, the Faurecia Active Wellness 2.0 seat concept can measure data on heart rate, eye gaze, head tilt, facial expressions, and other factors.

2. **Flexible Seating** – For the past 100 years, automotive designers have imagined light-duty vehicles with seats facing forward. Automated vehicles might eliminate the constraint of forward seating. With the potential elimination of driver controls, such as the steering wheel, pedals, and gear shifter, manufacturers can design the interior of the vehicle with greater flexibility and focus on cabin space and personalization for various uses (e.g., working, relaxing, social interaction, and many more). Swiveling seats are a likely function to accommodate more cabin space and enhance the passenger experience. The Mercedes-Benz Future Truck 2025 and numerous other vehicles have already demonstrated this feature on automated concept vehicles (see Figure 7 below).

   One of the major challenges for flexible seating is addressing motion sickness. Researchers have found that the main cause of motion sickness is a conflict between vestibular and visual inputs when not watching the road while in a moving vehicle.[27] The direction of gaze is a critical factor. Thus, passengers facing backwards or sideways have a higher probability of getting motion sickness, because they will see the road less.

   Another issue is certification from regulating government agencies. In the U.S., NHTSA regulates seat positioning. For NHTSA to modify Federal Motor Vehicle Safety Standards (FMVSS), researchers will have to demonstrate conclusively that alternative seating positions will not affect occupant safety negatively, degrade performance seatbelts and airbags, and so on. NHTSA might even choose to weigh in on motion sickness.

[27] Sivak, M., Schoettle, B. (2015), *Motion Sickness in Self-Driving Vehicles*, UMTRI

FIGURE 7: ALTERNATE SEATING ARRANGEMENT OF MERCEDES-BENZ F 015 CONCEPT VEHICLE

Source: Mercedes

3. **Replaceable Components** – As mentioned previously, the passenger's experience of an ACES vehicles is exceptionally important, especially for market penetration and consumer acceptance. As a result of frequent usage, the interior of a ridesharing vehicle is subject to damage and wear that could be off-putting to potential customers as time goes by, thus creating the need for easily replaceable components such as seat covers and carpeting.

4. **Smart Surfaces and Customizable Controls** – Smart surfaces blur the boundary between aesthetics and function. Smart surface technology enables the use of vehicle interior trims as part of a climate control system, display images, messages during a teleconference, or can become platforms for infotainment, GPS navigation, and other functions. Like a smartphone, smart surfaces provide user configurable and intuitive interfaces. shows an example of smart surfaces by Yangfeng.

FIGURE 8: INTERIOR TRIMS USED AS SMART SURFACES

Source: Yangfeng

5. **Personalization** – For a long time, consumer and after-market suppliers have concentrated on vehicles' exterior customization. Some vehicle owners enjoy customizing their vehicles via paint jobs, spoilers, and other aftermarket accessories or some combination of performance modifying and appearance changes to make their vehicle look and feel unlike any vehicle as it was delivered from the factory. Interviews conducted for this research revealed that as the exterior appearance becomes less and less important in an ACES vehicle, the personalization of interiors will be the next big thing for automakers and after-market suppliers. Unique entertainment and productivity tools could serve as differentiators in shared fleets. For example, many consumers will want to be able to control connectivity and other features such as climate control, radio, etc., through personal smart devices. This will be made possible and safe if vehicle occupants are not also driving.

IMPACT OF ACES ON MATERIALS

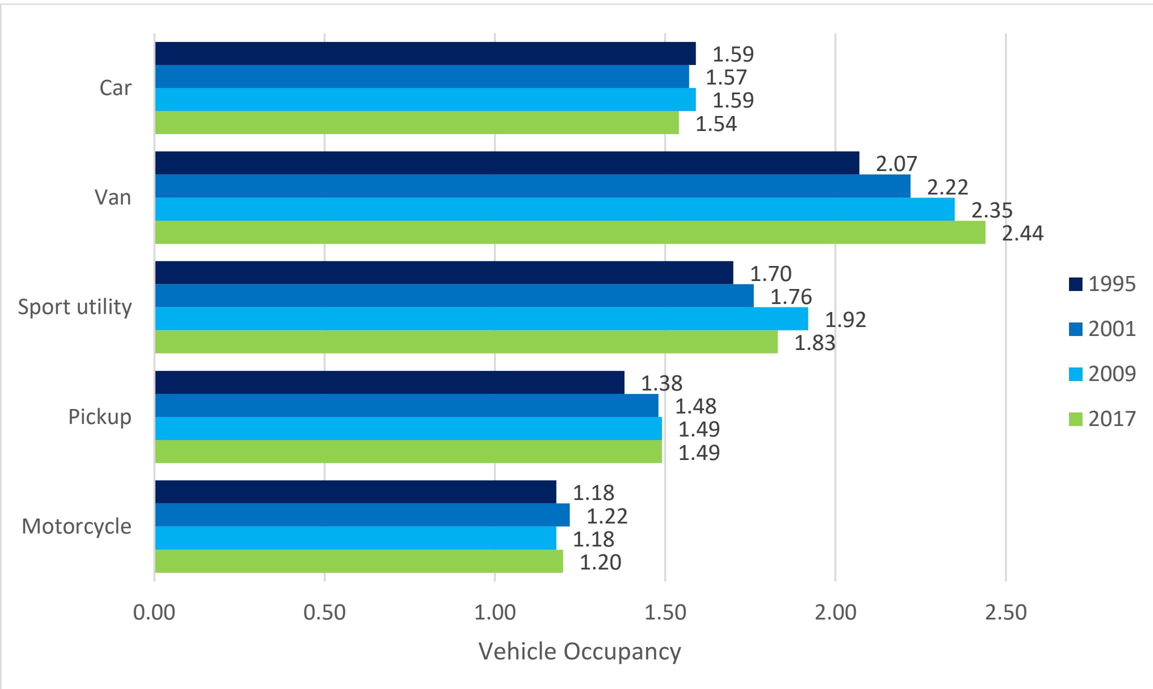
ACES technology will affect various factors governing vehicle engineering, and these, in turn, will affect the overall material mix. A typical vehicle is a mix of materials including various types and grades of metals, plastics, and composites. The body structure (body-in-white) and powertrain components are made of different grades of steel and aluminum, with a small percentage of magnesium, plastics, and polymer composites. Interior and exterior trim components make an extensive use of plastics. Seats and carpets use foam, metal frames, leather, and different fabrics. The following section discusses how changing durability requirements, testing procedures, safety regulations, and lightweighting targets impact vehicle materials.

Materials for Durability

Durability is the ability to withstand wear, pressure, or damage. The vehicles we drive today are a result of thousands of iterations in design and engineering. Vehicle manufacturers and part suppliers perform multiple durability tests such as corrosion resistance, noise, vibration, and harshness (NVH), leakage, sensor alignment before shipping the vehicle to the dealerships. Most durability testing methods are standardized by organizations like NHTSA (National Highway Traffic Safety Administration), SAE (Society of Automotive Engineers), ASME (American Society of Mechanical Engineers), ISO (International Organization for Standardization), ASTM (American Society of Testing Materials), DIN (German Institute for Standardization), IEC (International Electrotechnical Commission), ANSI (American National Standards Institute), NFPA (National Fire Protection Association), and USCAR/USAMP (United States Council for Automotive Research/Automotive Materials Partnership).

As discussed in the previous sections, taxis are deemed to be a good proxy for studying duty-cycles in ACES vehicles. Research shows taxi demand is cyclic in nature (see Figure 4). Durability requirements will depend on peak demand, and could also change due to an increase in average vehicle occupancy. The average number of persons occupying a personally owned vehicle is around 1.6, which has not changed much since 1995 (see Figure 9). With automated and shared vehicles, the average vehicle occupancy could increase to four because of increase in automated vehicles which are shared for travel. The increase in occupancy will lead to high usage of components, for example, doors of automated and shared vehicles may need to be open and closed multiple times per hour.

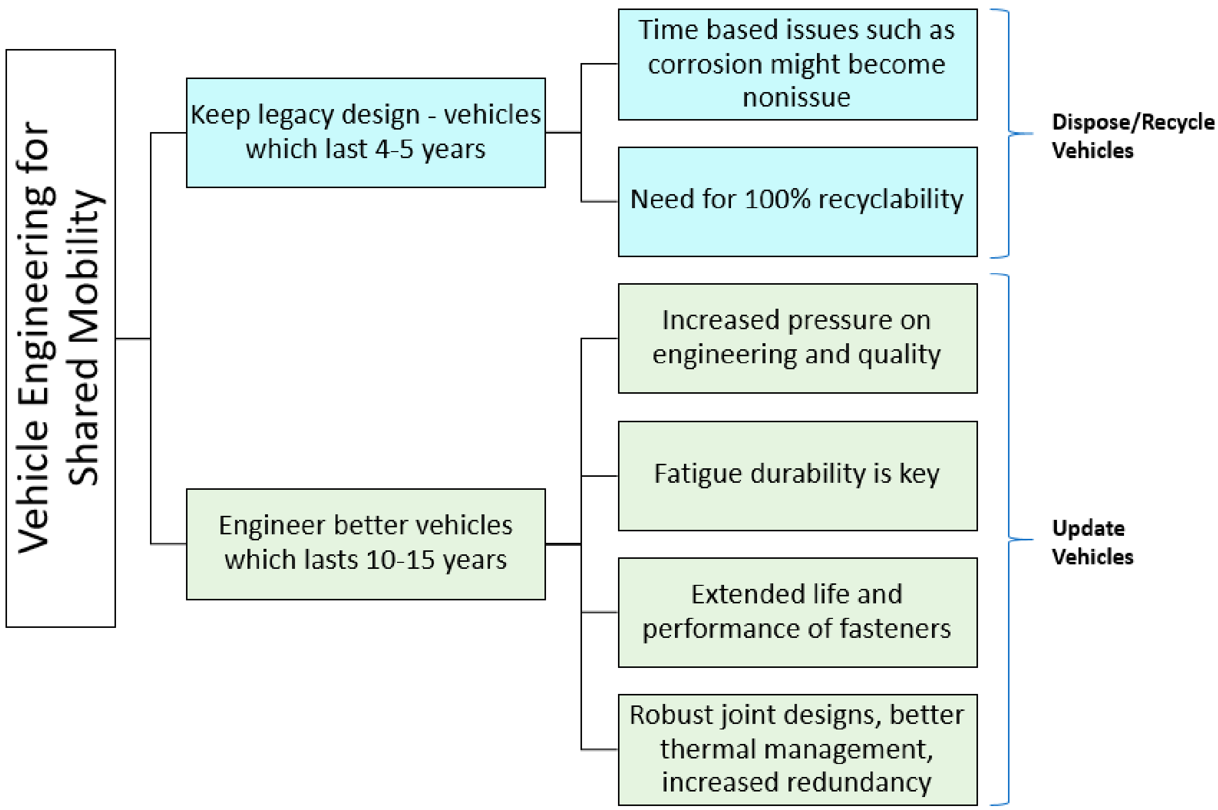
FIGURE 9: MILEAGE-WEIGHTED AVERAGE VEHICLE OCCUPANCY, 1995, 2001, 2009, AND 2017



Source: U.S. Federal Highway Administration National Household Travel Survey

The increase in annual vehicle miles traveled and heavier duty-cycles will put pressure on automaker and supplier engineering and quality departments. This gives rise to two approaches for approaching durability, as illustrated in Figure 10. The first option is to maintain legacy design methods using current durability requirements. In this scenario, ACES impact on durability will be significant. ACES vehicles will deplete maximum lifetime miles in four to five years. Hence, the fleet will turn over faster. The increase in vehicle turnover will create a need for greater recyclability since a large number of vehicles will be scrapped every year. In this case, some of the electronics might be transferable to the next car even if the vehicle's structure is scrapped. The second option is to engineer more durable vehicles that can last 10 to 15 years even with increased usage. In this case, the vehicles must have the capability for regular interior and software upgrades to keep them current.

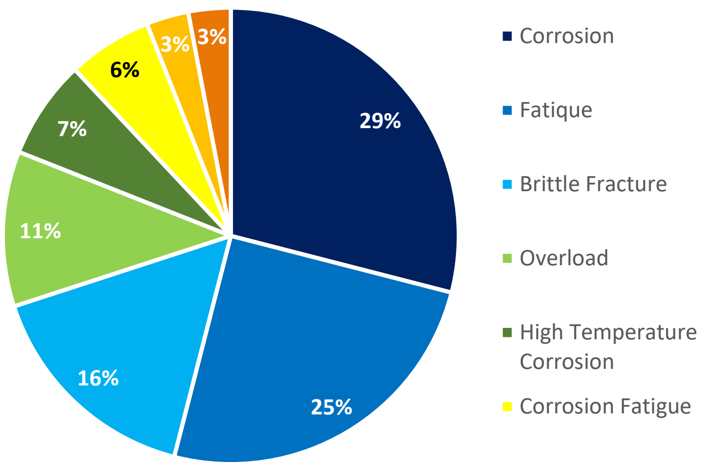
FIGURE 10: TWO WAYS TO APPROACH VEHICLE DURABILITY



Source: CAR Research

For ACES vehicles that are engineered to last 10-15 years, fatigue durability for high usage components will be critical. Fatigue is a failure process developed by the effect of the cyclic loadings. The aerospace industry has decades of experience in working with stringent fatigue standards since planes are in around-the-clock service. As shown in Figure 11, fatigue is one of the primary modes of failure in aircraft components. Experts interviews for this research stated that there is a great potential for knowledge transfer between the automotive and aerospace industries on the subject of fatigue durability, and some of the aerospace fatigue standards could serve as a starting point for future automotive durability standards.

FIGURE 11: MODES OF FAILURE IN ENGINEERED COMPONENTS FOR AIRCRAFT



Source: Materials Today Journal [28]

ACES technologies will not only increase the need for structural durability but will also significantly affect the durability of interior components such as seats, carpets, trim, and electronics. Yellow cabs in New York City (NYC) are a good proxy for studying interior usage of shared vehicles in an urban setting. Each yellow cab in NYC makes 36 trips per day on average.[29] Yellow Taxis serve around 600,000 passengers every day in NYC. With so many people sitting, talking, eating, and reading each day, the interiors of the vehicle get dirty very fast. Thus, the vehicle interiors need to be robust and resist dirt, scratches, and bacteria. The interior supplier community is already working towards the goal and are investing substantial sums of money in research and development of scratch- and bacteria-resistant materials for seats and trim. The interiors suppliers are also working on producing low-cost, replaceable, and recyclable trims. These trends could open up the market for greater use of biodegradable materials. Since fleet owners would also want interiors to be highly customizable, vehicle makers will want to offer multiple trim options to mix and match. Plastics and polymer composites provide excellent

[28] S.J Findlay, N.D Harrison (2002), *Why aircraft fail,* Materials Today, Volume 5, Issue 11
[29] de Blasio, Bill and Yassky, David (2014). *2014 TLC Factbook*. New York City Taxi & Limousine Commission

opportunities for customization and thus will benefit from this trend. Also, advances in additive manufacturing (AM) or 3D printing will help produce custom designs.

Experts, who were interviewed, believe the durability requirement for future vehicles will heavily depend on warranty and ownership models. Today, a typical automaker provides “bumper-to-bumper” coverage ranging from three years/36,000 miles to five years/60,000 miles; this is the general coverage that would pay to repair defects in factory-installed parts. Tires are not typically included because they’re usually covered under a separate tire manufacturer warranty. There are also drivetrain warranties that cover the engine, transmission, and transaxle parts. Drivetrain warranty coverage typically lasts longer than broad warranty coverage. Often, manufacturers also offer a separate warranty to protect consumers against corrosion. In calendar year 2016, top worldwide automakers paid just over $48 billion in warranty claims, which translates to $600 per vehicle.[30] With ACES technology, automakers might face unusually high warranty costs due to unknown considerations such as the frequency and severity of battery replacements, failure rates of sensors, and structural or chassis part replacements due to high wear. Automakers will be faced with three options to consider:

1. Absorb higher warranty cost – in this case the automakers will have to set aside higher percentage of revenue for covering warranty cost

2. Reduce warranty coverage – reducing coverage might lower the warranty accrual cost but might not resonate well with the fleet owners

3. Engineer more durable vehicles – Achieving this goal would require significant investment in R&D and increased materials and manufacturing costs.

If automated and shared vehicles are designed to last longer to meet increased durability requirements, engineers will need to make some critical decisions about which materials to use. There are two broad engineering options for parts:

1. Use same material with a greater safety factor – This approach will add significant mass to the vehicles.
2. Use a new material with higher performance – This approach will be mass-neutral or may even reduce mass, but could have significant impact on cost.

CAR researchers found that automakers are more likely to choose the improved engineering approach for ACES vehicles. This trend is already underway with the increased use of lightweight materials, stringent durability targets, extensive testing procedures, and increasing use of advanced manufacturing technologies to produce mass and performance-optimized parts. The automakers’ challenges lie in optimizing the balance between performance and cost.

[30] http://www.warrantyweek.com/archive/ww20180308.html

Materials for Safety

Automated vehicles' potential to save lives and reduce injuries is rooted in one critical and tragic fact: 94 percent of serious crashes are due to human error.[31] Fully automated vehicles that can sense more of the environmental conditions and act faster than human drivers could significantly reduce errors, the resulting crashes, and their human toll.

The Society of Automotive Engineers (SAE) has defined various levels of driving automation (see Figure 1).[32] NHTSA uses the SAE standard in its federal guidance for *Automated Driving Systems (ADS): A Vision for Safety 2.0*. While there are safety benefits at every level but the real benefits come at level four and five where the human driver is no more controlling the vehicle.

Sensors (LiDAR, RADAR, and vision systems) are the eyes, ears, and touchpoints of an automated vehicle. These components for level 4 and 5 automated vehicles must be protected from damage and cleaned regularly since the passengers will entirely depend on these sensors for driving them safely to their destinations. Even routine activities such as car washing can pose a threat to sensors. In a recent survey, nearly 40 percent of 245 U.S. car wash owners reported instances of a vehicle's forward collision avoidance system applying the brakes during the automated car cleaning process. About 16 percent of those surveyed noted incidents of bumper-embedded sensor damage caused by the cleaning brushes or bristles.[33] Problems with electronics can arrive from all directions and sometimes from not-so-obvious places. For example, vehicle's external paint scheme can pose problems to the LiDAR and RADAR sensors. Dark colors such as black, grey tend to absorb much of the signal transmitted from the increasing number of sensors being fitted to vehicles. RADARs (used to operate safety systems such as automatic braking) transmit radio waves and measure the time it takes for those waves to bounce back, and any changes in their frequency. From this it is possible to determine the range, position and velocity of objects around a vehicle. If some or all of the signal is absorbed instead of being reflected, RADAR sensors can miss critical inputs and provide faulty signals to other vehicle systems.[34] Paint suppliers are working on technologies that can make improve the reflective qualities of darker colors over a wide range of wavelengths.

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[31] NHTSA, https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety

[32] SAE (2016). *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles J3016_201609*

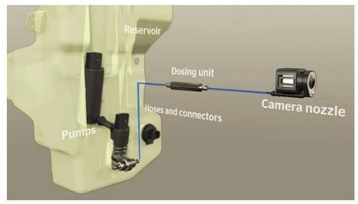
[33] https://www.sae.org/news/2018/04/why-car-washes-threaten-automated-vehicles

[34] The Economist (2018), *How paint jobs can make sensors and automated cars safer*

An automated car cannot drive with dirty sensors. To provide good visibility in all conditions and for infallible security, sensors must be perfectly clean. The sensors must also perform same in all weather conditions. Suppliers are working on a range of technologies for keeping sensors clean (see Figure 12 for examples). There is a need to develop sensor coatings which can resist dirt, ice, and water.

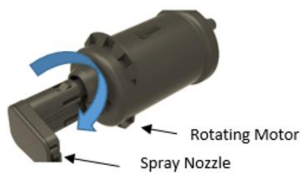
FIGURE 12: SENSOR CLEANING TECHNOLOGIES

Google's self-driving car unit Waymo showed last year how it uses small windshield wipers to clean the LIDAR domes on its cars



Continental Camera Cleaning System

Ficosa ADAS Sensor Cleaner



Valeo sensor cleaner

Companies such as Uber, Waymo, GM, Ford, and Tesla are developing and testing Level 4 automated vehicles on public roads currently. Such test deployments have provided some information on the current status of the technology used to operate automated vehicles. Uber and Waymo have deployed small fleets of test vehicles that have started to service public passengers. Recent fatal crashes, however, such as those involving Uber and Tesla vehicles, reveal current limitations in a technology that is still in the development phase. The National Transportation Safety Board (NTSB) and NHTSA investigations of the 2018 crashes are ongoing, and the final determination on the causes of these crashes have not yet been reached.

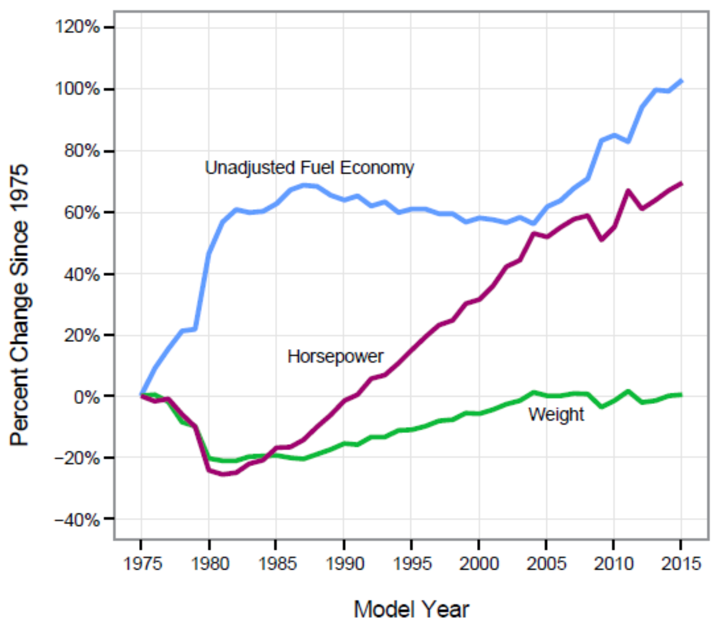
Speculations are high and opinions vary widely on safety regulations for the future automated vehicle. NHTSA is reviewing FMVSS standards related to automated vehicles, and aims to update the regulations in the near future. In the meantime, the U.S. Congress is moving legislation aimed to address the lack of national regulatory guidelines in automated driving. The Senate voted the AV START Act out of committee in September 2017, and the U.S. House of Representatives passed the SELF DRIVE Act that same month. The SELF DRIVE Act aims to establish a transitory framework until the FMVSS is updated. There is a consensus among experts that in the short term, the current federal safety regulations will remain in place, at least till all the vehicles on the road are fully automated. With little change in safety requirements, experts believe the impact on materials due to safety regulation changes will be minimal.

Cybersecurity is another major safety challenge for automakers working on automated vehicles. Driverless vehicles will be at least as vulnerable as computers to all the existing security threats that regularly disrupt our computer networks. The automakers, suppliers, and government regulating agencies are working to safeguard future automated vehicles from cyber threats.

Materials for Lightweighting

Lightweighting is not new. Henry Ford famously said, "Excess weight kills any self-propelled vehicle." The weight of the U.S. vehicle fleet has remained relatively flat over the past decade despite automakers' increased use of lightweight materials (see Figure 13). The reason behind this trend is an increase in vehicle content over the years which has offset any mass reduction.

FIGURE 13: AVERAGE NEW VEHICLE FUEL ECONOMY, WEIGHT, AND POWER (PRODUCTION WEIGHTED)



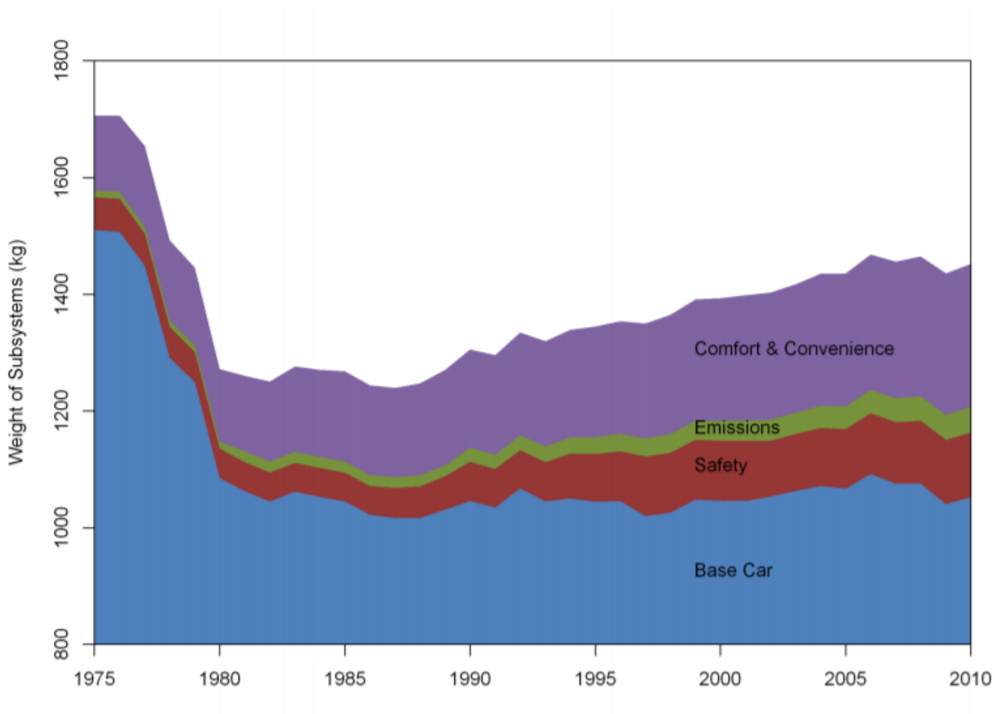
Source: Draft Technical Assessment Report, EPA and NHTSA, July 2016

With the arrival of ACES technology, the pressure on automakers to design lightweight vehicles will intensify. Four major factors will contribute weight to future vehicles

1. Passenger Comfort Features

Consumers are increasingly demanding new comfort and entertainment features in their vehicles. Research has shown that the weight of comfort and convenience features has consistently increased since 1990 (see Figure 14).

FIGURE 14: CHANGE IN VEHICLE SUBSYSTEM WEIGHT 1975-2010

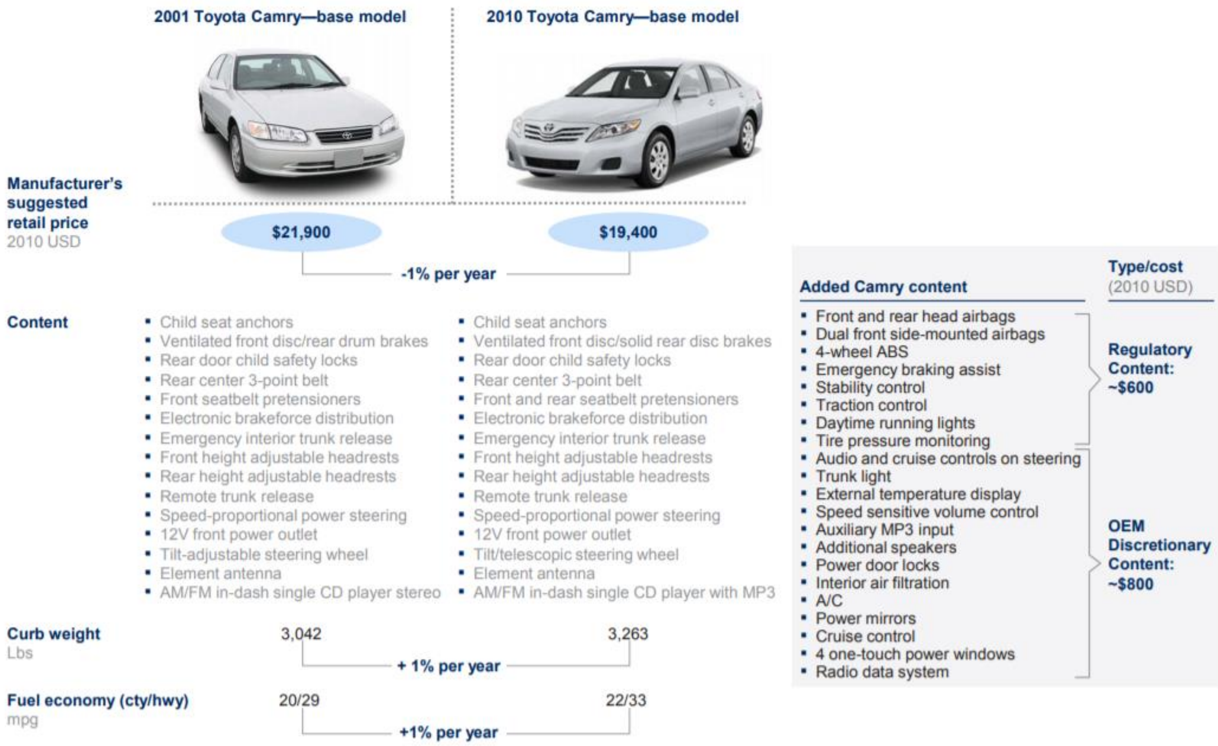


Source: MacKenzie, D., et al., Determinants of U.S. Passenger Car Weight, Massachusetts Institute of Technology, 2012

For example, Toyota Camry's curb weight increased by one percent per year – partly due to OEM discretionary content (see Figure 15). Experts believe this trend will only increase in automated vehicles. CAR research has shown that around five percent curb weight could be added back to the vehicle due to safety and performance features between now and 2025.[35]

[35] Baron, J., Modi, S. (2016), *Assessing the Fleet-wide Material Technology and Costs to Lightweight Vehicles*, CAR

FIGURE 15: TOYOTA CAMRY FEATURES AND CURB WEIGHT FOR 2001 AND 2010 BASE MODELS



Source: Edmunds; McKinsey

2. Batteries

Conventional vehicles with greater fuel capacity can travel farther without refueling. Similarly, battery electric vehicles with larger battery capacity can travel farther on electricity. However, batteries have considerably lower energy densities than liquid fuel. When a vehicle is filled with 10 gallons of gasoline, it contains approximately 337 kWh of energy embodied in the fuel (33.70 kWh = 100 percent of the energy of one gallon of gasoline).[36] A vehicle with 10 gallons of fuel on board weighs an additional 63 pounds, and it gradually drops that weight as the fuel is combusted. A BEV battery pack may contain 100 kWh of energy and weigh 1400 pounds. Each extra pound of battery weight to increase range requires extra structural weight, heavier brakes, a larger traction motor, and even more batteries to carry around the additional mass. For example, the Tesla Model S, with its 4,600 pound (2,086 kg) curb weight, has about 1,600 pounds for the battery alone.

3. Sensors and Related Components

Automated vehicles will have many added sensors and computer systems for driving and navigation. CAR research found that the components required for Level 4 and 5 will add 300-400 pounds to vehicles, on average.[37] The primary source of additional weight is not in the sensors and computer chips; instead,

[36] https://www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf
[37] Discussions with automakers

it is in the wires, thermal management system, cleaning system, and other parts and components that interact with the sensors.

4. Part Redundancy

Engineers try their best but cannot plan for every eventuality. Any design, whether it is for an automobile, a ship, or an airplane, must be done in anticipation of potential failures. Therefore, there are always parts with functional redundancy to ensure safe operation under unforeseen conditions and vehicle abuse. For human-driven, gasoline-powered automobiles, the industry has more than 100 years of experience and data to optimize parts, their function, and weight. With ACES, the engineering requirements could change dramatically. Without a historical data series, engineers will not feel confident in predicting all modes of part failure. Thus, part redundancies will rise to ensure safe on-road vehicle performance, and the increase in the number of parts will add vehicle weight.

Since the pressure to lightweight is expected to increase with the arrival of ACES technology, automakers will continue to explore lightweight materials for vehicle construction. CAR research has shown automakers and tier-1 suppliers are making substantial investments in mixed-material solutions for mass reduction. Materials evaluated for vehicle construction include high strength-to-weight ratio materials such as ultra-high strength steels, aluminum, magnesium, plastics, and polymer composites. A CAR survey of nine automakers revealed that automakers are expected to increase the use of:

- Higher strength steels for up to five percent vehicle curb weight reduction,
- Aluminum, magnesium, plastics for five to ten percent vehicle curb weight reduction, and
- Polymer composites for fifteen percent or more vehicle curb weight reduction.

For high volume vehicles, existing stamping and assembly infrastructure will keep driving use of steel and aluminum, but automakers are evaluating plastics for several metal replacement opportunities in the body structure.

Recent CAR research found that the U.S. fleet will need to achieve up to five percent mass reduction on an average to meet the Obama administration's fuel economy standards for 2025.[38] Even if the proposed fuel economy and greenhouse gas emission standards recede in the U.S., the global standards will encourage automakers to invest in lightweighting their fleets. Material suppliers are well aware of this trend and are investing in research and development of lightweight, high strength, and readily formable materials. For example, steel suppliers are developing generation three (gen-3) steels which have very high tensile strength as well as high elongation; hence, they can be cold formed (shorter cycle times than hot forming). The aluminum industry is developing new alloys in the 7000 series and is working to reduce costs. The plastics and polymer composites industries are developing new chemistries to tailor material performance to meet automakers' needs.

ACES vehicles are projected to have lower sales volume to start, which will open opportunity for composites because of low tooling costs required to form these materials. The use of carbon fiber

[38] Baron, J., Modi, S. (2016), *Assessing the Fleet-wide Material Technology and Costs to Lightweight Vehicles*, CAR

reinforced plastics (CFRP) might increase for applications in structural reinforcement. However, there are issues around CFRP supply chain, cost, and cycle times that need to be addressed before these materials can be put to broader use in the vehicle. The battery cage is another area of opportunity for polymer composites. Batteries are highly flammable, and therefore need to be protected and separated from the passenger cabin. Most battery cages are made of steel today, but automakers are increasingly using aluminum and polymer composites for additional lightweighting and safety performance. New rigid structural foam materials can also be used for battery protection because they are flame retardant, durable, and provide thermal insulation to minimize battery inefficiency at low temperatures.

Few experts believe the components for Level 4 and 5 automated vehicles are adding significant weight because most components are off-the-shelf, hence, they cannot be customized to fit vehicle's mass targets. The relative weight of automated systems may change as the technologies mature. For batteries, there are numerous chemistries currently in development with the goal to increase energy density and reduce weight. Solid state is one such promising technology that can increase the energy density and reduce weight up to five percent compared to Li-ion batteries. Although, solid state battery is in initial phases of research and it may take a long time for commercialization. Weight also could be reduced in urban ACES vehicles, because people might not demand comfort and entertainment features such as a ten-speaker stereo system, DVD players, heated and cooled seats, or other creature comforts for a 15- to 20-minute ride.

Materials for Superior Ride Experience

Automated vehicle fleet owners will be able to differentiate their service based on the overall customer experience they provide. They will strive to offer an excellent experience from booking the ride to exiting the vehicle. As vehicles use more lightweight materials, the NVH profile will change. NVH will become an essential criterion in automated and shared fleet for driving customer satisfaction. This is especially the case for electric vehicles since road noise is much more pronounced without engine noise to mask it. Future material selection could be influenced by new criteria requirements such as the acoustic profile of the material. Automakers are investigating several materials to improve NVH, for example, polycarbonates versus glass to reduce high frequency wind noise.

Immaculate and hygienic interiors will also be a large part of customer experience. Shared vehicles will undergo wear and tear, especially ACES vehicles which are expected to be in use for up to 22 hours a day. Scratch resistance will become necessary to maintain the interior conditions of the vehicle. Bacteria resistance will also be just as important to maintain a sanitary cabin area for passengers. Self-cleaning and self-repairing materials are also in development.

Materials for Ensuring Connectivity

Both vehicle connectivity and sensor-based systems supporting automation are likely to impose demands on materials used to encase them, near them, etc. While automated vehicles (SAE levels 4 and 5) might or might not use vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) connectivity to supplement sensor-based systems for safe operation, many automakers will continue to provide non-safety-critical connectivity (e.g., telematics, infotainment, etc.) regardless. These components will require materials that do not interfere with transmitting and receiving signals. The industry has lots of experience at this already to support telematics, satellite radio, and other on-board systems. Automakers and suppliers also are working on new antenna designs that allow multiple systems (dedicated-short range communication, AM and FM radio, satellite radio, cellular, etc.) to use a single antenna, and these new designs also will present opportunities and challenges for materials. For example, LiDAR uses light in the form of pulsating lasers that can be blocked by everyday opaque objects. RADAR uses radio waves that can be obstructed by any material, but some materials (such as metals) obstruct more than others. Automotive engineers will have to make sure the materials and coatings encompassing the sensors are transparent to electromagnetic waves used by these systems, and they likely will need to design and deploy new components that keep sensors from becoming occluded due to dirt, dust, and other substances encountered in the road environment.

Engineers of ACES vehicles must be mindful of all of the various factors discussed above when deciding which materials to use in automated and shared vehicles. Moreover, the decisions will also be governed by cost, global supply-chain, and available resources.

Impact of ACES on Manufacturing

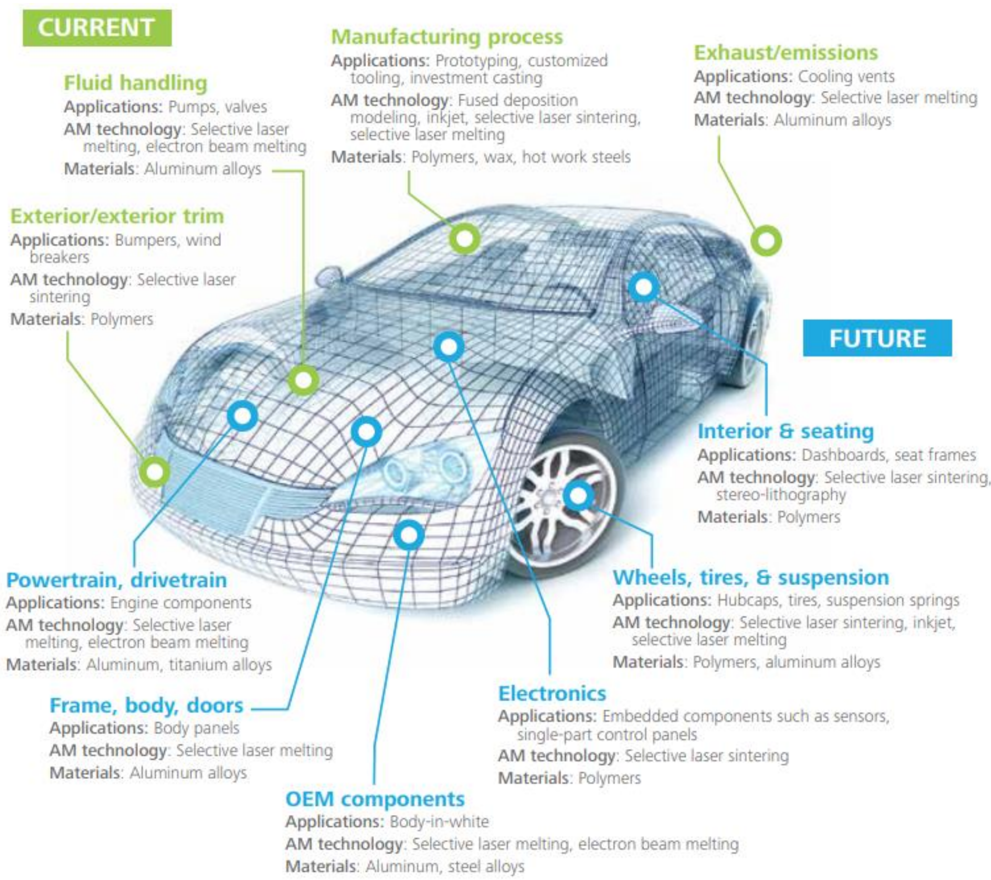
The automotive industry is exceptionally adept at high volume production as well as in the production of niche market products. Hundred years of experience have increased productivity, improved quality, and reduced vehicle costs. Automakers are continually evolving their manufacturing techniques to optimize their processes further. Experts suggest that ACES technologies may force automakers to rethink their manufacturing strategies. Most think there may not be a revolutionary change in manufacturing but will change existing processes in the long run. However, new players in fast-growing markets like China may completely revamp the traditional approach to manufacturing since they are not constrained by tradition and stranded capital investment. Moreover, shortened development cycles are another factor that will force automakers to rethink manufacturing strategy. The rapid development of autonomous vehicles may result in forgoing the traditional multi-year development cycle and utilize a more agile approach that improves rapidly and can deliver technology to retrofit existing in-market vehicles. In the world of ACES, flexible manufacturing will be the key to success.

Future vehicles bodies are expected to use different types of materials in subassemblies, and these materials will impact stamping operations, body shops, and paint shops. Sensors and other components of automated driving systems will add complexity to general assembly and testing. The next section examines these impacts in detail:

Stamping/Tool Shop – Metals are fabricated into vehicle components by a variety of processes – casting, extrusion, roll forming and ambient-temperature forming (stamping). For simple shapes (such as bumper beams and rockers) ultra-high strength steels (UHSS) are roll formed at ambient temperatures but for more complex shapes (such as B- pillars and front–end members) some advanced high strength steels (AHSS) require hot stamping. Automakers' investments in the dies and equipment for hot-stamped parts are expected to increase. Correspondingly, fabricating high-volume parts from plastics will require capabilities in injection molding, which most automakers and suppliers already have. For lightweighting and part consolidation, automakers are investigating polymer composites (using thermoset resins). Production of polymer composite parts require investments in resin transfer molding (RTM), compression molding, autoclave, et. cetera. Automakers will need to invest or relocate billions of dollars to make such changes to the stamping and tooling shops.

Innovative manufacturing technologies such as additive manufacturing (AM) or 3D printing could bring revolutionary change in stamping plants and tool shops. The biggest challenge in commercializing AM is cycle times which are far too long for mass production scale currently. Automakers, suppliers, and start-ups are investing substantial sums of money and resources for quick progress in developing AM for automotive use. The global market for AM in automotive is expected to grow with a compound annual growth rate of 26 percent. AM parts could also be used in vehicle repair and service parts. Figure 16 shows current and future application of AM technologies in the automotive industry.

FIGURE 16: APPLICATION OF ADDITIVE MANUFACTURING IN AUTOMOTIVE



Graphic Source: Deloitte analysis

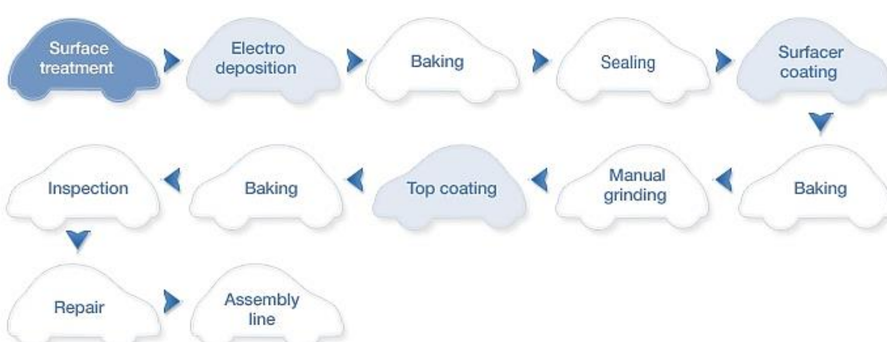
Body Shop - Vehicle bodies are joined traditionally by resistance spot welding (RSW). There can be as many as 5000 spot welds in the typical body-in-white of a mid-size car. However, automakers cannot use conventional RSW process for multi-material applications due to the vast differences in melting points between dissimilar materials. Adhesives, fasteners, and laser welding are the expected to become more prominent joining technologies in the future. This change will not be accomplished easily since welding delivers excellent cycle times and low cost (around five cents per spot). On the other hand, adhesives are expensive due to higher material costs and longer cycle times. Mixed-material application in the body-in-white and changes in primary joining technology will affect automotive manufacturing body shops significantly.

Body shops will continue to change based on many factors mostly driven by lightweighting which is equally important for both ICE vehicles and ACES vehicles. Since ACES vehicles are expected to have lower volumes at first, body shops will need to be aligned for low volume production. However, ACES vehicles alone are the not the only driver for body-in-white (BIW) manufacturing change.

Paint Shop – The automotive paint process consists of electrocoating (e-coat), primer, and multiple paint layer applications. The body-in-white needs to go through the paint process which consists of a bake oven to cure the paint, sealants, and adhesives in the vehicle. Vehicles experience their highest chemical and thermal history in paint shops. Paint shops would have to be reimagined for ACES vehicles. There are three major issues to be addressed – coefficient of thermal expansion (CLTE) differences, corrosion, and sensor integration.

The paint bake oven temperatures range from 180-250 degrees Celsius. The CLTE measures the fractional change in size per degree change in temperature at a constant pressure. The materials in a multi-material body will expand differently due to the difference in CLTE. These differences can distort the body structure if the joints are rigid and do not allow for free expansion. The effect could also drive components for Level 4 and 5 automated vehicles to be added after body and paint shop, rather than incorporating into the structural build.

FIGURE 17: VEHICLE PAINT PROCESS STEPS



Source: KCC Paintings

The second paint shop issue is corrosion. Vehicle's today are designed to last ten plus years. The electrodeposition (e-coat) process protects against long-term corrosion. If shared vehicles deplete their lifetime miles in three to four years, then in theory, the paint shops might be able to reduce the current emphasis on corrosion protection. Lastly, sensors integrated in BIW need to be safeguarded by high oven temperatures.

Assembly Shop – The most significant impact of ACES will be in general assembly (GA). There are hundreds of components such as powertrain, electronics, trims, seats, and others that are added to the painted body-in-white in GA. For ACES vehicles, the number of these components will increase to include cameras, RADAR, LiDAR, batteries, additional wires, and other supporting electronics. This will further complicate the assembly process, and it will make end-of-line testing more complicated, expensive, and time-consuming. Advanced data analytics companies are already applying artificial intelligence to tackle this challenge.

Another challenge is the integration of components for Level 4 and 5 automated vehicles into the existing vehicle. Most of these parts are off-the-shelf which leaves little room for optimization. While these characteristics may change in the future, the integration challenge will remain. Location of sensors should allow them to read, detect, and transmit to objects around them. Automakers will also have to consider the serviceability of components for Level 4 and 5 automated vehicles. A poorly placed sensor could make an automated vehicle unusable after a minor crash. For example, cameras are built into the bumper system currently. In a fender bender situation, it will be expensive to repair the automated driving system, and difficult to calibrate to factory standards.

Impact of ACES on Business Models

Revolutionary advancements in technology to improve vehicles' value and people's lives is a big mission, but doing so while maintaining or increasing profit margins is challenging. Once the technology is ready for commercializing there are decisions to be made for the successful operation of a business which includes identifying revenue sources, customer base, suppliers, production sites, products, and details of financing. For a long time, the automakers have based profits primarily on vehicles sales. With the arrival of ACES and innovative mobility services, the revenue streams will diversify.

Automotive companies, technology firms, mobility providers, and many other organizations are working to define various business models for the deployment of ACES vehicles. A few of the main parameters for determining mobility services using ACES passenger vehicles are:

- Pricing level (e.g., from basic to high-end vehicles and related services);
- Fleet ownership (e.g., same fleet owner and operator, fleet owner different from fleet operator); and
- Service type (e.g., purely on-demand rides, flexible or fixed route, flexible or fixed schedule).

The next section examins the impact of ACES on various aspects of the automotive business:

Vehicle Production

There are around 15 global automakers that design, engineer, and produce about 100 major vehicle brands. Automakers' in-house manufacturing sites produce most brands, with only few exceptions that are produced by contract manufacturers. ACES technology will challenge the traditional vehicle production and sales model. Figure 18 shows three future options for ACES vehicle engineering and production.

FIGURE 18: ACES VEHICLES ENGINEERING AND PRODUCTION BUSINESS MODELS

Outsourced Production Model

- Auto companies design and engineer the structure and interiors
- Production outsourced
- Auto companies operate their own fleets

Engineering Company Model

- Auto companies design and engineer the structure and interiors
- Vehicle produced by generic sites
- Fleet companies like Uber, Lyft, Ola operate the fleet

Mass Customization Model

- Auto companies design, engineer, and manufacture the core structure
- Interior design selected by fleet operator
- Fleet companies like Uber, Lyft, Ola operate the fleet

Source: CAR Research

The first option for automakers is to keep vehicle engineering in-house, operate a fleet of shared vehicles, but outsource production to contract manufacturing sites. Incorporating low-volume vehicles in high-volume production lines is a logistical challenge and is not cost effective. Since ACES vehicles will have low production volumes in the initial years, outsourcing production might be a viable strategy. The recent moves from Jaguar and BMW to outsource their electric vehicle production to Magna Steyr in Europe confirms this trend. Once the production strategy is determined, the next challenge is operating the fleet. To quickly get into the fleet operation business, some automakers are buying mobility companies. Figure 19 shows recent automaker partnerships, acquisitions, investments, and in-house brands related to mobility, driving automation, and connectivity. Investments in Mobility as a Service (MaaS) companies is helping automakers stay in touch with technologies around the service business and generate non-traditional revenue. This strategy helps in avoiding risk of investing only in new ACES technologies with their long development times before generating revenues. If such a consolidation trend continues, the industry might favor option one.

FIGURE 19: MAJOR AUTOMAKERS' PARTNERSHIPS RELATED TO MOBILITY, CONNECTIVITY, AND DRIVING AUTOMATION

Source: CAR

The second option is the engineering company model, where traditional auto companies retain only the vehicle engineering part of the business for ACES vehicles. The vehicle production is outsourced to contract manufacturers, and third-parties such as carsharing, ridesourcing, taxi companies, or technology companies operate the fleet.

The third option is when traditional automakers design, engineer, and produce only the core structure of the vehicle and the interior components are selected and sourced by fleet operators. Automakers may assemble these interior components at their manufacturing locations. This approach is analogous to the airline industry where companies such as Boeing produce airplane's core structure, and fleet operators such as Delta, Southwest, or Virgin select the interior design and seat configuration.

Software plays a prominent role in each of the business models described above. Most of the customer interaction would be through software – primarily via mobile devices. Thus, automakers would either have to aggressively develop software skills or partner with software companies to run their operations.

Automakers may experiment with different business models to start. Experts reason that shared mobility will be an added business model, not a complete replacement, and that revenues from traditional vehicle sales will not disappear entirely.

Automaker – Supplier Business Relationship

Suppliers play a vital role in research, development, production, and supply of innovative technologies to automakers. With uncertainties around market and timing of ACES vehicles, it's challenging to identify areas of investment that can create long-term value. Indeed, many suppliers will face tough decisions regarding whether and how to divest components where profits don't come under pressure, and how to position themselves to pursue the most attractive opportunities.

The automakers will rethink the terms and conditions before signing long-term contracts with suppliers. Warranty models could guide future business terms. For example, suppliers might be responsible for high wear components such as tires, suspensions, seats, et. cetera in shared vehicles.

One possible future business model is the revenue share model where suppliers share revenue with automakers, but provide their products or service for free. This model could be feasible for products that require high investment in infrastructure, for example, battery systems production. This scenario will likely make sense when most of the revenue is coming from the fleet operation. In the current scenario, most revenues come from vehicle sales. The revenue sharing model could be riskier for suppliers than the current business model because sales forecasts can be changed by uncontrollable factors such as gasoline prices, geopolitical risks, or economic conditions. In the aerospace industry, planes are rarely sold by manufacturers to airlines but are more commonly leased via financial services companies. Yet, most material suppliers have conventional point of sale relationships with plane manufacturers and do not engage in shared revenue models.

At the dawn of shared mobility, suppliers will have to form internal mobility-focused divisions and start targeting fleet operators (as the true influencers of future materials and design) rather than automakers.

Role of Dealers

Dealers today are the primary customer of the automakers. It is the dealer who interacts directly with the consumer and maintains a relationship on automaker's behalf. Dealers earn money in two ways: first by making profits on new and used vehicles sales, and second by servicing the vehicles in use. In the world of shared mobility, consumers will no longer buy and own vehicles, thereby challenging the primary business model of dealers. Opinions on the future of dealers vary widely across the industry. Few experts believe there will be no dealers or similar middleman in the future business model. The automakers will sell vehicles to the fleet operators directly or operate their own fleet. Other think dealers will play a vital role in the ACES world, especially in service and maintenance. Few also believe that large dealership networks may operate their own fleets. Nevertheless, dealers will be challenged to rethink their primary business model to survive.

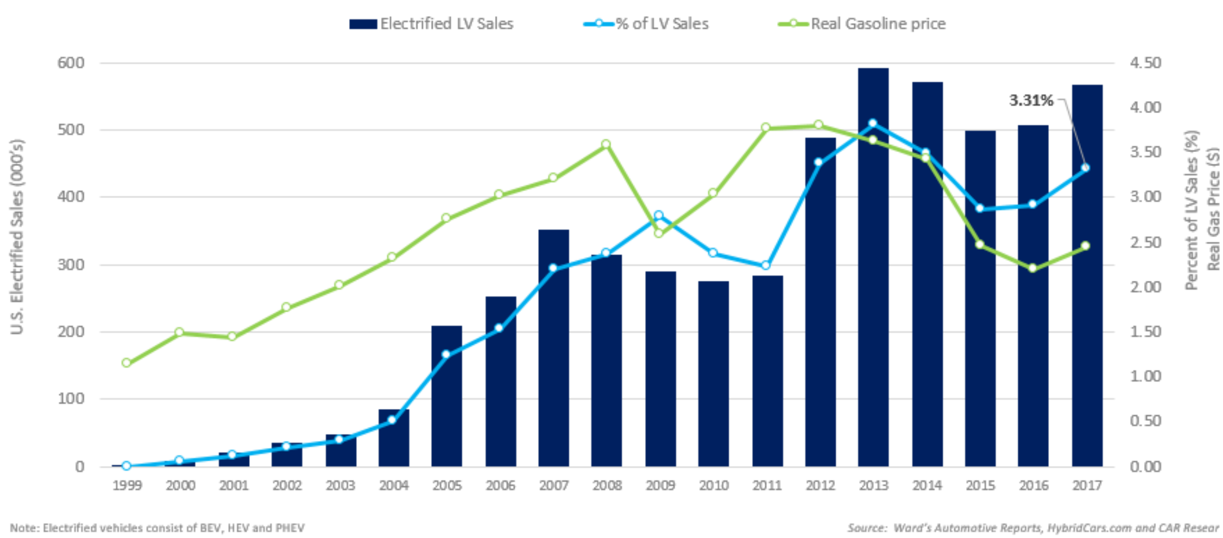
Legislative and Regulatory Framework

When automated, connected, and electric vehicles are deployed in shared mobility services, legislators and regulators will define specific rules that govern their operation. This framework will most likely evolve from rules that currently apply to carsharing, ridesourcing, and taxi operators. Thus, requirements regarding insurance, vehicle inspection, and passenger safety and security might also have an impact on the ACES design, materials, and manufacturing.

CUSTOMER ACCEPTANCE AND COST OF OWNERSHIP

The rate of adoption of electric vehicles in North America is slow. In 2017, only three percent of light vehicles in the United States were electrified, which include hybrid vehicles (see Figure 20). Pure electric vehicles represent less than one percent of the U.S. market.

FIGURE 20: U.S. ELECTRIFIED LIGHT VEHICLE SALES AND TAKE RATE



Source: Ward's Automotive, HybridCars.com, CAR

Factors behind slow uptake of EVs are low gas prices, range anxiety, high battery replacement cost, low resale value, and limited charging infrastructure. Industry experts believe this trend might continue until battery prices decrease substantially. According to a report in Bloomberg News, Li-ion battery packs are now at $209 per kWh, an 80 percent drop since 2010. Projections show with advancements in battery production technology and an expanding supply-chain, Li-ion battery packs costs could fall to $100 per kWh by 2025. Researchers are also working on innovative chemistries such as solid-state electrolytes. Battery cycle life is measured in cycles, with an industry standard of cycles to 80 percent capacity often used as a benchmark. According to Oak Ridge National Laboratory, a high-voltage (5V) solid-state battery can achieve an extremely long cycle life of over 10,000 cycles while retaining more than 90 percent of its original capacity.[39]

CAR researchers found that most automated vehicle programs are using electric vehicles and hybrids for development. Components for Level 4 and 5 automated vehicles require battery power and supporting electrical infrastructure which is already available in an electric vehicle, enabling faster implementation. CAR projections show automakers will continue to use electric vehicle platforms for automated vehicle development. Electric vehicles are also better for automated mobility services because they would be easier to maintain. Charging could also be less labor intensive with inductive charging. Assuming customers will worry less about the underlying propulsion technology in automated vehicles, this trend could prove to be one of the most important factors for driving future EV sales.

There are also many unanswered questions about the affordability of automated vehicles. Automakers and suppliers are investing millions of dollars for research and development of ACES. However, the innovative electronic components which will drive automated vehicles are costly. For example, Velodyne's original 64-laser LiDAR cost $75,000. Experts suggest the decrease in cosmetic requirements for the suppliers of exterior components might help to compensate for the higher technological cost. Also, the prices for components for Level 4 and 5 automated vehicles may come down in the long run when manufacturers are able to achieve economies of scale. For example, Velodyne is advertising a $7,999 price for a 16-laser model introduced in 2014, but has set target pricing of less than $500 per unit in automotive mass production quantities. Nevertheless, for the early adopters, the technology will still be very expensive. For ACES vehicles that are part of fleets, higher acquisition prices are less of a problem than for privately-owned AVs, because with high utilization rates and optimal ride pricing, shared vehicles' initial cost could be recouped reasonably quickly.

There are uncertainties around the cost of ownership and market penetration of ACES vehicles. Automakers believe generational acceptance of increased value in ACES vehicles could allow the price per ride to increase in the future. One can make an analogy by comparing similar scenarios in other industries. For example, customers are willing to pay $1,000 for certain models of mobile phones because the device is capable of doing additional tasks such as taking photographs, sending emails, ordering food, and providing navigational assistance. Similarly, ACES vehicles will not just be a transportation tool but will create additional opportunities. For example, commuters can use traveling time for work or rest to increase personal productivity. Residents and businesses can reclaim parking spaces. Vehicle emissions may fall. Consumers will save vehicle maintenance time. The market will value these benefits positively and allow vehicle prices for fleet owners to increase in the short run.

Experts suggest, in the short term, connected, human-driven ICE vehicles could be used for promoting ride-hailing and ride-sharing as a 'low-tech' and cost-effective way to reduce traffic and GHG emissions while increasing vehicle utilization and passenger density per miles traveled. Conventional vehicle

[39] A High-Energy Solid State Battery with an Extremely Long Cycle Life, OakRidge National Laboratory, https://www.ornl.gov/content/high-energy-solid-state-battery-extremely-long-cycle-life

designs, materials, and processes, independent of electrification and autonomy, can allow next-generation technologies to grow in use without urgently upsetting the automotive market.

SUMMARY OF FINDINGS

CAR researchers interviewed several experts from automakers and suppliers to understand the impact of ACES vehicles on design, materials, manufacturing, and business models. The following sections summarize the findings of this study on each of the discussed topics.

Design

Vehicle design is driven by many factors including function and aesthetics. Interior design will be very important for ACES vehicles. Since functionality plays a large role in governing design, ACES vehicle design will depend on its intended use. Current research shows that consumer loyalty is driven by appearance more so than functionality and price, but these preferences are subject to change for shared vehicles. Experts suggest function, for example aerodynamics, may drive exterior design in ACES vehicles. Interior design will be critical for ACES vehicles. The interior design will likely feature biometrics, flexible seating, scratch and bacteria resistant material, replaceable components, smart surfaces, and personalized trims. There will be greater emphasis on cabin space and less on A-pillar visibility and rearview field. Lastly, in regards to structural design, the change from ICE to EVs will create new opportunities in packaging, along with a lower center of gravity, and ability to utilize front compartment space. Overall, these design changes permit greater freedom to design studios and packaging engineers.

Materials

For ACES vehicles, material selection will be driven by design optimization, durability, safety, lightweighting, ride experience, and needs for connectivity and automation. ACES vehicles will be operated much more than conventional vehicles on a daily basis. This higher utilization will lead to greater reliance on components that require improved structural durability. Durability requirements will likely rely on warranty and ownership models. Interior durability will become critical and therefore there will be a demand for customizable and replaceable materials such as plastics and polymers. The broad engineering approaches are using either the same material with a greater factor of safety or using a new material with higher performance.

Safety will be another factor in material selection. U.S. federal safety regulations are unlikely to relax in the near future. In the short term, federal safety regulations (FMVSS) will not change significantly until all vehicles on the road are fully automated (SAE Level 4 at least), leading experts to believe the impact of safety regulations on material selection will be minimal in this time frame. In the safety arena, sensors such as LiDAR and RADAR will require protection from the elements and some method of preventing them from becoming occluded due to dirt and other substances in the road environment. Additionally, due to the thermal hazards of batteries, flame retardant materials are likely to be preferred in many areas of the vehicle.

Finally, the need for lightweighting will increase the use of mixed-materials and polymer composites. Due to the weight increase caused by the migration from ICE vehicles to EVs, and the addition of components for Level 4 and 5 automated driving, materials with full recyclability and high strength-to-weight ratios, such as high-strength metals, plastics, and polymers, will be considered and desirable.

Manufacturing

Revolutionary change in legacy manufacturing plants are not expected in the near future; however, new players (such as vehicle manufacturers in China) that are starting from scratch have the potential to revamp manufacturing, because they are not constrained by stranded capital in legacy equipment. Additive manufacturing could bring revolutionary change if commercialized for production parts. Furthermore, dependent on the designed lifetime of the vehicle, manufacturers might not need e-coat paint in their paint shops (if a vehicle is designed for a short life). Lastly, assembly will become much more complicated with added components for automation and required calibrations due to sensor integration. This also will affect repair and maintenance, suggesting the design and manufacturing for reparability could take on added importance.

Business Models

ACES vehicles will impact business models in numerous ways. MaaS is expected to be an added business model, not a replacement for direct-to-consumer vehicle sales. Three main production models are most likely to exist side by side: the outsourced production model, the engineering company model, and the mass customization model. Warranty models could guide business terms. Suppliers may also have to work directly with fleet operators. Components for Level 4 and level 5 automated driving currently are very expensive, but uncertainties about customer valuation remain because of the unique benefits offered by shared, automated vehicles. Generational acceptance of increased value in ACES vehicles could permit the price increase in the future as features and content expands.

Automated, Connected, Electric, and Shared (ACES) vehicle technologies are compelling automotive engineers to reevaluate vehicle design, materials, and manufacturing technologies. Increased duty-cycles, emphasis on interiors, battery and sensor protection, and the changing customer perceptions and preferences for vehicle performance will change fundamental engineering requirements. These changes will pave the way for use of new materials and new manufacturing technologies. As the vehicle lifecycle decreases, full recyclability and life-cycle-assessment will become critical. The timing of deployment and pace of technology introduction are affecting how new products are developed and by whom.

Future Research Opportunities

This report studied the board impacts of ACES technology on vehicle design, materials, manufacturing, and business models. There are several future research opportunities to broaden the scope of this study, including:

- Impact of ACES on commercial trucks
- Melding ACES within the city infrastructure
- Government regulations for automated vehicles
- Testing procedures for ACES vehicles
- Focused research on ACES impact on steel/aluminum/polymer composites/magnesium
- Dealership sustainability
- Impact of ACES on manufacturing 4.0 or smart factory initiatives

REFERENCES

AAA (2018). *Vehicle Technology Survey*. Retrieved from AAA Newsroom

Baron, J., Modi, S., *Assessing the Fleet-wide Material Technology and Costs to Lightweight Vehicles*, CAR, September 2016

Bhuiyan, Johana (2018). *Uber powered four billion rides in 2017. It wants to do more — and cheaper — in 2018*.

car2go (2017). *White paper - The five conditions essential to successfully operate automated carsharing fleets in the future*

de Blasio, Bill and Yassky, David (2014). *2014 TLC Factbook.* New York City Taxi & Limousine Commission

European Conference of Ministers of Transport (ECMT), *Glossary for Transport Statistics*, United Nations Economic Commission for Europe (UNECE).

Federal Highway Administration (2018), U.S. DOT, https://www.fhwa.dot.gov/ohim/onh00/bar8.htm

Feigon, S. and C. Murphy (2018). *Broadening Understanding of the Interplay Between Public Transit, Shared Mobility, and Personal Automobiles*. Pre-publication draft of TCRP Research Report 195. Transportation Research Board, Washington, D.C.

Giffi, C. A., Vitale, J., Schiller, T., & Robinson, R. (2018), *A Reality Check on Advanced Vehicle Technologies Evaluating the Big Bets Being Made on Autonomous and Electric Vehicles, Deloitte Insights*

Hall, Jonathan and Krueger, Alan (2015). *An Analysis of the Labor Market for Uber's Driver-Partners in the*

Kumar, M. , Townsend, J. D. and Vorhies, D. W. (2015), *Enhancing Consumers' Affection for a Brand Using Product Design.* J Prod Innov Manag, 32: 716-730. doi:10.1111/jpim.12245

Lomas, Natasha (2017). *Uber has seen a sharp drop in new driver retention this year: Apptopia*, Techcrunch, published Jun 23, 2017

Lyft (2018). *Economic Impact Report*.

OakRidge National Laboratory (2014), *A High-Energy Solid State Battery with an Extremely Long Cycle Life*, https://www.ornl.gov/content/high-energy-solid-state-battery-extremely-long-cycle-life

S.J Findlay, N.D Harrison (2002), *Why aircraft fail*, Materials Today, Volume 5, Issue 11

SAE (2016). *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles J3016_201609*

SAE (2016). *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles J3016_201609*

Sivak, M., Schoettle, B. (2015), *Motion Sickness in Self-Driving Vehicles*, UMTRI

Smith, B., Spulber, A., Modi, S. Fiorelli, T. (2017), *Technology Roadmaps: Intelligent Mobility Technology; Materials and Manufacturing Processes; and Light Duty Vehicle Propulsion*, CAR

The Economist (2018), *How Paint Jobs Can Make Sensors and Automated Cars Safer*

The Economist (2018), Self-Driving Cars Will Require New Business Models, https://www.economist.com/special-report/2018/03/01/self-driving-cars-will-require-new-business-models

Wallace, R.,Brugeman, V.S. (2011), *Green and Connected: A White Paper for the Michigan Department of Transportation*, CAR

APPENDIX 1 - INTERVIEW QUESTIONNAIRE

ACES definition – A SAE level 4/5 vehicles with electrified powertrain. It may or may not be shared.

Timeframe – 2030 and beyond

Questions:

1. **Durability and Safety**
    a. If the vehicles are used 40-60% of the day as opposed to 5% today, how will it affect the design and factor of safety of components?
    b. Will ACES have a significant impact on the actual materials used today or will it be predominantly a geometrical optimization?
    c. What type of protection ADAS components need on top of occupant protection?
    d. How could battery protection regulations change vehicle design?

2. **Lightweighting** – As electrified powertrain and ADAS technologies will add significant weight to the vehicles, need for lightweighting will increase.
    a. How would materials change if vehicles in future are 25% lighter than today's median?
    b. What is expected to be the average added weight for ADAS features?

3. **Recyclability and Renewability** – As autonomous, shared vehicles will have a much shorter lifecycle due to continuous service (think of taxis today), full recyclability will be vital.
    a. What role with life-cycle-analysis (LCA) play in future?
    b. Can we achieve full recyclability will polymer composites bonded with adhesives?
    c. Is it possible to recycle/repurpose Li-ion batteries?

4. **Manufacturing**
    a. Will ACES require a major re-design of body-shops, paint shop, and general assembly?
    b. What role could Industry 4.0 play in ACES manufacturing?
    c. What role could Additive manufacturing play in vehicle manufacturing? Will it be limited to tooling?

5. **Business**
    a. If automakers provide vehicles as a service instead of selling them, how could the OEM-supplier business model change? Will OEM start requesting suppliers to qualify their products by use/lifecycle?
    b. What changes do you anticipate in supplier liabilities and legal requirements in a fully autonomous ecosystem?
    c. What could be the potential impact on vehicle dealers due to new mobility models?

6. **Scratch and Bacteria resistance** – For shared vehicles, users would want the interior to be bacteria free and look fresh. We will need smart materials that can heal themselves and interior components that can resist dirt and bacteria. Please comment on research and investments by OEMs and suppliers for such materials.

7. **Cost**
    a. How can the industry advance material technology without increasing cost exponentially?
    b. What is the expected additional cost of ADAS features to offset?

