THE SOFTWARE-DRIVEN MEGATRENDS SHAPING THE AUTOMOTIVE INDUSTRY

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INTRODUCTION

The automotive industry is in the process of a technology-driven revolution that will not only advance the safety and sustainability of personal transit but will also transform how consumers interact with their vehicles and the original equipment manufacturer (OEM) brands behind them. Over the course of the next 10 years, the simultaneous rollout of three major automotive technology trends – autonomous driving, electrification, and software-defined vehicles (SDVs) – will combine to deliver new mobility applications and in-cabin experiences, far beyond what has been possible in mechanically-defined, internal combustion engine (ICE)-powered vehicles to date.

Delivering on these three megatrends represents a significant challenge, requiring automakers to invest in a host of new enabling technologies, ranging from high-performance compute to ultra-reliable connectivity and artificial intelligence (AI), with most of these new enabling technologies requiring expertise further and further away from the conventional, mechanical engineering automotive skillset.

Even after the automotive industry has developed and deployed the necessary technologies to enable electric, autonomous, and software-defined vehicles, OEMs will find themselves in a new reality wherein their longstanding, conventional differentiators of ICE refinement and reliability, fuel efficiency, and overall driving sensation are no longer relevant. It will be essential for automakers to shape their future brand identities through unique software-defined functions within the digitally-native domains of the digital cockpit, autonomous driving, and electrified mobility, or via applications that exploit the opportunities that exist across these domains.

Given the gulf between current automotive engineering expertise and the software-centric expertise needed to deliver and thrive in the autonomous, electrified, and software-defined future, automakers must rely on a mixture of in-house investment, third-party solutions, and partnerships with existing giants in software-defined expertise, with the best balance between ownership, outsourcing, and partnership varying from each automotive brand to the next.

SOFTWARE-DEFINED CAR

OVERVIEW

The concept of software-defined functions in vehicles is far from new, with software having replaced mechanical processes and applications since the adoption of fuel injection in ICEs. Indeed, the volume of software in even a modest passenger vehicle today can often be measured between 50 and 100 million lines of code. However, future software-defined vehicles will be markedly different from today's vehicle, with individual software-defined functions replaced by an SDV, with the whole value proposition of the vehicle being shaped and re-shaped in the software domain. The distinction between trims and even models will no longer be achieved through multiple hardware iterations, but through the software content of more standardized hardware platforms.

ADVANTAGES

Continuous Integration and Continuous Delivery (CICD)

The historic approach of tying software innovation and deployment to new model launches has caused a significant lag between the development of a new software-defined application and its deployment in the market. This results in a dated user experience, particularly when compared to the state-of-the-art as defined by the consumer electronics space.

Disentangling software development and hardware development in SDVs will, therefore, enable a much faster time to market for software innovations, ending the automotive industry's infamous reputation for dated user experiences.

Minimize Hardware Complexities

Defining the vehicle's value proposition in hardware means shipping and operating a different hardware configuration for each trim and defined value proposition. By building the vehicle experience around software, fewer hardware platforms are needed, even across the brands of an OEM, reducing complexity and expense. Consolidating today's bloated architecture of 100+ electronic control units (ECUs) into higher performance compute clusters (domain or zonal controllers) can reduce the complexity of each model, minimizing the cost and weight of the wiring harness.

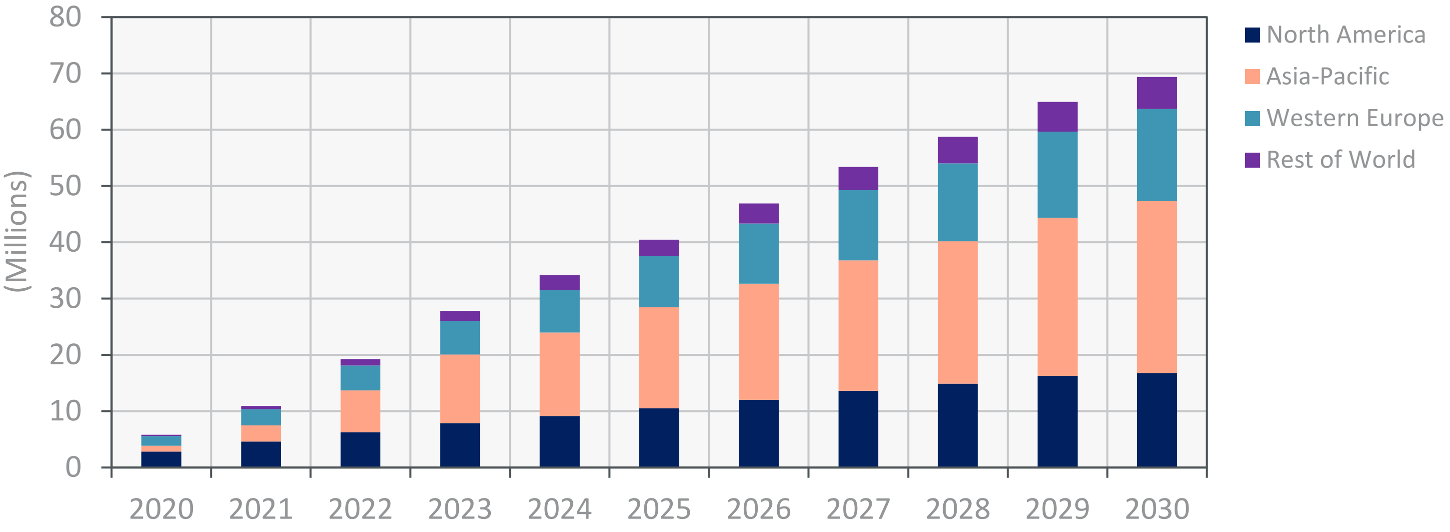
Lifecycle Management

Hardware-defined vehicles remain static throughout their lifecycle, with the same functionality as first delivered at point of sale. As software can be maintained and upgraded over-the-air (OTA), vehicles that are defined in software can be both maintained and upgraded over many years post sale. OTA bug fixes and patches help the OEM avoid costly physical recalls and keep their vehicles robust against new cybersecurity threats that might emerge over the course of the vehicle's lifecycle on the road.

Furthermore, with proper "headroom" in the form of excess compute resources and other hardware that might be redundant for the functionality at point of sale, OEMs can use OTA software updates to add new functionality, even years after the vehicle was first shipped. This presents an opportunity for automakers to build a new revenue stream outside of new vehicle sales. For example, General Motors (GM) has expressed an ambition to produce between US$20 billion and US$25 billion in revenue from software and services by 2030, with Stellantis having a comparable expectation of €20 billion by the same year.

Chart 1: Vehicles Shipping with Functional OTA Capabilities

(Source: ABI Research)



KEY ENABLING TECHNOLOGIES

The transition from software-defined functions in individual domains to a truly software-defined vehicle requires a complete transformation from the vehicle architecture built on a suite of new enabling technologies.

Domain Controllers and Zonal Architectures

The current automotive architecture is defined by ECUs organized in a flat topology and connected through the controller area network (CAN) bus. Each new software-defined function added to the vehicle effectively requires a new ECU to be connected to the CAN bus. In SDV architectures, the electrical/electronic (E/E) architecture is shaped around high-performance compute clusters connected by high-bandwidth, low-latency, and secure networking protocols..

High-Performance, Heterogenous Compute

Consolidating the tasks of multiple ECUs into more performant compute clusters requires a pivot from microcontroller units (MCUs) to high-performance and energy-efficient systems-on-chip (SoCs). The variety of software tasks that the SDV needs to support will also drive the adoption of heterogeneous compute platforms featuring a central processing unit (CPU), graphics processing unit (GPU), application-specific integrated circuit (ASIC), and neural network acceleration (NNA) cores.

High-Bandwidth, Low-Latency Compute

Networking high-performance compute clusters will require new networking protocols, such as Ethernet and PCIe, to deliver the required bandwidth and latency.

Cybersecurity, Middleware, and Hypervisor

Consolidating software and applications that currently reside on separate devices into centralized compute clusters requires the adoption of software "plumbing," such as middleware to enable third-party developers to interface with the vehicle's resources, and hypervisors to isolate mission-critical from non-mission-critical functions.

Ubiquitous Connectivity

To maintain and update embedded software, as well as stream content and services from the cloud, SDVs require ongoing cellular connectivity. The cellular network is continually evolving in terms of bandwidth, latency, and reliability, opening up new applications in both the infotainment and autonomous driving domains. For example, improvements in download speeds can enable high-resolution content streaming, while faster latency and greater reliability can power cooperative perception and maneuvering in autonomous vehicles.

KEY APPLICATIONS AND USE CASES

Key applications for the software-defined car can be divided into two groups. First, there are the new user experiences and driving functions that can delivered through the digitization of the different vehicle domains, such as the cockpit, electric drivetrain, and driver assistance/autonomous driving. Second, there are the new business models that emerge through the maintenance and upgrading of these software-defined domains. For automakers, these new business models represent an additional revenue stream that is proportional to the connected cars already on the road, reducing their exposure to fluctuations in the new vehicle sales market. From the consumer's perspective, regular OTA updates result in a vehicle with a dynamic and constantly evolving value proposition, keeping the consumer's car fresh and up-to-date throughout its lifecycle.

Autonomous driving and electrification technology megatrends are addressed in dedicated sections in this paper, so the remainder of this section will focus on the software-defined cockpit use cases.

Rich Multimedia – Software-Defined Audio and Immersive Video

With vehicle cabins featuring numerous large and high-resolution displays, and powerful multi-speaker premium audio systems, new software-defined cabin experiences have generally followed those deployed in the home, smartphone, and other consumer electronics. However, the automotive context has the unique factor of driver distraction to accommodate, which has shaped the applications that have gained traction to date, and those which are expected to take hold in the medium term.

Software-defined audio, which includes powerful EQ-shaping opportunities, as well as impulse response technologies to create artificial audio environments, is a key application in the short term, as it delivers a significant upgrade in an experience that the driver can appreciate while safely on the move.

Richer and more immersive video will be enabled through the integration of commonly available streaming services, leveraging large, high-resolution displays and powerful audio systems to deliver an immersive media experience that exceeds that of a brought-in device. Middleware accommodating for multiple video formats and digital rights management (DRM) will allow for content to be streamed from the cloud, in the vehicle and mirrored from brought-in devices.

In the short term, the market potential for immersive multimedia will be limited to passenger-oriented displays, particularly in the rear seat, due to distraction concerns. However, with the average vehicle occupancy being only 1.3 persons, actual consumption of video content will be minimal. In the medium term, electrification will make 30-minute stops at DC fast charging stations a semi-regular occurrence. While stationary, drivers will be able to enjoy immersive media such as video, and in these contexts, software-defined media experiences could make charging sessions less arduous to the driver.

In the long term, partial and full automation will begin to eliminate the distraction issue, permitting more regular engagement with immersive media such as video streaming.

Gaming

Similar to in-vehicle video, gaming is an experience that has commonly been enjoyed in the home, but which will now increasingly be featured in vehicles. As SDV cabins feature more of the technologies that shape the home, including large, high-resolution, and high-frequency displays, and powerful, multi-speaker audio, gaming is expected to make the transition from the home and into the next generation of connected cars. Given the fast response times required by a smooth gaming experience, 5G or even edge-cloud compute is considered a key enabler, particularly when gaming on the move and at highway speeds.

As with in-car video, distraction concerns will limit the adoption of in-car gaming to passengers and charging sessions for the next 5 years at least, with automation holding the key to wider use.

AI Personal Assistants

With distraction concerns shaping what experiences can be supported in the short to medium term, voice controls have become a popular user interface, allowing drivers to interact with vehicle functions without looking away from the road or taking their hands off the wheel.

Furthermore, AI-powered natural language understanding has made interaction more conversational, also reducing cognitive load.

Current systems operate on a "wake word" principle, requiring the driver to activate the assistant and engage with vehicle functions. Future systems will be more proactive, with the voice interface serving as only part of a broader AI personal assistant solution, which will ingest data from internal and external sensors to make the driver aware of developing situations.

In-Car Commerce

The applications and use cases discussed above all rely on a common set of hardware – displays, multi-speaker audio, powerful SoCs, in-cabin microphones, and high-bandwidth connectivity, with the highly distinct experiences being delivered through software. This provides the opportunity for OEMs to offer these applications and others in a number of different ways, either at the factory, at the point of sale/dealership, or after the vehicle has been deployed on the road, with the head unit offering the best interface for drivers to add these ad-hoc features.

Potential business models include one-off transactions for new functionalities purchased via the head unit that remain permanently available, on-demand purchases for functionalities that are temporarily available, such as highway automation features on long journeys, or subscription models that give the user access to functions for as long as the consumer renews the service.

Enabling integrated and secure payments will also open opportunities for in-vehicle purchases of other goods and services, with vehicle-centric purchases such as fuel, charging, tolls, and parking expected to gain the most traction.

Augmented Reality

A further software-defined function that will shape automotive cabins in the long term is augmented reality (AR). These take the form of overlays that blend reality around the vehicle with metadata that give the driver and passengers an enriched understanding of the environment. When combined with specialist hardware that projects content onto the windshield, AR heads-up displays (AR-HUDs) can enable drivers to keep concentrating on the road, while still receiving information that would otherwise require a shift of attention to another display.

As an inherently interactive display, AR-HUDs can deliver key information to the driver with minimal cognitive load. This could prove highly valuable in semi-autonomous vehicle contexts, where an AR-based human-machine interface (HMI) could help manage the interaction between the functions of the semi-autonomous system and the human co-pilot, communicating the intentions and perception of the system in an easily digestible way that still allows the driver to observe the outside environment.

AUTONOMOUS DRIVING

OVERVIEW

Driving tasks can be repetitive and arduous, and by most measures, humans are not good at safely performing these tasks. Automating driving tasks can improve safety, while also giving back time that is currently consumed by manual vehicle operation, delivering a combination of societal and individual advantages.

ADVANTAGES

Safety (SAE Level 1 – Short Term)

Even modest, low-cost, and widely adopted levels of vehicle automation can deliver significant safety advantages. Active safety applications do not replace driving tasks but supplement the driver's abilities through obstacle detection and collision avoidance interventions. While drivers can become tired or distracted, active safety systems continue to deliver within their designated operation parameters.

Reclaimed Time (Level 3 and 4 – Mid to Long Term)

SAE Level 1 active safety systems provide either longitudinal or lateral assistance systems to the driver, while SAE Level 2 systems provide a combination of longitudinal and lateral assistance to the driver, but still require the driver to constantly supervise their operation.

In higher levels of automation (SAE Level 3 and Level 4), drivers can disengage from driving tasks, with the degree of disengagement corresponding to the operational design domain (ODD) of each semi-autonomous implementation. The factors informing these ODDs include geography, road type, weather, regulations, and ambient lighting. In so far as drivers can disengage, they effectively claw back time that would have been consumed either performing driving tasks or supervising a less capable system.

This reclaimed time can be devoted to entertainment, rest and relaxation, or productivity.

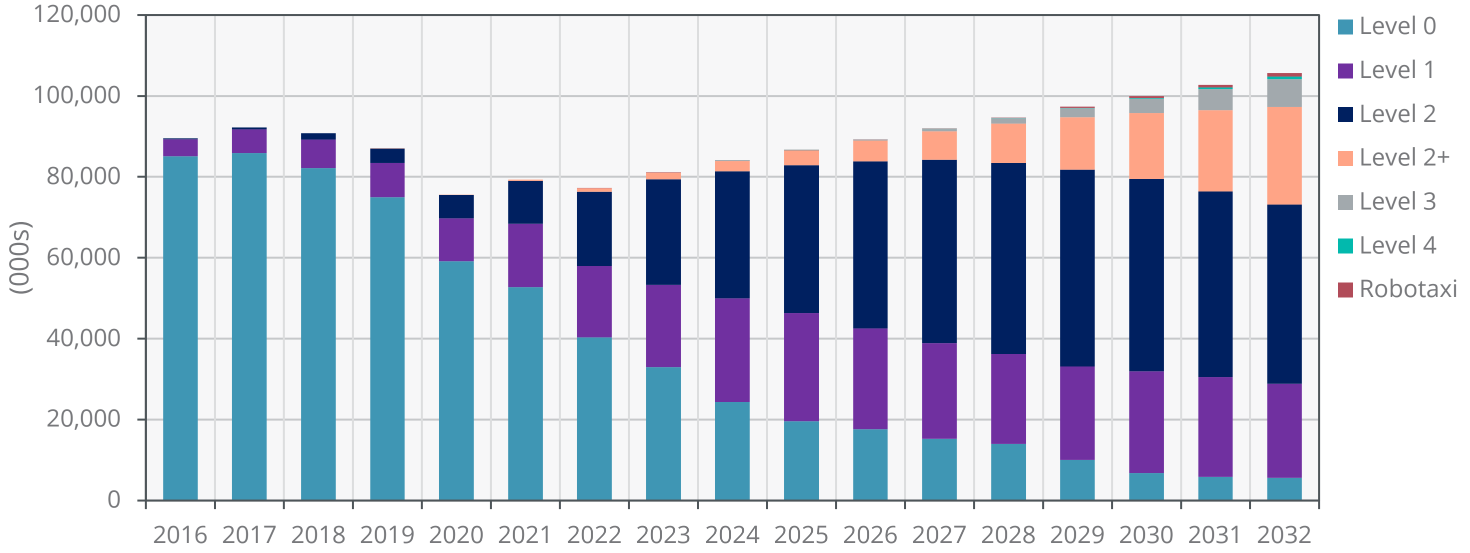
Sustainability (Robotaxis – Mid to Long Term)

In the long term, when all driving tasks can be automated in a broad operational design domain, the degree of driver disengagement extends to no driver being present at all. In these circumstances, the prospect of fully driverless operation opens a whole new approach to personal mobility, in which shared fully-driverless vehicles form the basis of a smart mobility service. The green shoots of this mobility revolution are already visible in small-scale deployments across the globe, with the potential, when deployed at scale, to deliver considerable societal benefits.

In particular, the use of shared assets with higher utilization to satisfy the demand for personal mobility could reduce congestion, free up space currently occupied by parking lots, and hand back vehicle-centric spaces (i.e., parking garages) for better use in urban contexts.

Chart 2: New Vehicle Shipments by SAE Level

(Source: ABI Research)



KEY ENABLING TECHNOLOGIES

Automated driving applications, ranging from basic active safety to more comprehensive unsupervised autonomous driving, rely on a common set of basic enabling technologies. These include sensing, processing and software governing perception, sensor fusion, and motion planning or control. The specific capabilities of each enabling technology component varies significantly, depending on the target application.

Sensing

Camera sensors form the backbone of automated driving perception, delivering the semantic insight needed to identify road users, boundaries, and other obstacles, with structure from motion techniques widely used to deliver range estimation. With camera sensors sometimes compromised by occlusions, poor weather, and extreme lighting, secondary and tertiary sensors such as radar and light detection and ranging (LiDAR) add greater robustness to perception in some applications. In general, camera-radar sensor fusion powers active safety and supervised automation, while unsupervised applications require the “third opinion” of a LiDAR sensor.

High-Performance and Heterogenous Compute

To enable fast response times, all automated applications, ranging from basic active safety through unsupervised automation, require local computing resources. As the number of automated tasks and the degree of driver disengagement increases, so do the requirements in terms of compute power and heterogeneity. The specifics of each compute platform depend heavily on the software architecture enabling the applications supported, but in general, an active safety system can consume as little as 0.25 tera operations per second (TOPS), while unsupervised automation can consume as much as 350 TOPS to 1,000 TOPS, again depending on the efficiency of the enabling software.

In addition to greater compute performance, higher levels of automation require more heterogeneous compute platforms, including CPU and GPU cores, and ASICs dedicated to certain compute tasks, in particular, NNA.

Software and Artificial Intelligence

Software shapes every autonomous vehicle application, with a series of distinct but scalable modules governing perception, sensor fusion, localization, path planning, and motion/control forming the autonomous vehicle (AV) stack. To address the vast array of scenarios that AVs must safely navigate, many AV developers have made wide use of machine learning techniques to develop neural networks that can be inferred at the vehicle edge.

Digital Maps

Accurate maps that are quickly updated to reflect reality are essential to localize vehicles in most AV applications. Some active safety systems can also benefit from digital maps, such as intelligent speed assistance (ISA).

KEY APPLICATIONS

Active Safety and Driver Convenience

Advanced driver-assistance system (ADAS) adoption has now reached approximately 60%, with the most prevalent applications driven by formal regulation, such as the General Safety Regulation (GSR) 2 in Europe, or by the work of safety ratings agencies, such as the New Car Assessment Program (NCAP) and the Insurance Institute for Highway Safety (IIHS). Systems such as automatic emergency breaking (AEB), lane departure warning/lane keeping assist (LDW/LKA), and blind spot detection (BSD) are already widely adopted, with driver monitoring systems (DMS) and ISA set to grow rapidly throughout the decade.

On top of these safety applications, convenience features that can repurpose the same enabling technologies have also rapidly proliferated as automakers look to deliver as much value add as possible, including adaptive cruise control (ACC), relative speed-based routing (RSR), and high beam assist (HBA).

Level 2+/Level 2.5

Autonomous driving will evolve along two key dimensions: feature automation and driver disengagement. Features that can be automated include speed and following distance control, lane keeping, overtaking maneuvers, taking exits, merging into traffic, etc.

In most markets, drivers are still required to constantly supervise all driver-assistance systems, resulting in a SAE L2 system. In SAE L3 systems, drivers can temporarily disengage from driving tasks within the conditions of the ODD but must remain available to re-engage if the system requests. In SAE L4 systems, the system can deliver all driving functions without any supervision from a human driver.

Historically, most of the AV ecosystem expected the market to evolve at an equal pace in both dimensions, with feature-poor and supervised L2 systems becoming feature-moderate and semi-supervised L3 systems and feature-rich L4 systems. Level 2+ or Level 2.5 introduces a new feature /engagement combination – feature-rich and driver-supervised. Indeed, some L2+ systems are expected to be so rich in the number of driving tasks they can automate that they will deliver point-to-point navigation, with every maneuver, urban and highway, automated on the driver’s behalf – but still requiring their supervision.

This delivers a more compelling experience than today's feature-poor L2 systems, while minimizing the OEM's risk exposure and avoiding the need for exotic and expensive technologies associated with driver disengagement, such as LiDAR.

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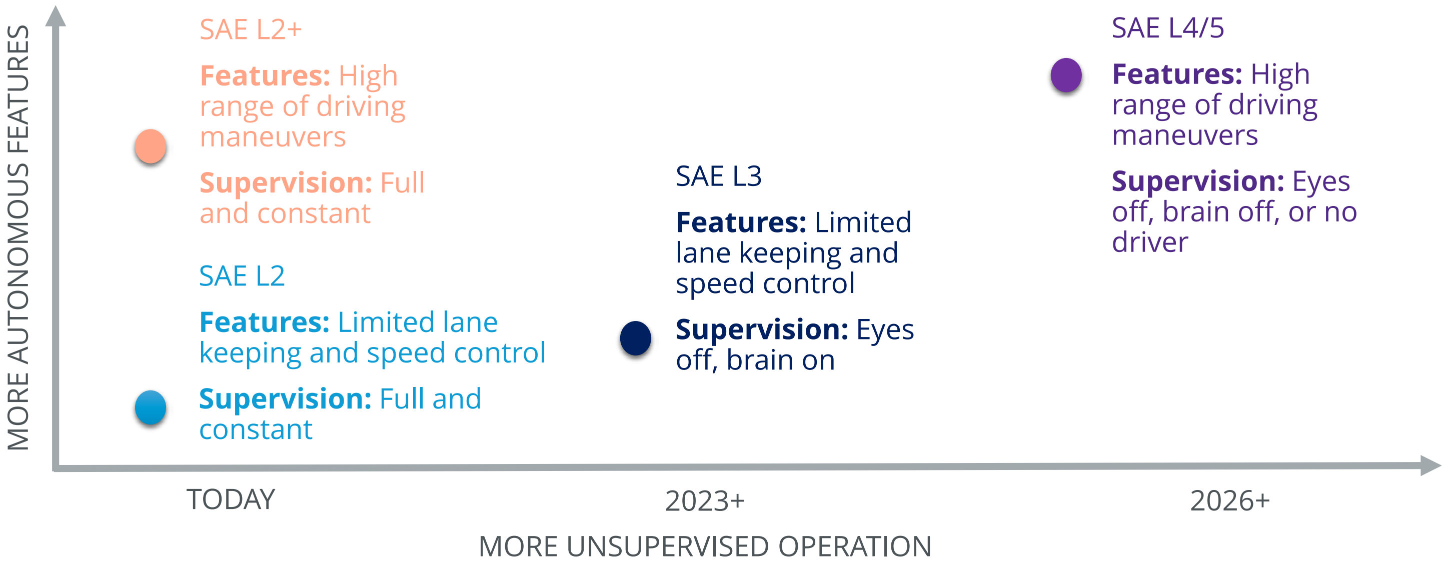


Figure 1: Evolution of Autonomous Driving

(Source: ABI Research)

Automated Highway Driving

The most repetitive driving tasks typically occur in highway driving, with long commutes and cross-country trips representing the best opportunities to hand time back to the driver. Furthermore, as an ODD, the structured nature of the highway is widely seen as an easier challenge to overcome than the complex urban environment, with its mix of road users and complex junctions. Therefore, most passenger vehicle OEMs are targeting unsupervised highway automation in the short to midterm, given significant expected value for consumers.

Point-to-Point Navigation

In the longer term, the automation of urban driving scenarios is expected to unlock the next level of consumer experience – door-to-door or point-to-point navigation, without requiring the driver to perform any of the tasks needed for safe navigation. While Level 3 systems will still require human drivers to be available as a backup, Level 4 systems will deliver point-to-point navigation without any human input.

Robotaxis

As discussed in greater detail above, the removal of drivers altogether will unlock an era of safe, low-cost, and shared mobility. This AV application will roll out slowly alongside the adoption of semi-autonomous features in the passenger vehicle space.

ELECTRIFICATION

OVERVIEW

Governments across the world are committed to the goal of net zero carbon dioxide (CO2) emissions by the middle of this century – a goal considered essential to avoiding climate disaster. With transportation currently representing 20% of global CO2 emissions, and road transport accounting for 75% of this fifth, achieving the net zero goal will require a rapid pivot toward zero-emission road transportation.

Of all the alternatives to ICEs, battery-electric powertrains are the most mature and widely supported technology.

ADVANTAGES

Sustainability

Electrified mobility, when universally adopted, can deliver substantial CO2 savings. Currently, electric vehicles (EVs) are relatively energy-intensive in their production, with several years of operation required to reach the break-even point. However, even with today's energy-intensive manufacturing, a typical EV will emit 50% less CO2 by the end of its lifecycle. Greater manufacturing efficiencies will further reduce the CO2 emissions associated with production.

Finally, the nature of EV powertrains means zero tailpipe emissions in their use. This can mean reducing and ultimately eliminating harmful emissions when driving in urban areas and other inhabited spaces, improving public health through reduced inhalation of particles and harmful gasses.

Robustness

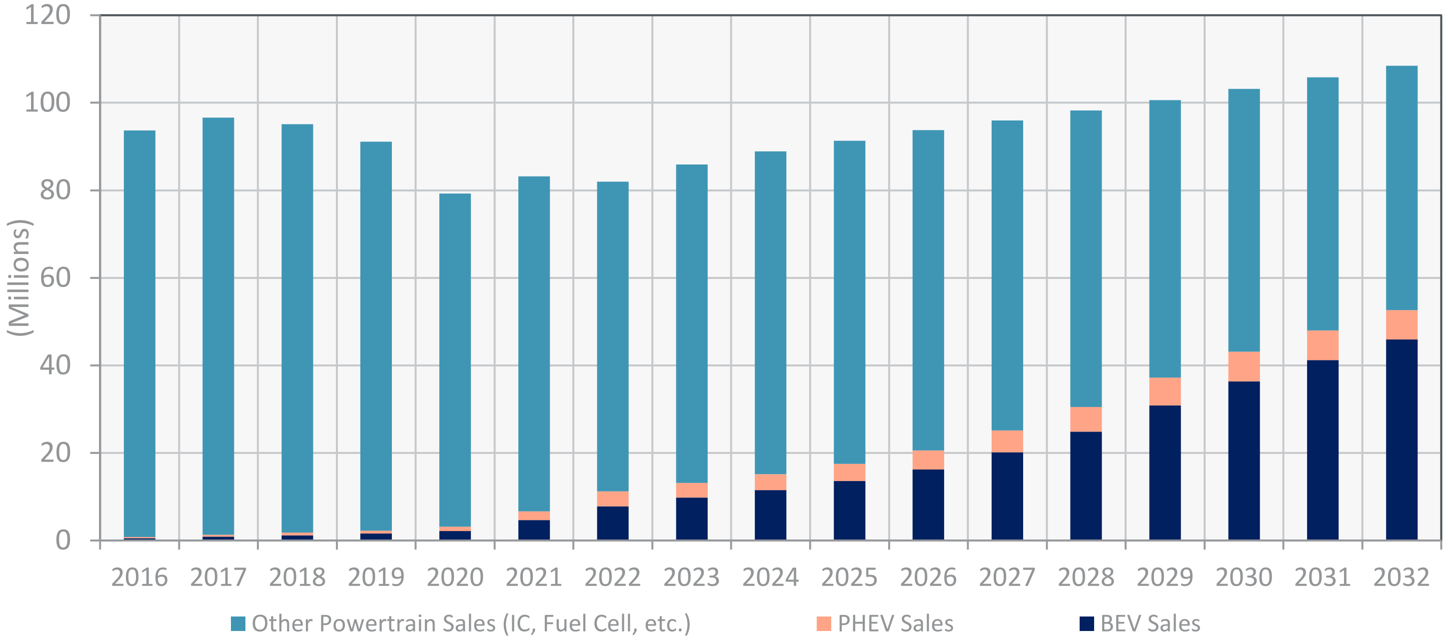
By nature, electric powertrains involve few moving parts in their operation, and do not require many of the components and maintenance services that ICEs do. As a result, they incur far fewer maintenance costs, with EV fleets already reaping the rewards of greater uptime and longer service life. This is also reflected in the warranties offered by OEMs for their EVs, which often exceed 8 years or 100,000 miles.

Performance

When considering the typical performance measures for an ICE, EVs tend to exceed ICE alternatives in almost every respect. The use of electric motors allows for near-instantaneous delivery of maximum torque, resulting in acceleration curves from modest EV models that rival performance-oriented ICE alternatives. On the opposite end of the spectrum, EV powertrains, by virtue of their fewer moving parts, tend to be quieter and smoother than their ICE equivalents.

Chart 3: New Vehicle Shipments by Powertrain

(Source: ABI Research)



KEY ENABLING TECHNOLOGIES

Batteries

Batteries are the essential component in any EV, storing the charge necessary to propel a heavy vehicle over considerable ranges. The market has coalesced around the lithium-ion battery technology due to several factors, including efficiency, energy density, power density, and the lack of “memory effect” that requires strict charge and discharge behavior for proper maintenance, which is found in alternative chemistries.

Innovations in cathode materials, such as nickel, manganese and cobalt (NMC), lithium nickel-cobalt-aluminum oxide (NCA) and lithium iron phosphate (LFP), as well as anode materials such as silicon and graphite, are creating new opportunities for OEMs to build batteries that meet the best balance of energy, power, sustainability, and cost for different implementations.

Battery Management

Battery management systems govern the individual cells that make up the vehicle’s battery, ensuring that the voltage of each cell does not become too high (overcharging) or too low (over discharging), preventing degradation and maximizing battery life. Improvements in processing and software have improved accuracy, increasing the distance between the safe maximum and safe minimum voltage, increasing vehicle range and overall safety.

Charging Infrastructure

Recharging EV batteries depends on a vast network of charging stations, blending private off-road charging with public charging to provide the range needed to deliver on consumers’ needs. Currently, around 80% of charging is performed at home, with the typical EV owner having access to off-road charging at home, relying on a combination of destination charging and range-extension charging to supplement the miles required. A growing number of EV owners in dense urban environments rely purely on the growing public charging network to satisfy their mileage demand.

Most public chargers and all home chargers are AC slow chargers that typically take hours to add significant miles to the vehicle range. Increasingly, DC fast chargers capable of charging rates of 50 kilowatts (kw) to 300 kw+ are being deployed, which will allow for the addition of significant miles in a short time period, supporting longer journeys.

Traction and Motors

Converting chemical energy stored in the battery into highway speeds relies on a series of propulsion components, including inverters, traction motors, and the drive transmission. Compared to a conventional ICE powertrain, an EV uses 60% fewer components to deliver propulsion.

KEY APPLICATIONS

Hybrid Vehicles

Now a declining subsegment of the EV market, hybrid electric vehicles (HEVs) played an important role in kickstarting adoption. Plug-in hybrid vehicles (PHEVs) combine a modest standalone EV powertrain with a conventional ICE setup to deliver a small range (typically less than 30 miles) of zero-emission driving and longer ranges of ICE-powered operation. In practice, what was intended to be the best of both worlds turned out to be the worst of both worlds.

PHEVs do not benefit from the core advantages of lower maintenance costs and zero-emission operation, instead incurring extra inefficiencies through the need to support the weight, cost, and complexity of two powertrains.

Emissions-Free Mobility

The most basic but most advantageous application for EV powertrains is widespread emissions-free mobility, which is key to meeting climate change-mitigating targets and improving quality of life in dense urban areas.

Software-Defined Performance

As much a challenge as an opportunity for automakers, EV driving experiences will be effectively defined by software. Within the constraints of what can be supported by the specific energy and specific power of the battery, the precision of the battery management systems, and the specifications of the DC motors, there is considerable scope to shape the parameters of the driving experience in the software domain.

Acceleration curves and maximum speeds are currently dictated by the hardware specification of the ICE and drivetrain, whereas in the EV context, these parameters are largely defined in software. It is incumbent on automakers that have historically shaped their brand identities around the performance, efficiency, and robustness of ICE platforms to now investigate how they can shape a distinct driving experience in software.

While the scope of this challenge cannot be underestimated, as with all SDV functions, there are considerable upsides. The same vehicle can be redefined from a comfort-oriented value proposition to a performance-oriented value proposition through an OTA software update – allowing the same platform to support different experiences for different users, or for the same user at different times.

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