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Technology Roadmaps:

Intelligent Mobility Technology, Materials and Manufacturing Processes, and Light Duty Vehicle Propulsion

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The Center for Automotive Research, a nonprofit automotive research organization, has performed detailed studies of the contribution of the automotive industry and its value chain in the U.S. economy for more than 35 years.

CAR's mission is to conduct independent research and analysis to educate, inform and advise stakeholders, policy makers, 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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Introduction

Major technological advances to both products and manufacturing processes are accelerating innovation throughout the automotive industry. To capture the scope of these technologies, the Center for Automotive Research (CAR) was called upon by Innovation, Science and Economic Development Canada (ISED) to develop and validate a technology roadmap for the automotive sector. This roadmap provides a broad understanding of technology trends throughout the industry from current year to beyond 2030.

CAR identified and reviewed over a hundred existing roadmaps published by consulting firms, independent think tanks, trade journals, and CAR's own research. CAR also conducted literature searches and reviewed announcements at key industry events to identify any emerging technologies that were not covered in existing roadmaps. Based on the information gathered, CAR synthesized the research and existing roadmaps into three groups: Intelligent Mobility Technology; Materials and Manufacturing Processes; and Light Duty Vehicle Propulsion. Once these synthesized technology roadmaps were developed, CAR convened a roundtable of 25 experts from each of the technology groups to validate the findings.

This whitepaper synthesizes the results from the technology roadmap project conducted for ISED and adds further interpretation of the challenges and concerns related to the projected technology and manufacturing trends.

Intelligent Mobility Technologies

Advances in connectivity, automation, and new mobility services are powerful agents of change affecting the automotive industry, the larger transportation sector, and beyond. To better assess the potential and likely directions and magnitude of change, the Center for Automotive Research (CAR) developed a "technology roadmap" that reflects input from a wide array of industry experts. This roadmap is the result of CAR's in-house research, completed by a critical analysis of reports from leading consulting firms, investment banks, and universities and validated by select industry leaders and stakeholders. While there is an overall consensus on the direction and nature of changes through which the industry is going, a great deal of uncertainty remains in predicting specific timeframes.

The World We Know

Vehicle automation, connectivity, and mobility encompass trends in technology and business models that have been in motion for decades; however, in the last five to 10 years, the transportation sector has witnessed an acceleration in technology development and strategy decisions. In this period, automated vehicle systems that influence the lateral or longitudinal (or both) motion of a vehicle, including applications such as automated park assist, adaptive cruise control, and automated emergency braking, have become available on an increasing number of new vehicles. Eventually, this trend is expected to culminate in fully automated (i.e., SAE Level 5[1]) vehicles. In a parallel evolutionary track, numerous advanced driver assistance systems (ADAS) that warn, aid, and assist drivers were introduced

[1] SAE International, a global association of engineers and related technical experts in the aerospace, automotive and commercial-vehicle industries, has defined six levels of levels of automation for on-road motor vehicles that are detailed in the J3016 standard. Level 5, Full Automation, is defined as "the full-time performance by an Automated Driving System of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver."

in 2000-2010 on higher-end vehicles. ADAS serve to automate specific vehicle systems for improved safety and better driving, though a human driver remains in command.

Vehicle connectivity covers a wide variety of functional systems, from telematics and infotainment to vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications focused on cooperative, active safety. In recent years, great progress has been made developing and testing V2V and V2I equipment and applications, and regulatory rule-making has us on the brink of a V2V mandate.

New mobility services (NMS) provide entirely new business models or reshape existing models with technology, such as ridehailing linked to for-hire vehicles or ridesharing linked with carpooling. Generally, NMS are enabled by emerging technology platforms and wireless connectivity that allow for more convenient, efficient, and flexible travel. Their beginnings can be placed roughly in the 1990s. Real growth occurred in the 2010s when the number of different concepts (or business models) and companies increased substantially; NMS are especially appealing in dense urban areas.

Drivers of Change, Technological and Otherwise

Intelligent mobility technologies are enabled by several recent technology innovations, including digital cellular networks, powerful computer processors, various sensors (including GPS), data fusion, and machine learning. Automotive manufacturers are always on the look-out for innovative technologies to differentiate their products. Intelligent mobility technologies will be increasingly important in the marketing of new vehicles, as well as nurturing relationships with consumers. Automotive manufacturers and tech companies big and small have engaged in a race towards the development of these technologies, and automakers are now competing with new players in the emerging mobility industry to remain relevant and innovative. Automakers are particularly interested in connectivity, automation, and ADAS, because they offer car buyers new solutions for safety and convenience, and such features can increase the profit margin of vehicle sales and offer new revenue streams.

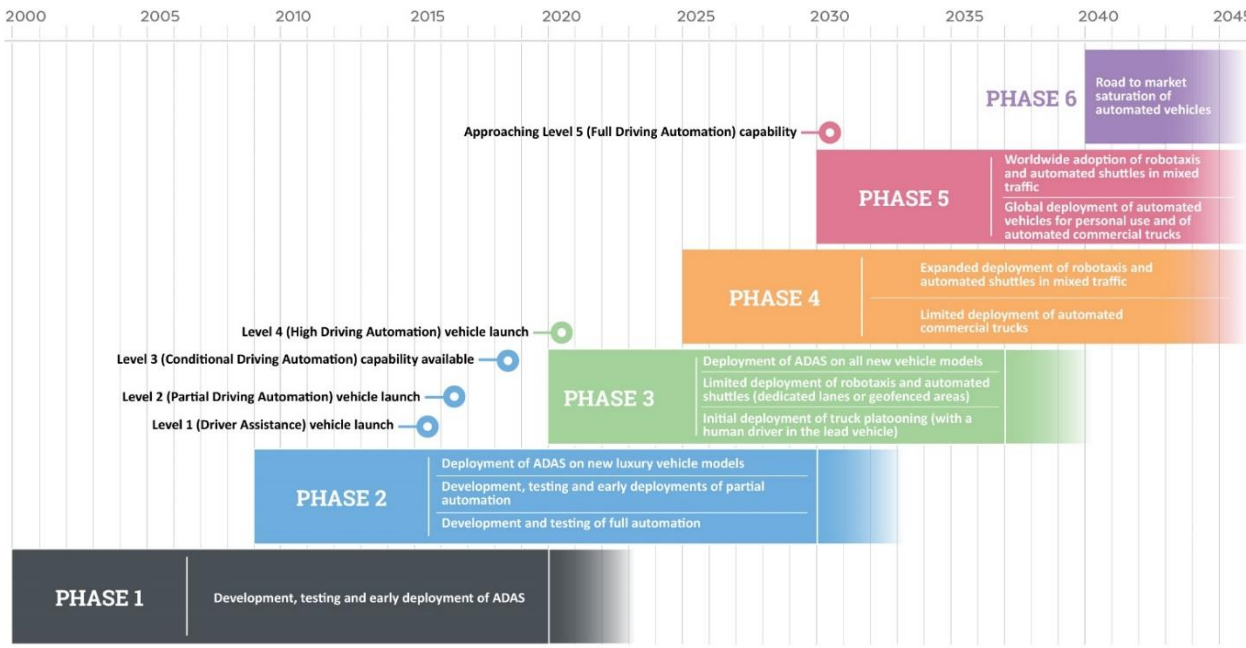
Consumers' desire for seamless, reliable, and convenient transportation has been crucial for the rapid growth of ridehailing, but this same desire also underpins new mobility services such as carsharing, ridesharing, and microtransit. Ridehailing and carsharing companies are disrupting the transportation sector by providing more ways to have access to vehicles without ownership. Automakers are hedging their bets against these disruptors by testing new business models themselves, seeking to go beyond the old models of selling cars to individuals and developing new mobility services in-house.

The World on the Horizon

North American, European, Israeli, and Japanese companies are leading the development of automated vehicles, but Chinese companies are accelerating their efforts and quickly catching up. Furthermore, tech companies and startups are disrupting traditional supply chains by developing software, chipsets, and sensors for automated vehicles. In turn, many automakers are developing driving automation technologies in-house to assure their companies remain relevant and profitable in a future in which software, data, and connectivity are more valuable than the mechanical elements of a vehicle.

ADAS features will be increasingly common in the coming decades (see Figures 1 and 2). Some of those features likely will be mandated or included in safety-rating systems, such as the New Car Assessment Program (NCAP). Fully automated vehicles likely will be first launched as low-speed automated shuttles; pilot tests for automated shuttles are already in progress. Many experts predict that driverless taxi services will be available in select urban areas as soon as 2020, while automated vehicles for personal use will be available in 2030 or later.

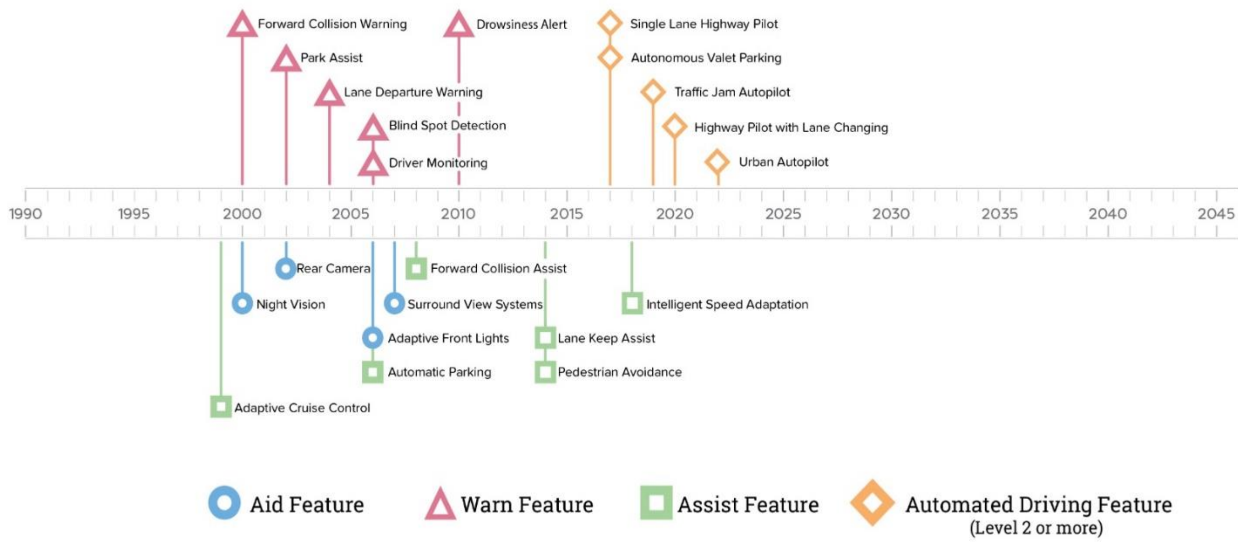
Figure 1: Roadmap for Advanced Driver Assistance Systems and Vehicle Automation Technologies



Source: CAR Research

Many automotive manufacturers are developing vehicles with automated driving systems, and several have pledged to introduce conditional automation (SAE J3016 Level 3), such as automated highway operation, within the next year or two. Other automakers indicate that such conditionally-automated systems are too complicated from a human-factors perspective and intend to skip to higher levels of automation that do not require a human driver at all. There is no consensus in terms of strategy among automakers and suppliers on this point. Finally, it is too soon to predict whether it will be possible to produce fully automated vehicles (SAE Level 5), capable of operating anywhere and in all situations.

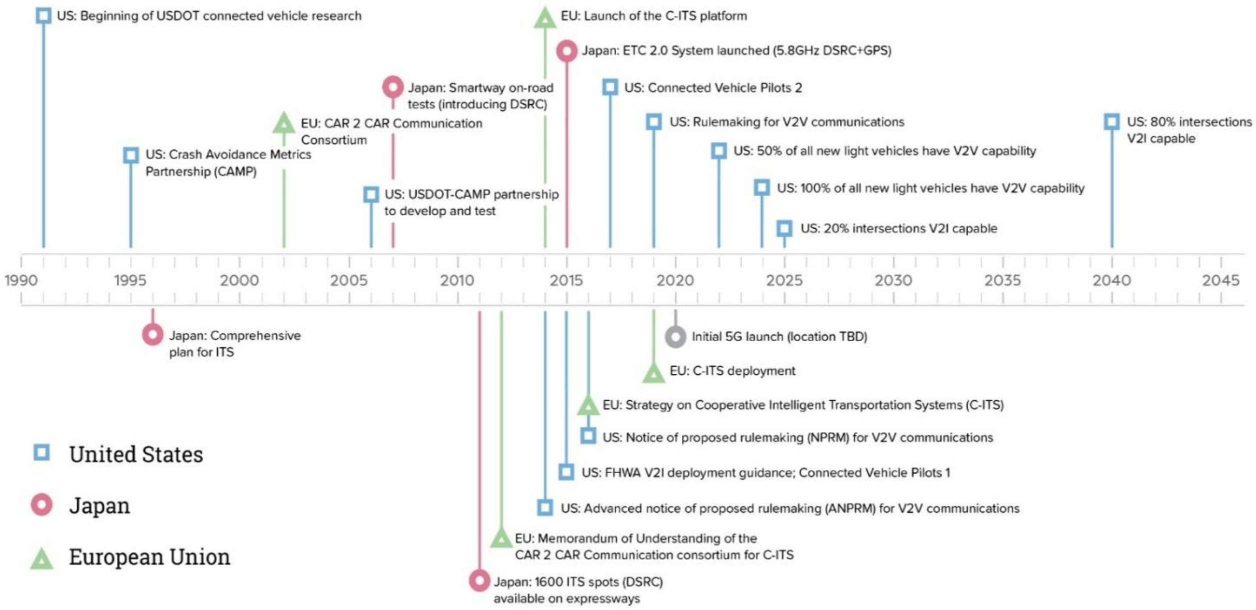
Figure 2: Timeline for Launches of Advanced Driver Assistance Systems and Automated Driving Features



Source: CAR Research, BCG

Clearly, connectivity will play an increasing role in the auto and mobility sectors in the coming years (see Figure 3), but it is less clear what specific communication technologies will be most pertinent and prevalent. The United States likely will have a leading role in the large-scale deployment of V2V and V2I safety applications if the mandate for V2V-capability on light-duty vehicles proposed in December 2016 is issued. Automotive and tech companies, as well as governments, have pledged to make substantial efforts for the deployment of V2V and V2I applications based on Dedicated Short-Range Communication (DSRC) in the 2020s, both on the infrastructure and vehicle side; however, the exact timeline is highly dependent on the priorities of the new U.S. administration, which currently has not appointed a new administrator to lead the National Highway Traffic Safety Administration (NHTSA). European countries and Japan also have expressed commitments to create the legal framework needed, invest in V2I infrastructure, and support the development of V2V applications. Progress will not be limited to DSRC-based connectivity. The launches of first 5G mobile networks, the next telecommunications standards beyond the current 4G LTE standards, will occur around 2020, and 5G is expected to enable a variety of commercial- and convenience-oriented applications. Whether or not 5G can support cooperative, active safety, however remains an open question.

Figure 3: Timeline for Vehicle Connectivity Technologies

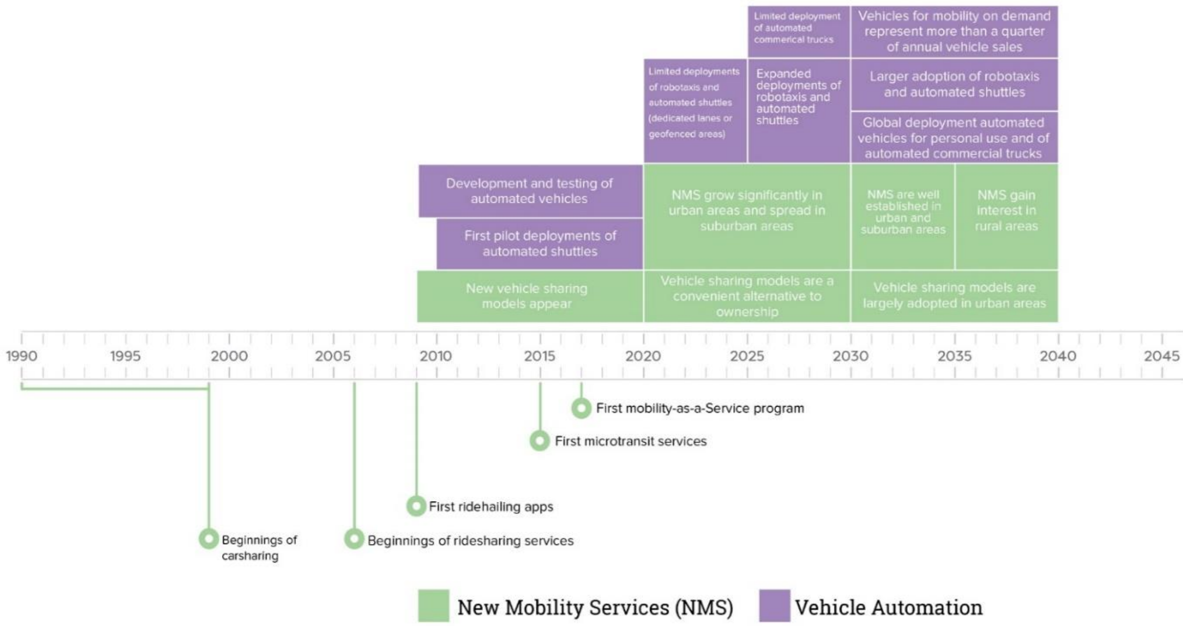


Note: The exact year when all new U.S. light vehicles will have V2V capability is dependent on having a V2V mandate in FMVSS and on the specific phase-in period required.

Source: CAR Research

New mobility services are expected to diversify and grow significantly in cities and to spread beyond urban areas in the 2020s and 2030s, benefitting from the convergence with vehicle automation (see Figure 4). In the 2020s, sharing models will become a convenient alternative to vehicle ownership for an increasing share of the world's population. By 2030, ridehailing/taxi rides will represent almost a quarter of miles traveled worldwide (see Figure 5). After 2030, vehicle-sharing models will be largely adopted in cities and viable NMS models will be introduced in rural areas.

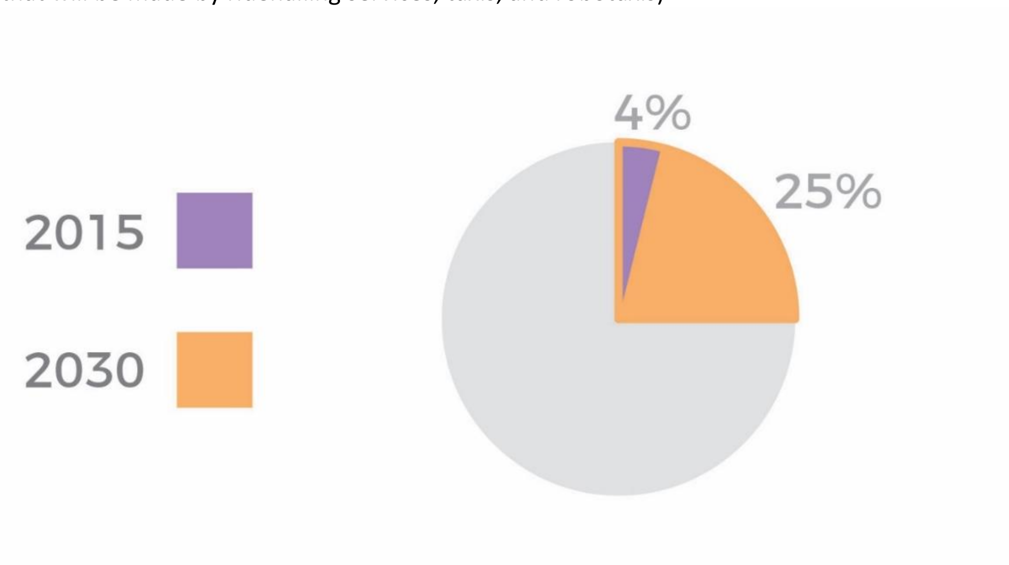
Figure 4: Roadmap for New Mobility Services and Vehicle Automation Technologies



Source: CAR Research

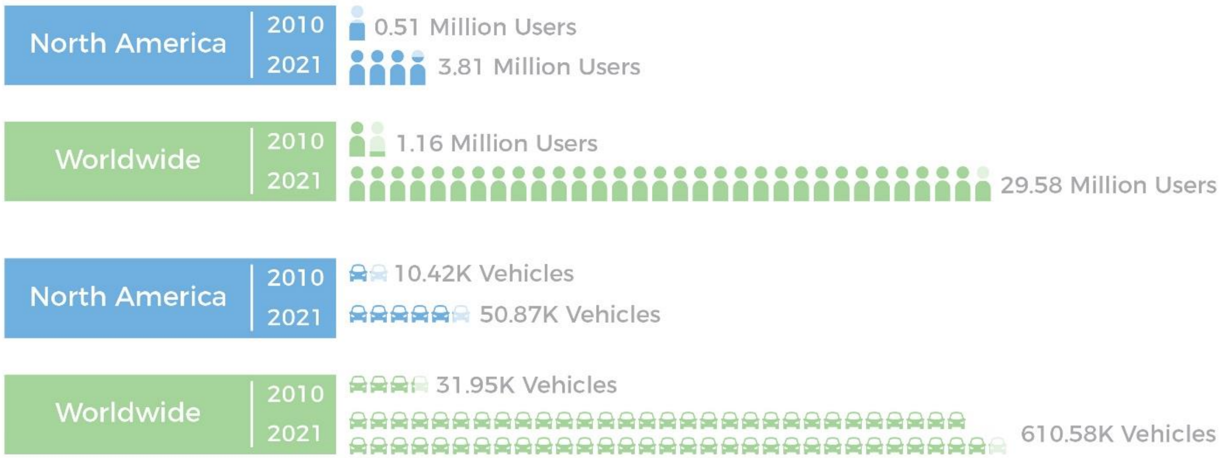
Figure 5: Growth Projections for Carsharing and Ridehailing

Growth of ridehailing/taxi services in the United States and worldwide (percent of annual vehicle miles traveled that will be made by ridehailing services, taxis, and robotaxis)



Source: Morgan Stanley

Growth of Carsharing Programs



Source: CAR Research

Enablers and Threats

These forecasts and timelines (see Figure 6 for an overall view) could well be affected by related developments. For example, faster development of key enabling technologies (such as in the area of artificial intelligence) could hasten the market availability of full automaton, and lack of consumer acceptance could delay it.

Enablers

The range of potential enablers is broad and dependent on the precise technology. The deployment of automated vehicles is dependent on the improvement of key enabling technologies, such as human-machine interface, driver monitoring, object recognition, artificial intelligence, sensors (miniaturization and cost reduction), cloud computing, cybersecurity, and 3D high definition maps. Substantial public and private investment in V2I and 5G infrastructure would facilitate the rollout of connectivity applications. The growth of new mobility services will be boosted with increased development of dense and walkable urban areas, where these services are most successful. The use of NMS will also increase with integration of different transportation modes through mobility-as-a-service systems and the convergence with vehicle automation and connectivity.

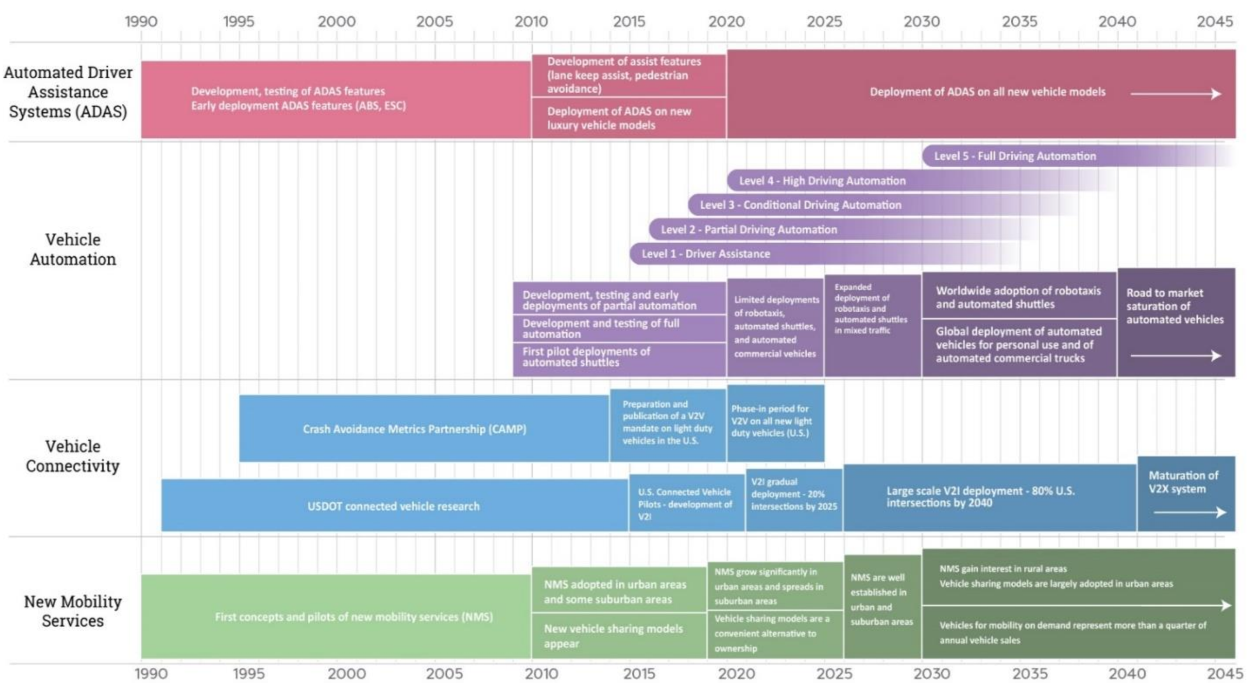
Threats

Threats and potential delays also can come from several different directions, and ultimately sales of connected and automated vehicles, as well as the use of new mobility services, will depend on consumer acceptance and this could change dramatically in the aftermath of a major connected and automated vehicle crash, recall, or cybersecurity attack. Cost is an important concern; if these vehicles remain too expensive for the average consumer, then sales will suffer. For new mobility services, the main limitation is a lack of appeal beyond dense urban cores. Insufficient public investment could delay deployment of V2I infrastructure for decades, and a lack of rigorous communication standards will limit interoperability. Given current travel behavior patterns related to length and duration of work commute trips, as well as current pricing schemes for NMS, these services remain an expensive option compared to public transit. Nonetheless, even at current prices, some NMS such as ridehailing services often operate at a loss, an unsustainable strategy in the long term if the service is completely dependent on market forces.

Monitoring the Future

Industry stakeholders are well advised to closely monitor how these enablers and threats are evolving. This includes attention to technical breakthroughs (e.g., progress on solid-state Lidar, a sensing method that measures distance to a target by illuminating that target with a laser light), regulatory and legislative efforts in North America and beyond, mergers and acquisitions, and more. Specifically, stakeholders should monitor future legislation on automated vehicles and data protection in countries across the world, as well as mandates, like the proposed one for V2V on all light vehicles sold in the United States. Legislation and regulation could hinder the development of connected and automated vehicle technology and new mobility services, depending on national and local policy positions. The latter likely will not be favorable if the observed safety or traffic congestion benefits will be lower than expected.

Figure 6: Global General Timeline



Source: CAR Research

Materials and Manufacturing Technologies

New materials with better performance characteristics are introduced into vehicles for various reasons, but primarily for improving crashworthiness, noise and vibration, overall cost, and fuel economy. The regulatory pressure to improve fuel economy is expected to accelerate the evolutionary rate of the introduction of lightweight materials into the vehicles.

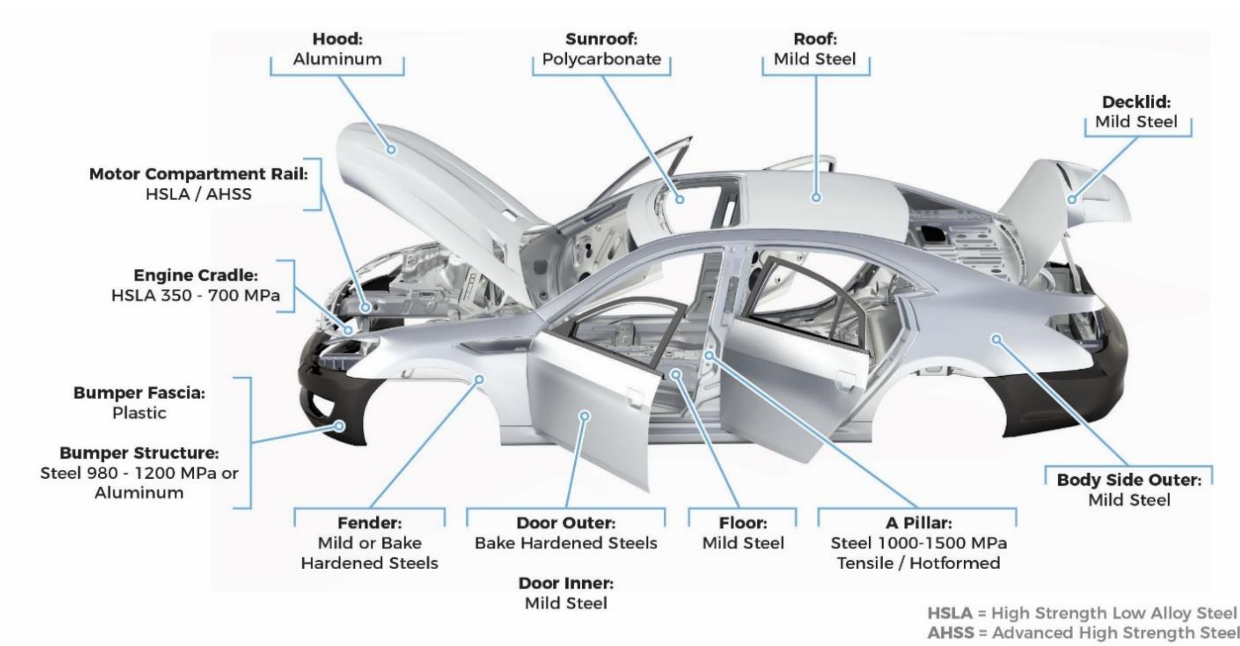
In order to understand the current material technology in the vehicles and future material trends, this whitepaper presents material and manufacturing technology roadmaps identified by extensive cross-company research and inputs from various industry experts along with primary research from the Center for Automotive Research (CAR) of survey data from nine automakers. This survey data includes 42 model year 2015/2016 vehicles, covering four vehicle segments (cars, CUV, SUV, light trucks). These 42 models represent approximately 50 percent of the U.S. light-duty vehicle sales. The survey requested detailed data on current materials used, forming technology, and joining technology on 20 components from every vehicle surveyed. Automaker opinions on material technology usage in the selected components for 5, 10 and 15 percent vehicle mass reduction were also queried. CAR published the results of this study in 2016.[2] To validate the results, material experts from different companies and organizations with more than 150 years of combined work experience were invited for a half-day roundtable discussion.

The World We Know

Current Industry

Product engineers try to work on the philosophy of the right material at the right place. Figure 7, shows the current most commonly used materials for major structure components. Theoretically, a material can be used to make vehicle parts if it is commercially available, can be manufactured with an available technology, and meets the performance requirements.

Figure 7: Materials Used Most Commonly for Major Vehicle Structure Components in the Current Fleet

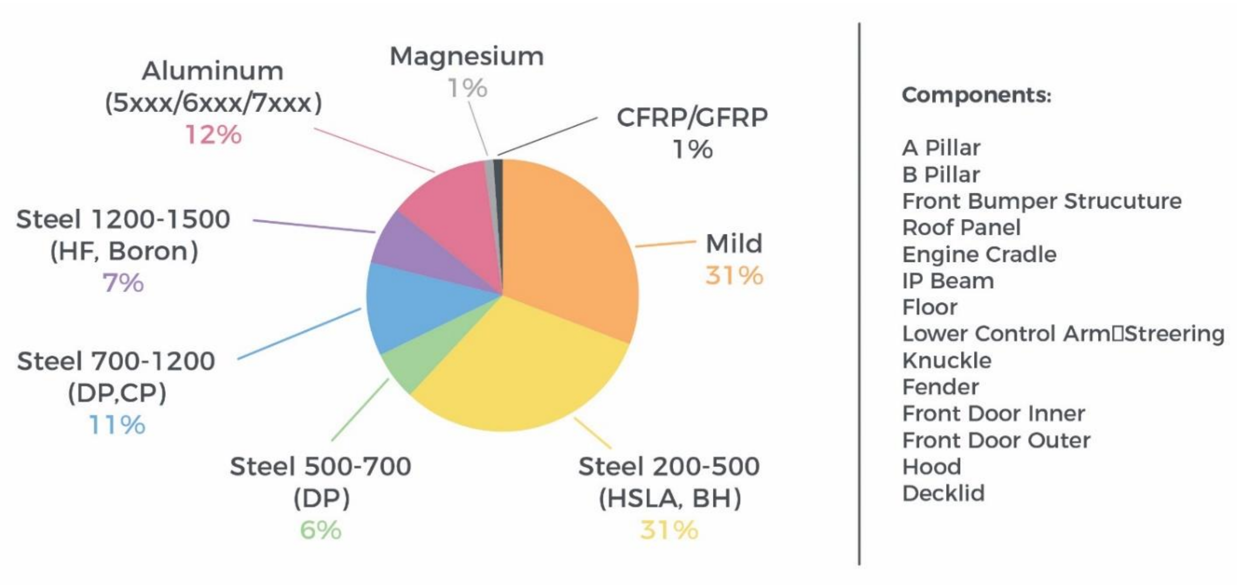


Source: CAR Research

However, designers cannot use every available material because they are constrained by practical day-to-day difficulties such as supply-chain, infrastructure, cost, reparability, environment, etc. Figure 8 shows the current material mix in 14 major vehicle components from the body structure and closures.

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

Figure 8: Current Vehicle Material Mix Based Upon 14 Major Components from 42 Mass Produced Vehicles



Source: CAR Research

Vehicles today are predominantly steel structures with some use of aluminum. The grades of steel range from mild (270 Mega Pascal (Mpa) tensile strength) to hot-formed boron (1500 MPa plus tensile strength). Magnesium and polymer composites are used in some components mostly on higher end vehicles.

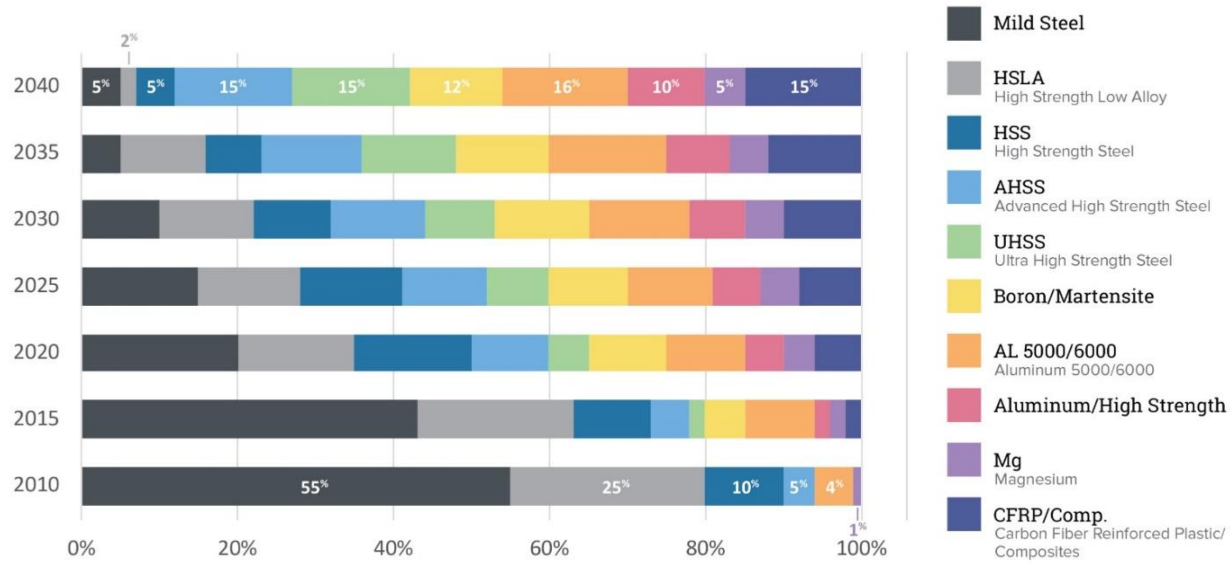
The predominant manufacturing technology today is cold stamping, but higher strength steels are difficult to cold form. The use of hot stamping is increasing as the heat increases the ductility of the material which helps in forming complex shapes without cracking. For plastics and carbon fiber composite parts, injection molding and resin transfer molding are currently the most common production technologies respectively.

The World on the Horizon

The regulatory pressure to reduce carbon emissions and the race to improve performance are drivers for change to the material mix in the vehicles. Automakers are looking for materials with higher strength-to-weight ratio which reduces weight, while improving performance. CAR research indicates the U.S. fleet will achieve a five percent curb weight reduction by 2025 through greater use of aluminum predominantly in the closures and body-structure. Interiors are also a recent focus for lightweighting as it is considered dead weight.

Figure 9 shows the change in material mix in the U.S. fleet between 2010-2040. Experts agree that no single material wins in the race to lightweighting. A weight and performance optimized vehicle will have a mixed-material body structure. The industry is already experiencing this shift in recently introduced vehicles which use materials customized for each area of the car to simultaneously advance driving dynamics, fuel economy, and cabin quietness.

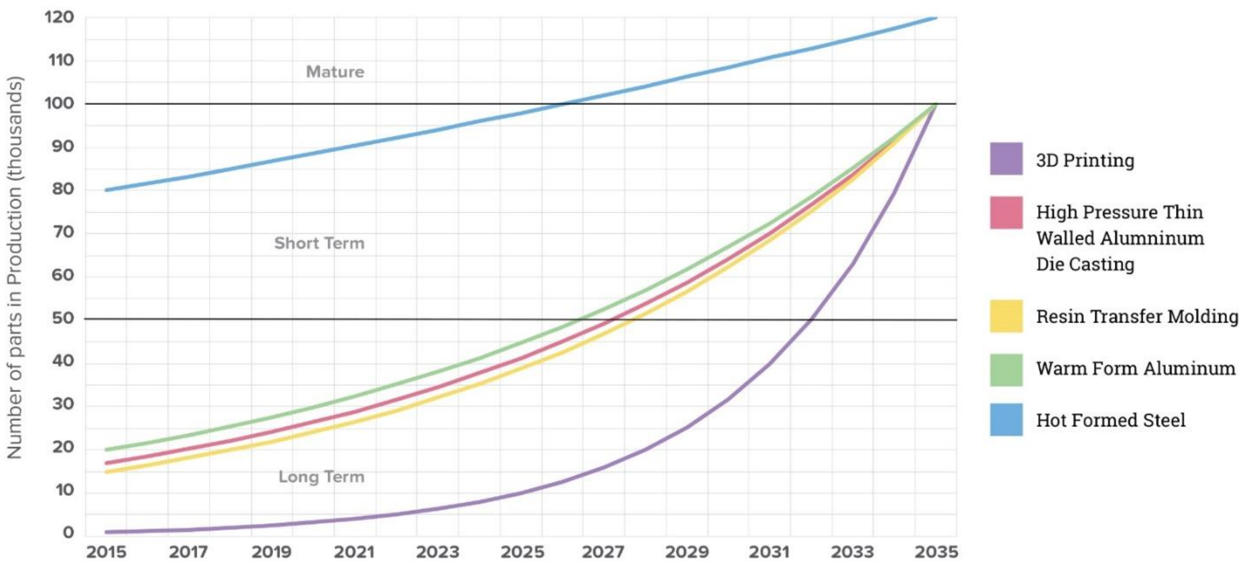
Figure 9: Material Distribution in the U.S. Fleet (Body-in-White Plus Closures), 2010 to 2040



Source: CAR Research

New manufacturing technologies are also advancing to achieve the speed and cost effectiveness required for mass production. Hot forming of steels is already used in high production parts and will reach maturity by 2025 as the need for ultra-high strength steels increases (see Figure 10). Maturity of a technology is a subjective term which depends on the vehicle program. In broad terms, a mature technology can be used in mass-produced vehicles (volume over 100,000 units a year), has multiple product applications, and is available from multiple suppliers with a global supply capability. Additive manufacturing, also called 3D printing, is a revolutionary technology with the potential to change the tool and die business but is not yet suited for mass production in terms of cost or cycle time.

Figure 10: Emerging Manufacturing Processes and Enablers for Growth, 2015 to 2035

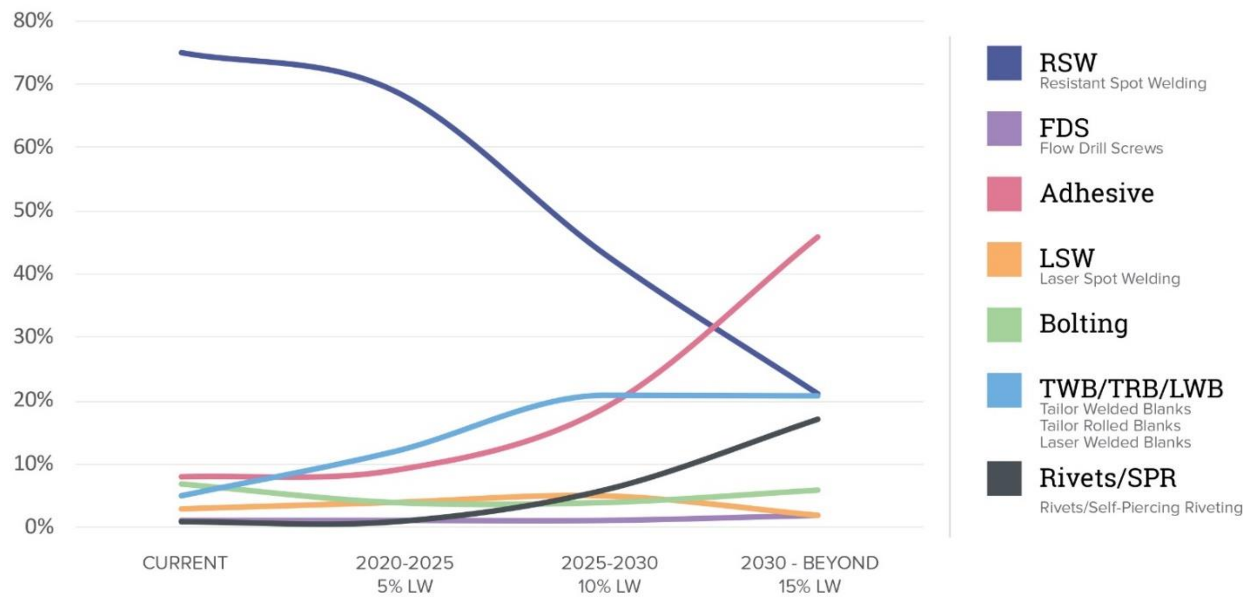


	3D Printing	High Pressure Thin Walled Aluminum Die Casting	Resin Transfer Molding	Warm Form Aluminum	Hot Formed Steel
Enablers for Growth	Reduce Cycle Time	More R&D Needed	Reduce Cycle Time	More R&D Needed	Increase Equipment Capacity
	Reduce Equipment Cost	Increase Equipment Capacity	Standardization of Operating Barometers	Increase Equipment Capacity	Reduce Cycle Time
			Develop Supply Chain for CFRP		

Source: NHTSA; CAR Research

With new materials come new challenges. Joining dissimilar materials is not easy, and is sometimes impossible to do using traditional resistance spot welding due to differences in melting point. Joining technologies–such as adhesives and advanced fasteners–will play an important role in achieving the optimized mixed-material architecture, since they have the ability to join any combination of dissimilar materials (Figure 11).

Figure 11: Trends in Joining Processes, Current Year to Beyond 2030



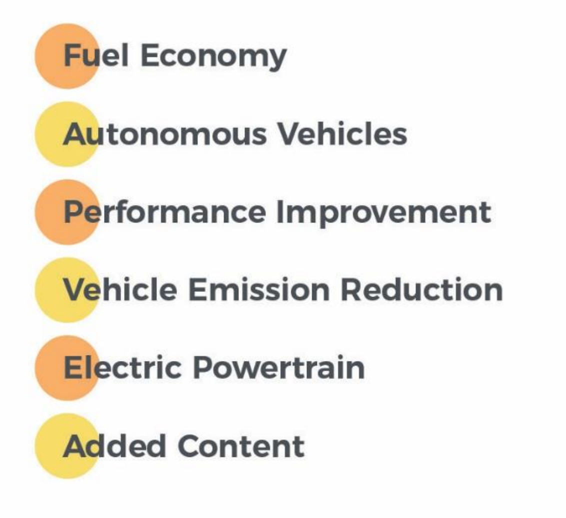
Note: LW= Lightweighting
Source: CAR Research, Lucintel

Enablers and Threats

Enablers

Heavier vehicles require more power to move the vehicle. To produce more power, engines burn more fuel. Thus, a lighter vehicle derives better fuel economy from the need for smaller propulsion packages. Lower fuel consumption also corresponds to lower exhaust emissions. Across the globe, governments are imposing regulations to control vehicle emissions to address climate change. This is the primary driver for increased usage of lightweight materials. To stay competitive, automakers add content to the vehicles every model year – such as improved infotainment features, driver assist sensors, increased leg and cargo space, etc. CAR's research indicates that by 2025, around five percent of the curb weight of the U.S. fleet will be added to every vehicle for safety and performance improvements (Figure 12). For example, an additional 200 to 300 pounds per vehicle will be added for automated driving features.

Figure 12: Drivers for Material Technology Change



Source: CAR Research

To maintain or improve performance and fuel economy, the weight added for the additional consumer and safety content needs to be offset elsewhere. Also, with increasing trends towards electrified powertrain, the weight differential between an internal combustion engine (ICE) and battery packages affects vehicle weight targets. In fact, battery electric vehicles (BEV) need to be much lighter than their ICE counterparts to get adequate driving range. The regulatory push towards BEVs coupled with rising customer expectations will increase the pace of introduction of lightweight materials into the vehicles.

Threats

Working with multiple materials in a manufacturing environment is not an easy task. Apart from joining, galvanic corrosion and thermal management are two major issues engineers face while designing vehicles with mixed-material body structures. While engineers worry more about the technical challenges, purchasing and manufacturing executives are more concerned about the cost of new materials and potential supply-chain risks. Newer manufacturing technologies such as additive manufacturing, resin transfer molding, thin walled die casting, etc. are not yet mature processes. These technologies have longer cycle times, as well as quality issues that need to be resolved for use in mass production across-the-board. Figure 13 lists major challenges the auto-industry is facing with new materials and mixed-material assemblies.

Figure 13: Challenges to Address for Faster Introduction of New Materials

Mixed-Material Joining	Difference in melting point between materials
Corrosion	Relative placement in the galvanic series and exposure to moisture
Thermal Expansion	Differences in coefficient of linear expansion (CLTE) cause materials to expand differently in the paint oven
Cycle Time	Automotive industry needs process cycle times to match line speed which is approximately one unit a minute for mass production
Cost	Cost of newer materials like carbon fiber is very high compared to steels. Carbon fiber for automotive costs $10 to $12 a pound, compared to less than a dollar for steel.
Supply Chain	Automakers are shifting towards global platforms. The availability of material across the world from multiple suppliers is critical.
End-of-life Recycling	Most materials used in automobiles should be easily recyclable for environmental reasons and to meet regulatory requirements
Repair	A hard to repair vehicle will have increased insurance cost and in turn will affect sales
Talent Gap	Engineers and plant workers need to be retrained to work with new materials and processes

Source: CAR Research

Monitoring the Future

Automated Vehicles	3D Printing	Low Temp. Fast Cure Adhesives	Aluminum to Steel Welding	Fuel Prices	Fuel Economy Regulations	Cost of Carbon Fiber	BEV Sales

Automakers, as well as new players in the Silicon Valley, are investing in automated vehicle technology. Automated vehicles may lead to new business models, insurance structures, and new mobility models that will affect vehicle design and hence the materials mix. The National Highway Traffic Safety Administration (NHTSA) estimated that in 94 percent (±2.2 percent) of the crashes the critical reason was the driver.[3] If human drivers can be replaced by automation, many of the crashes can be prevented and traffic deaths avoided. This will give vehicle designers flexibility to downsize vehicle crash structure

[3] Singh, S. (2015, February). Critical reasons for crashes investigated in the National Motor Vehicle Crash Causation Survey. (Traffic Safety Facts Crash Stats. Report No. DOT HS 812 115). Washington, DC: National Highway Traffic Safety Administration.

and use lighter materials. However, at this moment the future of automated vehicles and safety regulations are uncertain.

Another technology to monitor is 3D printing, which is currently used primarily for rapid production of prototype parts, but the future looks bright if the cycle time and equipment cost can be reduced. In materials, the steel industry is investing in developing high strength steels which also have high elongation. These "gen-3 steels" can limit the use of other lightweight materials due to potential cost differences, and because automakers are more invested in working with steel.

Other uncertainties include cost of polymer composites, innovations around dissimilar bonding technologies, and fuel prices which can change the roadmaps presented in this whitepaper.

Light Duty Vehicle Propulsion

Shaped by emissions and fuel economy regulations, and driven by customer expectations, light duty vehicle propulsion systems have evolved rapidly in recent years. However, many believe the industry may be on the verge of truly revolutionary change. The Center for Automotive Research (CAR) developed a roadmap to provide a better understanding of key propulsion system trends through 2030. This technology roadmap reflects a synthesis of stakeholder expectations and is the result of CAR's in-house research, completed by a critical analysis of publically available reports from leading consulting firms, research organizations, investment banks, and universities, and validated by select industry leaders and stakeholders. While there is general agreement on the direction of change, a great deal of uncertainty remains in predicting specific timeframes and technology pathways.

The World We Know

Current Industry

Manufacturers are investing in a wide range of propulsion technologies. The fact that they plan to do so for many years suggests great uncertainty. While regulations arguably drive light-duty vehicle advanced propulsion technology implementation, the success of many alternative propulsion technologies is ultimately determined by the customer. In a highly competitive market, vehicle performance and purchase price are critical. Manufacturers must balance regulatory and consumer requirements while developing and delivering solutions. Contrary to some reports, the answers are not necessarily clear.

For over a century, the dominant propulsion for light-duty vehicle has been the internal combustion engine (ICE), and in North America, the spark-ignited (gasoline) ICE. In that time, and specifically since the introduction of computer controls, the ICE has undergone a dramatic evolution. Yet, many believe the industry is on the verge of a propulsion revolution; they believe that the industry has in fact reached the electrification tipping point.

The World on the Horizon

Forecasts for future propulsion technology penetrations vary greatly. The following points are worth considering:

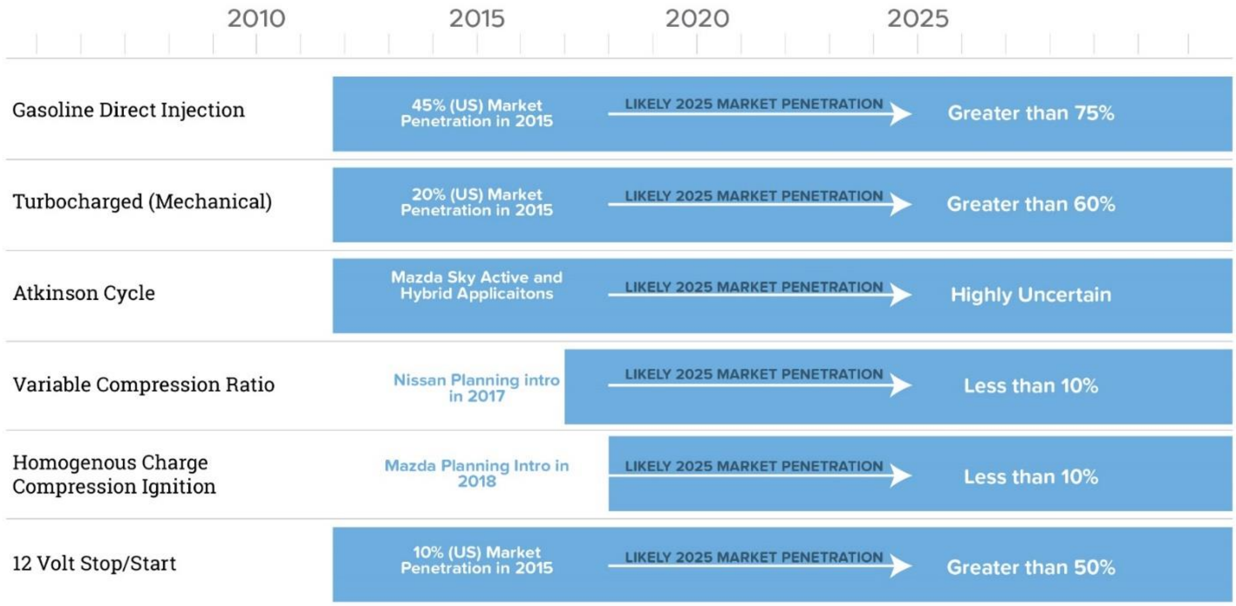
- First, the automotive industry appears to be at or near an inflection point in propulsion technology. Advanced battery development, further enabled by increasingly stringent emission regulations, has created expectations of a shift to electrification;
- Second, regional regulation differences and local market characteristics will create differing mixes of ICE, electrification and even fuel cells between regions. In many instances, more developed markets will likely be able to support more advanced propulsion technologies, while less advanced markets may take longer to accept these costlier higher-tech solutions;
- Third, at least in the mid-term (4-10 years) some governments may choose a technology solution, leading to a higher than (global) average penetration rate for that country. Conversely, other countries may choose to delay or minimize regulatory policy, thus decreasing the implementation of advanced propulsion technologies in those markets.

Globally as well as within North America, the ICE is likely to remain the most cost competitive mass market propulsion system through 2025. The automotive industry—suppliers and manufacturers—are masters of evolutionary change. There continues to be disagreement over how long ICE will be able to meet future standards. However, the industry will continue to refine, and add technology to make the spark-ignited engine even more efficient.

Gasoline direct injection and turbocharging for gasoline engines are expected to continue to increase penetration globally. These technologies have been integral to recent efficiency increases, and will continue to be tools for future gains. Atkinson cycle engines have recently been promoted by some U.S. regulators as a likely contributing technology, and is commonly used in hybrid vehicles. However, many manufacturers appear to have reservations about its effectiveness in non-hybrid applications. Variable compression ratio (VCR) and homogenous charge compression ignition (HCCI) are expected to see very early market introduction, but are likely to remain niche applications. 12-volt stop/start technology offers opportunity for reduced fuel consumption and greenhouse gas emissions, and will likely be widely implemented. Stop/start can be a relatively cost-effective means of reducing emissions, and could be key in many developing markets where cost is a significant barrier for new technology. (Figure 14).

Globally, diesel engines will continue to be part of the propulsion technology mix. However, diesel will face increasingly significant headwinds in many key markets as governments increasingly tighten NOx and particulate emissions regulation and focus on more rigorous testing. In recent years, diesel technology has lost share in Europe, and faces challenges from urban local emissions regulations in several regions

Figure 14: Internal Combustion Engine (ICE) Technologies



Source: CAR Research, USEPA/NHTSA Technical Assessment Report; Various media publications

Clearly, the electrification of light-duty vehicle propulsion is underway. However, the timing for mass market acceptance and the type of electrification remains uncertain. Hybrid electric vehicles (HEV) were introduced in the mid-1990s, and have struggled to gain consumer acceptance in most markets. While offering efficiency gains, the cost of two propulsion systems will continue to hinder HEV cost competitiveness. Plugin hybrid electric vehicles (PHEV) offer opportunity for zero emissions over short distances, and this may help with some local emissions challenges. However, PHEVs still incur the cost of two propulsion systems, plus added cost for a larger battery. While viewed by some as transitional technologies, HEVs and PHEVs will be an important part of the market through at least 2030.

Currently, 48-volt hybrids (mild hybrids) have gained initial penetration in Europe and China, but not in the North American market. These 48-volt hybrids appear to present opportunity as a transitional technology for luxury vehicles and possibly for pick-up trucks in North America.

Battery electric vehicles (BEV) may present opportunity for wider market acceptance in the coming decade. Regulations, and a strong commitment to BEV by proponents are driving increased expectations for the technology. However, market acceptance lags behind these expectations. BEV performance (range, recharge time, etc.) still does not meet most consumer requirements. In time, many of these issues may be resolved—or at least greatly minimized. If costs are significantly reduced, the 200 mile-plus range BEV with fast-charge capabilities could become an important part of the advanced propulsion equation.

It is important to note that even with the current enthusiasm for BEV, many major vehicle manufacturers continue to develop fuel cell electric vehicles (FCEV) as yet another alternative. Although significant cost, hydrogen production, distribution infrastructure, and onboard storage challenges greatly limit FCEV penetration over the next decade, FCEVs do offer short-term low-volume compliance opportunities. Also, the amount of investment by key players indicates the technology may present a viable long-term solution, and a defensive strategy against battery development delays (Figure 15).

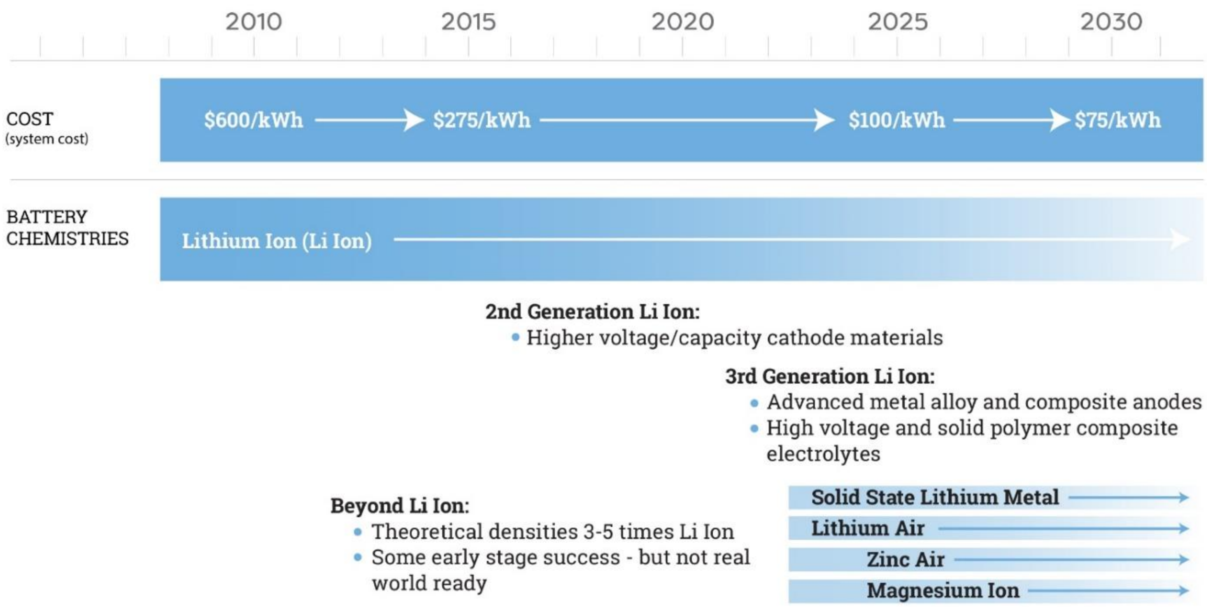
Figure 15: Electrified Vehicle Technology Pathways

Source: CAR Research, summary of various media publications

Advanced energy storage development is the single most critical enabler for reaching the electrification tipping point. Advanced battery development continues to track at an impressive rate. Battery cost estimates are very difficult to verify, with some published estimates being overly optimistic for marketing purposes, and others overly pessimistic. However, it is clear that costs are rapidly declining while performance is increasing. Second generation lithium ion battery packs costs are likely at or below $275 per kilowatt-hour (kWh). The battery packs are expected to decrease rapidly in the coming decade with $75 per kWh possible by 2035. And, as costs are reduced, energy and power are increasing. Third generation lithium ion battery technology—possibly reaching market after 2020—is expected to greatly improve performance characteristics and lower costs (Figure 16).

There are several battery technologies in early development stages that may replace lithium ion, but they appear to be at least a decade away from real world application—and likely much farther from mass market automotive use.

Figure 16: Advanced Battery Development Trends

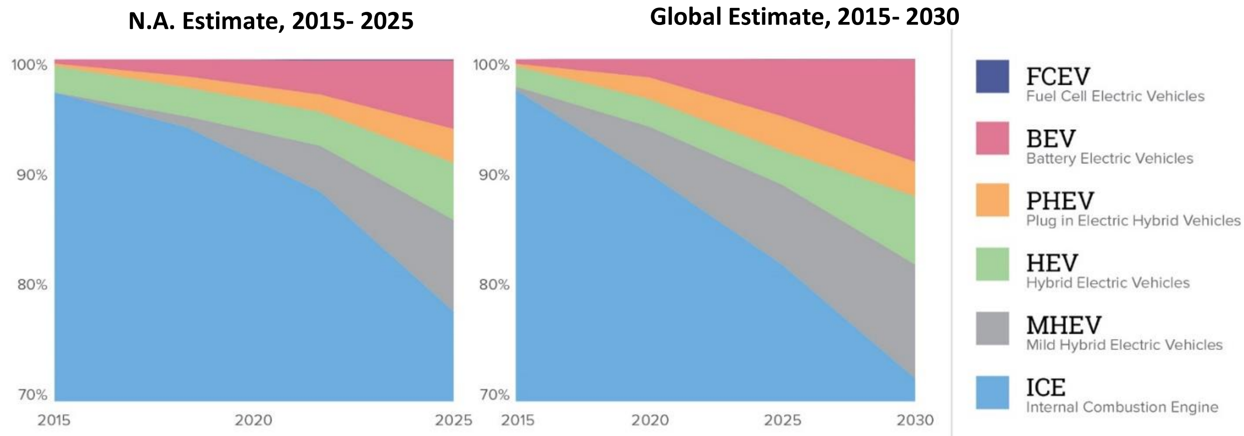


Source: CAR Research, summary of various media publications

As noted earlier, published forecasts for future propulsion technology penetrations vary greatly. Broadly, there are indications the global light-duty vehicle propulsion market may be at a technology tipping point, with significant change coming over the next 15 years. Electrification is happening, and BEVs, long a niche player in the market, appear to be developing rapidly. HEV and PHEV technology will be required to meet future emission standards. Yet the rapidity and completeness of this transition is far from certain.

It is likely at least 20 percent of the North American market, and nearly 30 percent of the global market will include some form of electrification by 2030. It is also likely electrification in some major markets may exceed these estimates. However, the internal combustion engine will continue to present a very strong cost/efficiency target for the consumer. Clearly regulation will drive this change, what remains uncertain is whether the consumer is willing to accept this revolution (Figure 17).

Figure 17: North American and Global Light Duty Vehicle Propulsion Technology Market Penetration 2015-2030



Source: CAR Research; USEPA/NHTSA Technical Assessment Report; Global EV Outlook 2016, International Energy Agency; Joining Forces to Tackle Road Transport CO2 Challenge, European Automobile Manufacturers Association; various others

Enablers and Threats

Enablers

Increasingly stringent emissions regulations will require increased application of advanced propulsion technologies, and even may open the door to an electrification revolution. Advanced battery development will be the important enabler in expediting significantly increased light-duty vehicle electrification. Cost reductions, combined with improved chemistries and more effective thermal management will increase battery capabilities and likely decrease charge time, making electrification more enticing to consumers. Two hundred-plus mile range, combined with quicker charge times, may also reduce charging infrastructure requirements.

The advancement of connected and automated vehicle technology is in many ways symbiotic with increased electrification for light-duty vehicle propulsion systems. As vehicles become more highly automated, they will quickly over-tax the twelve-volt system. Forty-eight-volt systems or greater may be required to supply power to automated technologies.

Threats

Consumer acceptance is possibly the most daunting threat to advanced propulsion technology. Low (and relatively stable) energy prices in the United States will continue to make market acceptance of advanced propulsion systems challenging. Even if battery costs continue to plummet as forecasted, ICE will present a difficult cost target with which to compete. Also, many consumers are cautious with new technologies. Backlash by the consumer is possible if future BEV (or FCEV) technology does not meet consumer expectations and this could occur either in the form of refusal to purchase the technology, or pressure on regulators to reduce regulations.

Monitoring the Future

Industry stakeholders need to monitor several key trends. Emissions and fuel economy regulation will be critical. Those countries that have the ability to implement top down regulation, or those where there is strong public support for environmental issues will likely have the ability to implement more stringent regulation. In countries where there is less central control or where consumers may not place a high value on environmental issues, implementing more stringent emissions regulation will be more challenging. However, globally, advancement will continue to happen.

Technology development will also play a pivotal role. Battery development is proceeding rapidly, but still needs improvement before the electric vehicle is perceived as a replacement for ICE. And, the industry will continue to refine the ICE.

These forecasts should be considered a guideline. There are many uncertainties driving light-duty vehicle propulsion. It is possible these forecasts underestimate the success of electrification over the next 15 years. However, proponents of vehicle electrification have been declaring the end of internal combustion for decades —yet ICE still accounts for approximately 98 percent of vehicles sold globally.

Conclusion

Among the three technology sections, there are several factors that could potentially impact the future advancement of technology in the automotive industry. They include, consumer acceptance; cost reduction and uncertainty; cross-sector communication; and policy and regulation.

The more accepting consumers are of new materials, technologies, or new mobility services—the more likely these technologies will advance. The market determines the success of a vehicle, not regulators or technology advancements. Consumers are concerned with safety, privacy and security issues, environmental impacts, efficiency, and cost. Governments can nudge consumers on a certain path, but in the end will not overpower consumer acceptance.

Relative cost competitiveness is another influential factor. Automakers and suppliers are cost-constrained, and make decisions on which advancements to pursue based on those that will not add significantly to the cost of the vehicle. The path of technology development and the pace of cost reductions are uncertain. Key examples include Industry 4.0, Additive Manufacturing/3D Printing, and New Mobility Business Models.

Increased cross-sector communication and communication between automakers and their suppliers, as well as within the supply chain is required to effectively incorporate technology changes into a product. As technology advances, cross-industry collaboration among the automotive industry as well as other industries will significantly increase due to the sophistication of technologies. This is evident in several partnerships and mergers among technology companies, startups, automakers, and suppliers. A breakdown in communication can lead to several inefficiencies including increased cost and waste of materials.

Long-term agreements on the regulatory future can also enable technology advancements. Automakers and suppliers are risk-adverse, and desire certainty in the direction set by governments. Uncertainty in public policy or the regulatory environment can be a barrier to technology advancement. If one government sets lower regulatory standards, overall global OEMs will continue to advance technologies to meet standards set in other countries, but may not be able to amortize those development costs over the entire global fleet when one large market differs substantially from the rest.