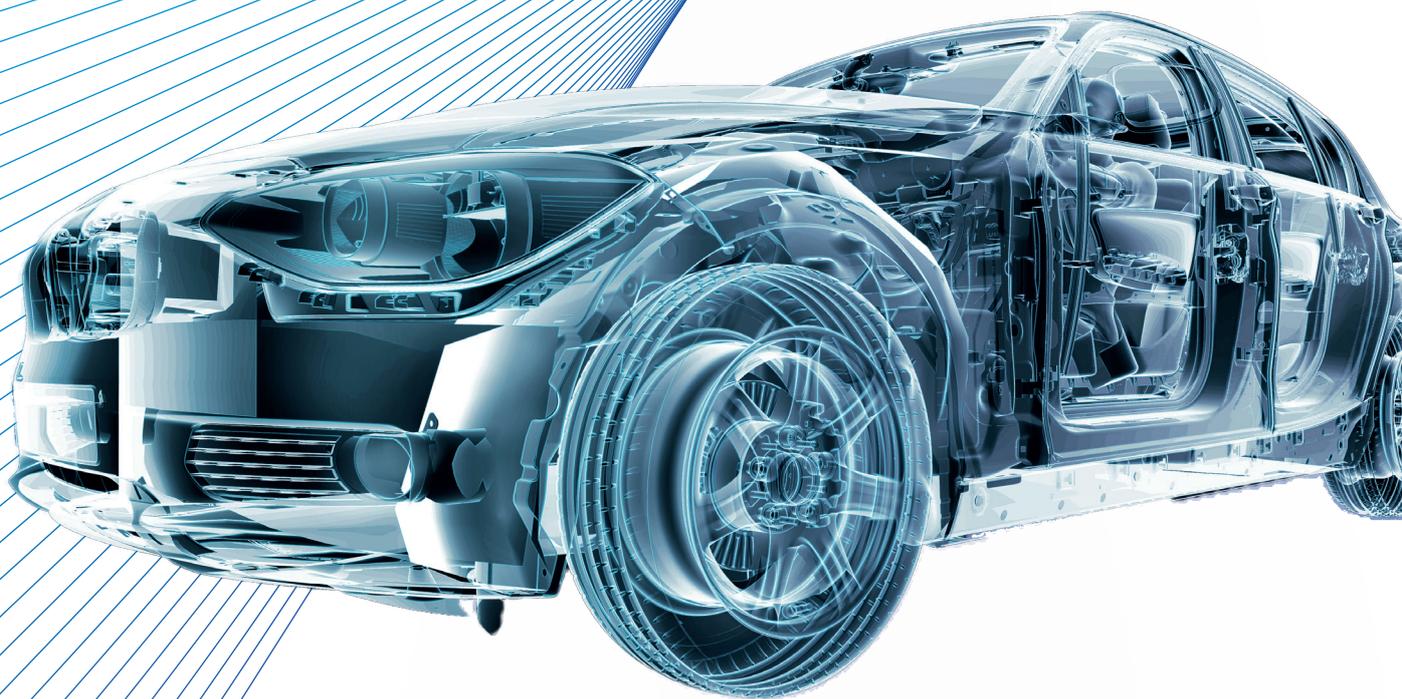


McKinsey
& Company

Automotive software and electronics 2030

Mapping the sector's future landscape



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Introduction and key insights

Autonomous driving (AD), connected vehicles, electrification of the powertrain, and shared mobility (ACES) are mutually reinforcing developments in the automotive industry.

Combined, they are not only disrupting the automotive value chain and impacting all stakeholders involved but are also a significant driver of the expected 7 percent compound annual growth rate (CAGR) in the automotive software (SW) and electrical and electronic components (E/E) market, i.e., from USD 238 billion to USD 469 billion, between 2020 and 2030.

At this rate, the SW and E/E market is expected to vastly outpace growth in the overall automotive market, which is estimated to grow at 3 percent CAGR in the same time span. As a consequence, SW and electronics have become the focus of most automotive companies and their executives.

In this context and based on our extensive research and analyses (Text box 1), we offer a perspective on three key questions:

- What are the specific trends and drivers of the automotive sector's SW and E/E growth dynamics and the changing landscape towards 2030?
- How are these drivers going to affect the automotive industry's long-established value chains?
- How can players in and outside of the industry optimally prepare for the upcoming market developments?

In the following three paragraphs, we provide a short answer to these questions while the remainder of this report will go into detail.

Text box 1
How we derive insights
for this report

The insights of this report were generated based on closely linked qualitative and quantitative research. For the qualitative insights, we held interviews with executives in the automotive industry and combined them with the knowledge of internal key experts within our automotive practice to build a holistic view on how ACES trends and additional drivers will influence the automotive SW and E/E market.

For our quantitative market insights, we built bottom-up market models for each of the core components within the automotive SW and E/E market:

- SW development, integration, verification, and validation
- Electronic control units (ECUs)/domain control units (DCUs)
- Sensors
- Power electronics
- Other components (harnesses, controls, switches, displays).

At the highest level, these models (excluding SW) calculate the market size following the same logic. Market size is the product of the number of a certain component per vehicle, its average selling price (ASP), and the number of vehicles produced in a given year. To achieve the proper granularity of each model, we distinguish the key automotive domains (e.g., advanced driver assistance systems (ADAS), body, infotainment) as well as characteristics such as vehicle segment, original equipment manufacturer (OEM) type, or SAE AV level. The number of vehicles produced each year is provided by a separate model in which we incorporate data from latest McKinsey insights. The size of the automotive SW market is calculated based on the workforce across the supply chain involved in SW topics and the number of vehicle platforms and variants across OEMs and tiers and their change over time.

Further details on the market models and their derivation are provided in the Appendix.

The SW and E/E components market will grow rapidly with significant segment-level variation driven by disparate impact of the ACES trends

The move towards a more centralized SW and E/E architecture is an overall trend and a key driver of the market's expected growth (7 percent CAGR) by 2030. Significant variation is expected across the market's various segments. Power electronics is expected to occupy the high end of the market's growth at 15 percent CAGR. Growth in the SW and sensors segments, expected to be at 9 and 8 percent, respectively, will be fueled by AD. The ECUs/DCUs segment will continue to hold the largest share of the market, but growth here is likely to be relatively low, at 5 percent. While ECUs/DCUs will be used increasingly in the application of AD, price decreases from efficiency gains will counter-balance growth in the segment. Electric vehicle (EV) platforms will be a new market for high-voltage (HV) harnesses, while the demand for low-voltage (LV) harnesses is expected to shrink, resulting in the harness segment growing at the slowest rate.

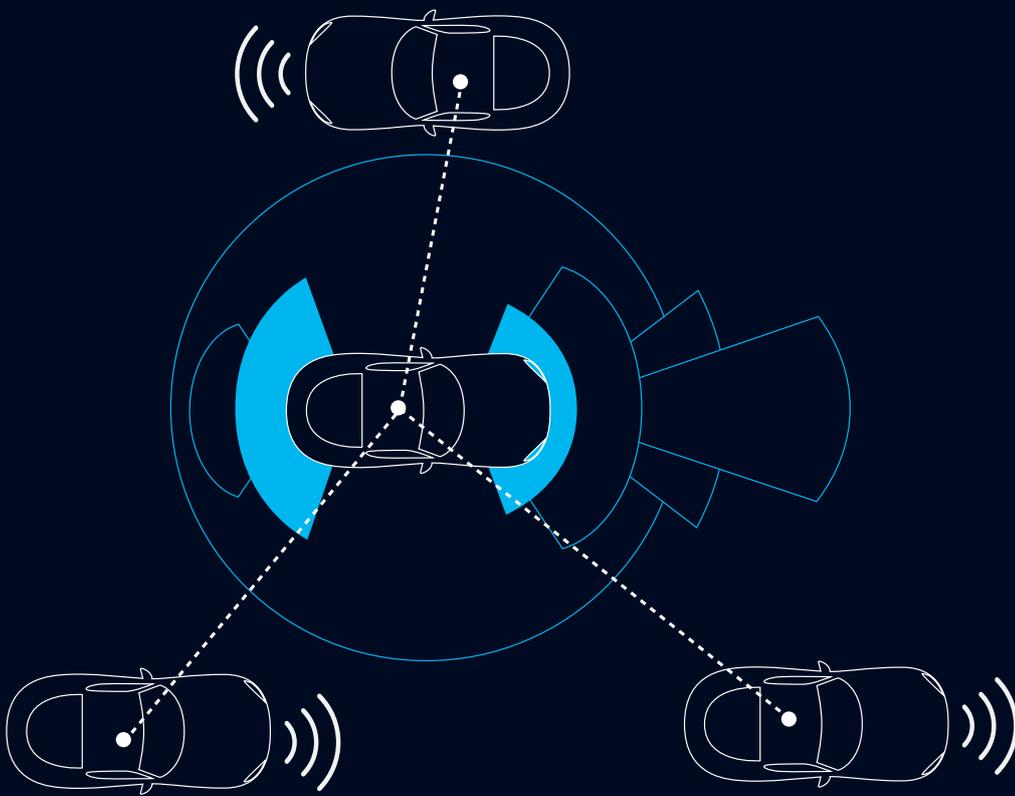
A separation of hardware (HW) and SW would fundamentally change the dynamics of the automotive industry's player and value landscape

The days of OEMs comprehensively defining specifications and suppliers delivering on them may be nearing an end. Neither OEMs nor traditional suppliers are in a position to fully define the technology requirements of new systems. Codevelopment between OEMs and suppliers is expected to become not just prevalent but necessary. In addition, tech-native companies are expected to more boldly enter the space. This will be made easier as HW and SW sourcing become more separate. This separation would break up established value pools, reducing barriers to entry. For OEMs, the separation would also make both sourcing more competitive and scaling less complex and allow for a standardized platform for application SW while maintaining competition on the HW side.

Both archetype-specific and cross-player strategies can position companies for success in the future landscape

The set of strategic actions for OEMs includes a plan to keep the cost of ever-growing HW and SW development under control and establish a more agile cross-functional development organization. Cross-functionality would benefit tier-1 suppliers, too, as would actively partnering with OEMs to define their E/E architecture. Tier-2 suppliers will want to further specialize and scale within an attractive niche to thrive even as many components become commodity. All players will benefit from building their SW delivery and E/E architecture capabilities, embracing latest technology innovation (including UI, UX, analytics), and abandoning absolutistic notions of competition while analyzing the benefits of a partnership within an emerging ecosystem.

1. Software and electronics will outgrow the automotive market



In the next decade, the automotive industry will face a magnitude of change that has not been seen in a century. This change will be driven primarily by four mutually reinforcing trends, i.e., autonomous, connected, electric, and shared (ACES) vehicles. These will result in different user behaviors and mobility preferences, shifting value pools, innovative business models, and new entrants into automotive. All of these trends are enabled by the advancement of technology in electronics and SW and thus have a substantial impact on the automotive electronics and SW market.

1.1 The software and electronics architecture in vehicles will see a major evolution

As shown in Exhibit 1, the overall trend is a transition from a decentralized architecture (components connected by a central gateway in the 3rd generation of E/E architectures), in which functions are running on dedicated ECUs with high SW-to-HW integration, towards more centralized systems with dedicated domain controllers (4th generation). Finally, the architecture is expected to evolve into virtual domains (5th generation), in which one control unit runs functions or (micro-)services of different domains (e.g., infotainment and body control). The centralization will go along with a separation of HW and SW, leading to vehicle systems being built as a layered architecture with clear abstraction points at operating system (OS) and middleware layers. While this evolution will occur across domains over time, infotainment and driving assistance are expected to be the forerunners, as areas of high performance and/or low safety or latency criticality are easier and/or more beneficial to transform.

The architecture evolution will impact multiple component markets:

- DCUs will become a new market segment with high-performance computing units being deployed in vehicles, especially for ADAS, and with higher autonomous vehicle (AV) levels, i.e., AD.
- ECUs will no longer be fully tied to the sourcing/development of SW functions. The change in business model is made possible by the separation of HW and SW.
- Automotive sensors, as a market, will be distinguished between smart sensors, which have a high degree of (pre-)processing capabilities versus raw sensors, which send data into a central DCU.
- Sensors, harnesses, ECUs, and other HW components will become increasingly standardized and commoditized with the transition towards SW-defined functions, i.e., functionality will be realized through SW instead of additional HW (e.g., ADAS functions enabled on-demand based on a standardized set of sensors).

The E/E architecture is evolving from independent, function-specific ECUs towards a centralized architecture

E/E architecture	Generation	High-level architecture	Main features
Vehicle centralized	5th		<ul style="list-style-type: none"> - Virtual domain - Limited dedicated HW - Ethernet backbone - Complex functions, high performance computing
	4th		<ul style="list-style-type: none"> - Central domain controller - Ability to handle more complex functions - Consolidation of functions (cost optimization)
Distributed	Today		<ul style="list-style-type: none"> - Stronger collaboration via central gateway - Cross-functional connection - Ability to handle complex functions, e.g., adaptive cruise control
	3rd		<ul style="list-style-type: none"> - Collaboration of ECUs within one domain - Domains: body/comfort, chassis, powertrain, and infotainment - 3-4 independent networks - Limited communication between domains
	2nd		<ul style="list-style-type: none"> - Independent ECUs - Isolated functions - Each function has its ECU (1:1 connection)
	1st		<ul style="list-style-type: none"> - Independent ECUs - Isolated functions - Each function has its ECU (1:1 connection)

SOURCE: McKinsey

1.2 ACES trends and the architecture evolution will result in significant growth in the automotive electronics and software market

The effect of the ACES trends and the architecture evolution is a significantly growing automotive electronics and SW market. While the global automotive market is expected to grow from USD 2,755 billion in 2020 to USD 3,800 billion at a rate of ~3 percent p.a., SW and E/E will grow at a rate of ~7 percent p.a. from a total market size of ~USD 238 billion to ~USD 469 billion (excluding battery cells).¹ Exhibit 2 shows the overall market figures as well as the breakdown by component and region.

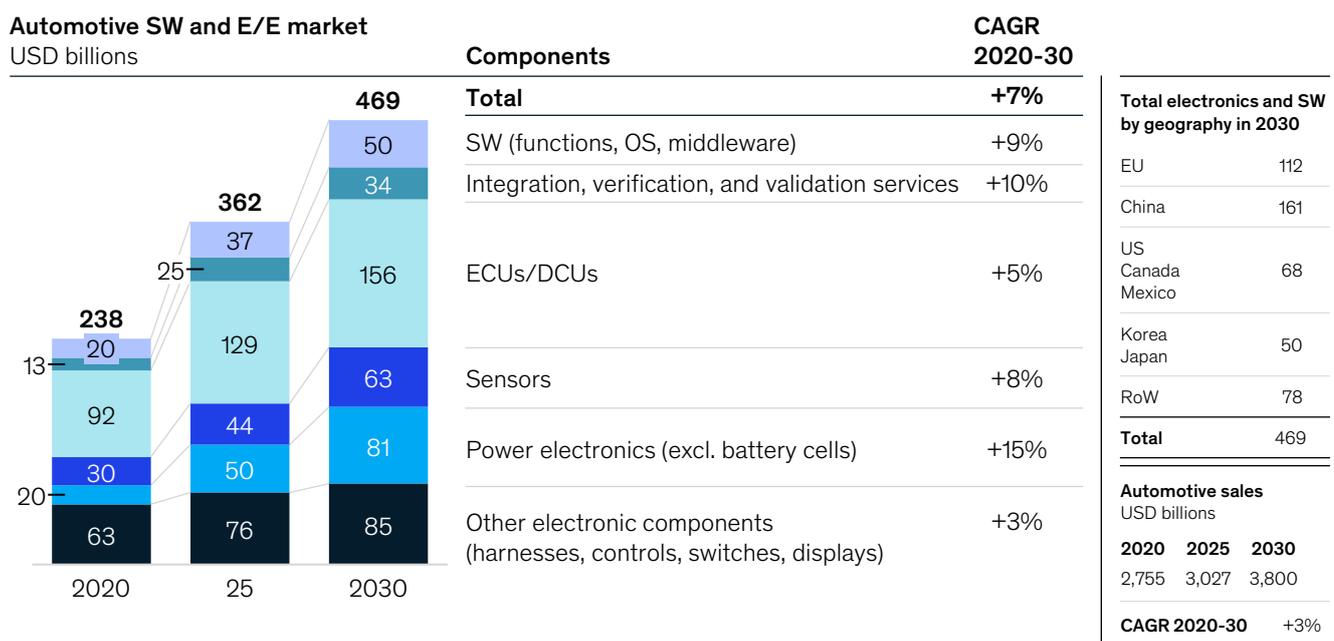
Both in 2020 and 2030, ECUs and later DCUs compose the component group with the largest market share. The moderate growth in ECUs/DCUs is the result of two counteracting effects, i.e., a growing vehicle market and higher instance of functions based on electronics in each car versus decreasing unit costs and a cost decrease due to ECU consolidation into DCUs. With a rate of ~17 percent p.a., power electronics is the component group with the largest growth rate, primarily driven by EV adoption. Growth in SW and sensors is largely driven by the development and adoption of AD, requiring advanced SW functionality (e.g., object detection and classification based on neural networks, raw data sensor fusion, and environmental modeling as well as algorithms for path planning), increased functional safety, and new sensor types (especially light detection and ranging, LiDAR). Other components are mostly growing in line with the automotive market due to higher electronics demand outweighed by decreasing unit costs. Geographically, the market will primarily be divided into the large regions of Europe, North America, and China, with regional hotspots for specific components, e.g., China for developing batteries and power electronics.

While growth of the total E/E market is expected to be stronger than that of the automotive market as a whole, the individual content of electronics and SW per car will differ hugely by segment, powertrain type, and SAE AV level. This is illustrated by three example vehicle configurations – a traditional SAE AV Level 1 volume car in the B segment (with an internal combustion engine, ICE), robotaxis (SAE AV Level 4 to 5 volume car in the C segment with battery electric vehicle (BEV) technology), and a premium SAE AV Level 3 vehicle with plug-in hybrid electric vehicle (PHEV) technology – see Exhibit 3.

¹ Revenue forecasts based on vehicle volumes from IHS Markit, Light Vehicle Production Forecast, October 2018; pull completed on November 6, 2018

Exhibit 2

Automotive SW and E/E market with a CAGR of 7% p.a. until 2030, largely driven by power electronics, SW, and ECUs/DCUs

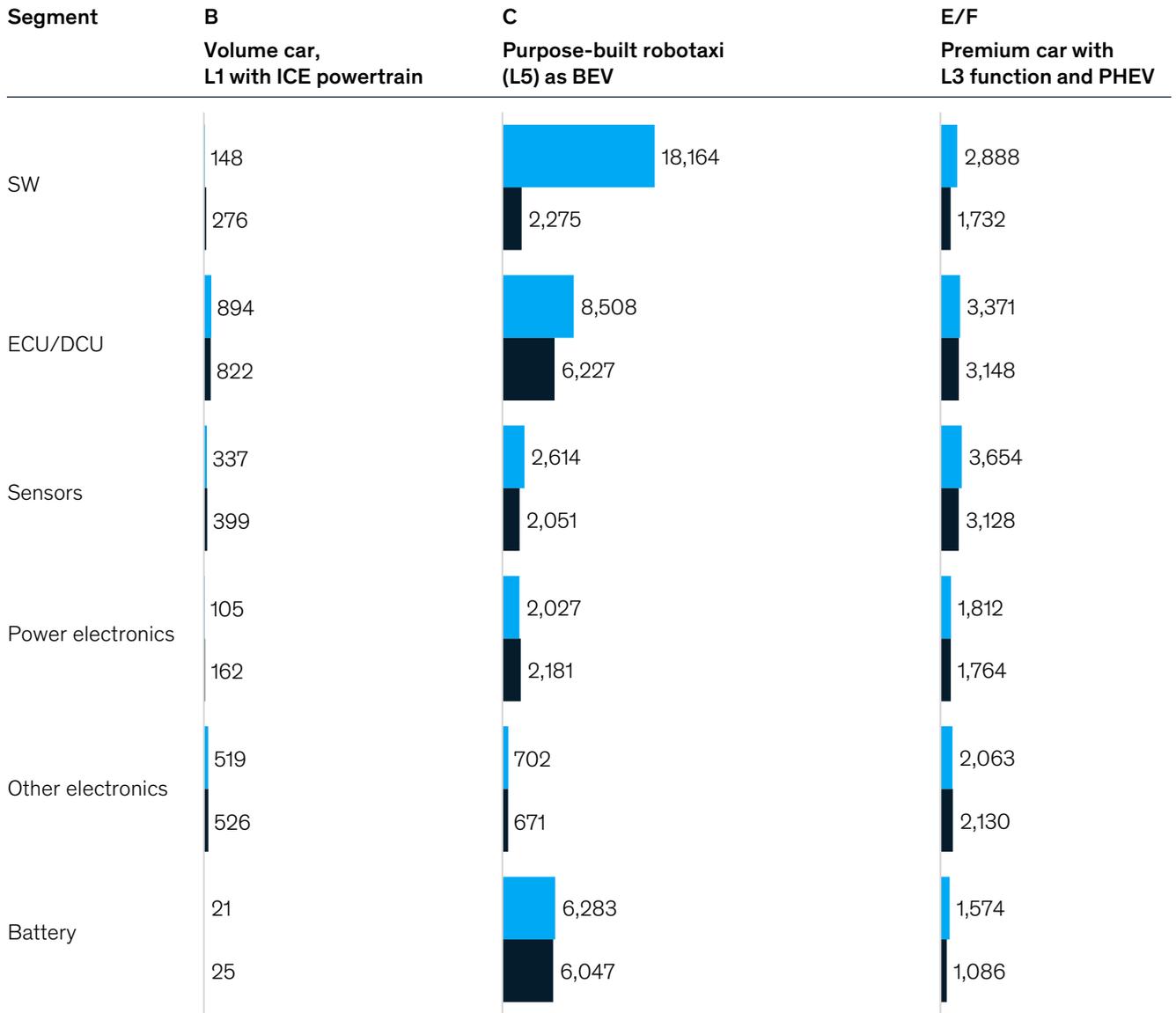


SOURCE: McKinsey analysis; Revenue forecasts based on vehicle volumes from IHS Markit, Light Vehicle Production Forecast, October 2018; pull completed on November 6, 2018

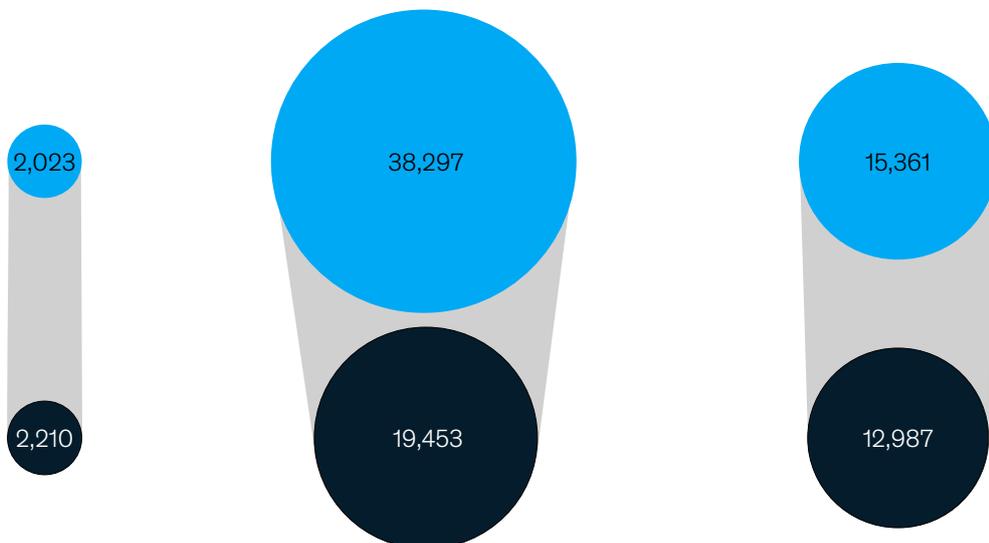
Automotive SW and E/E content per car

2025 2030

USD



Total



SOURCE: McKinsey analysis

Traditional SAE AV Level 1 volume cars in the B segment

The electronics content of these cars will only change marginally. While more functions will expand into the mass market, commoditization of electronics and SW functions due to standardization of the architecture and scale effects will lead to decreasing prices, keeping content per vehicle stable.

Robotaxis

Electronic and SW costs for robotaxis will be significantly higher in 2025, driven primarily by high costs for sensors as well as a low vehicle base, across which the significant SW costs for SAE AV Level 4 to 5 can be distributed. With increasing numbers of robotaxis and commoditization of sensor technology (especially LiDAR), robotaxis will see a significant drop in SW and electronics costs by 2030, improving the business case for them.

Premium SAE AV Level 3 vehicles with PHEV powertrain

Electronics components in these cars will slightly devalue between 2025 and 2030 due to scale effects. The largest drop in individual contribution to cost will happen in SW as standardization and application of SW on a larger vehicle base at nearly zero marginal costs allows for better distribution of initial development costs.

Thus, market growth can be strongly attributed to the increasing penetration of vehicles with higher SAE AV levels and electric drive vehicles (xEVs). The production numbers of cars equipped with SAE AV Level 3 are expected to grow from somewhere on the order of 100,000 vehicles in 2020 to more than 10 million vehicles in 2030. Additionally, the number of SAE AV Level 4 to 5 vehicles produced per year will surpass ~5 million in 2030. Finally, the worldwide share of EVs – hybrid electric vehicles (HEVs), PHEVs, and BEVs-produced is likely to grow from less than 4 percent in 2020 to more than 20 percent in 2030.

The growing base of cars equipped with AD systems or electrified powertrains highly relying on SW and electronics will drive market growth and open opportunities for companies in this sphere. In the following chapter, we will explain the trends and drivers of growth in each of the component groups shown in Exhibit 2 in further detail.

2. Key drivers of the automotive sector's changing landscape



While the overall market growth offers significant upside across all components, factors like AV penetration and powertrain distribution will impact component groups differently. Yet most of the components show strong sensitivity to those factors as well as the total number of produced cars. Our detailed bottom-up model of the automotive SW and E/E market allows us to identify and quantify the impact that the core drivers (i.e., ACES trends) will have on the market dynamics described above. We will explain these drivers in the following chapter.

2.1 Software: the global automotive software market will show dynamic growth

Our analysis of the automotive SW market combines a functional grouping of SW functionality with a value chain perspective. From a functional point of view, the market can be divided into several SW domains along the technology stack. The OS and middleware are the low-level SW components that enable HW/SW separation and implement low-level functions. The SW functions running on ECUs, DCUs, or smart sensors can be grouped according to their functional domain: powertrain, chassis, energy, body, ADAS/AD, infotainment, middleware, OS, connectivity and security, and connected services. For each domain we have analyzed how the SW development effort will evolve by 2030, depending on the complexity of the SW functions and influence of ACES trends.

From a value chain perspective, there are three main phases of the SW development process to be considered: implementation of core functions (including adaptation of functionality for specific vehicle platforms), validation and verification of intended functionality, and system integration of SW modules. Our analysis has considered how the ratios between these phases vary depending on the functional domain – e.g., safety-related functions contain a higher share of validation and verification in the total development effort.

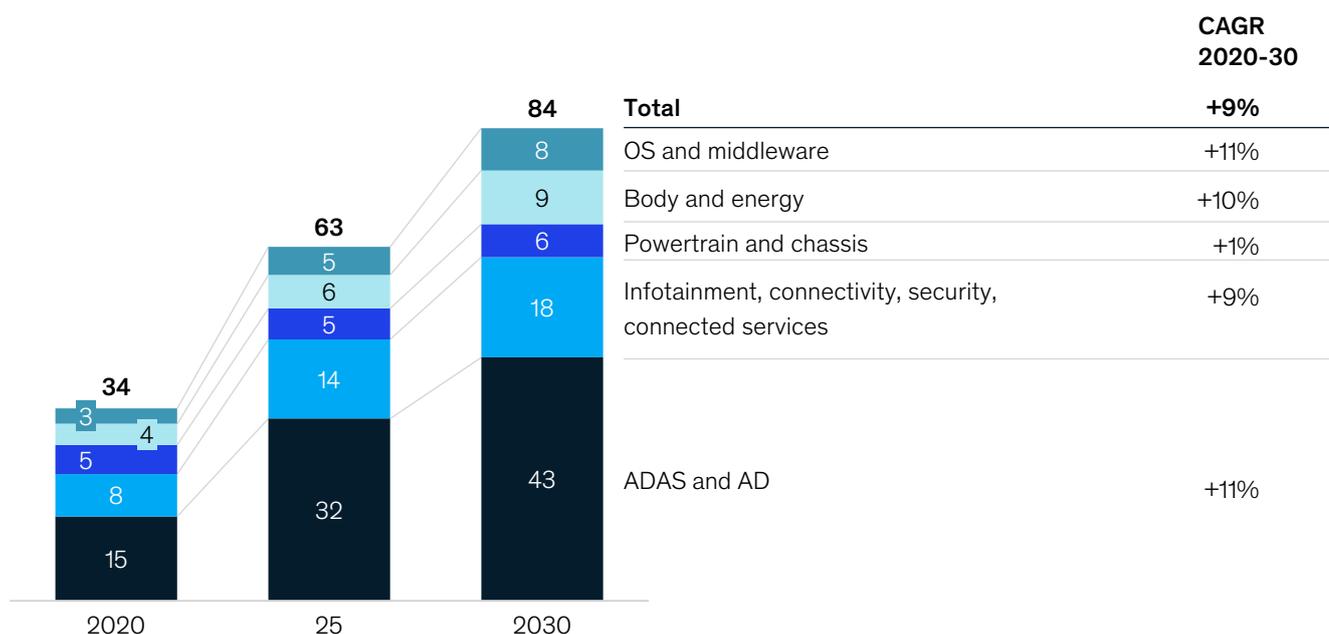
Some domains likely to grow strongly due to ACES trends, others to remain mostly constant or hit a plateau

Exhibit 4 shows the breakdown of the automotive SW development efforts by the different domains and tech-stack elements. Overall market size is expected to reach ~USD 84 billion by 2030 and therefore more than double over the ten-year period from 2020 when the market size is estimated at ~USD 34 billion. While overall SW development is expected to increase, this will probably not be the case for all vehicle SW functions. Particularly, development related to ICE powertrains is likely to increase at only 1.5 percent year over year, and the market for chassis-related SW is expected to stay almost flat until 2030. If the effect of a labor cost increase is controlled for, development effort for the chassis domain is expected to decrease by ~2 percent year over year as fewer ICE vehicle platforms are developed and the focus shifts to BEVs.

Exhibit 4

Breakdown of SW development efforts into domains

USD billions



SOURCE: McKinsey analysis

In turn, boosted by ACES trends such as increased connectivity, the pursuit of AVs, and electrification, other domains are expected to grow significantly. Functions in areas like AD, connected services, energy, or infotainment will gain complexity, as well as become increasingly relevant for a broader share of vehicle platforms.

OS and middleware represent a particularly interesting battleground. Specifically, established automotive tier-1 suppliers will compete in these areas with tech players who have experience in developing OSs in the consumer space. OS development efforts are focused on 3 OS types: event-driven, time-driven, and time-and-event driven, the last one being necessary for AD. We expect the market to converge towards a small number of alternatives for each type, which will in turn limit the size and growth of this market niche.

As already mentioned, developing the core SW functionality is only the first step in the development process. The important subsequent processes are customization for the specific vehicle platform, followed by validation, verification, and integration. After start of production (SOP) there is the maintenance of the SW, which is becoming more and more important and for our analysis has been treated as part of the normal development process. Combined, all of these stages increase SW development costs well beyond base costs for function development, as depicted in Exhibit 5.

Increasing software complexity and broader deployment of vehicle platforms to underpin growth of software market until 2030

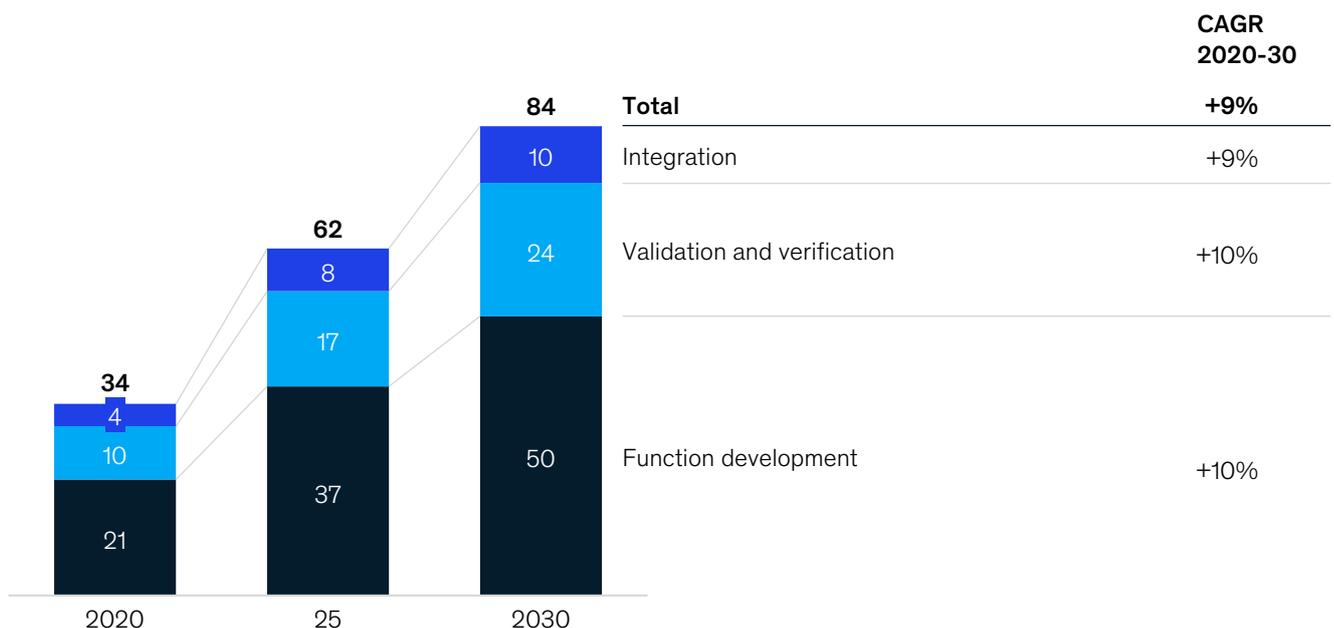
Three key factors contribute to the strong overall growth of the SW market: increase in SW complexity in the domains most influenced by ACES trends, customization effort for integrating functions in a growing number of platforms, and growing labor costs for SW developers.

In the upcoming years, SW will become one of the strategic development areas for the automotive sector. This is because the continuous expansion of vehicle functionality – becoming more connected, managing the electric powertrain, AD – is enabled by increasingly powerful SW just as much as by HW. These developments are mutually reinforcing. Take the domains of infotainment and connected services as an example: once vehicles are able to drive

Exhibit 5

Split of SW market into SW development, integration, and validation/verification

USD billions



SOURCE: McKinsey analysis

autonomously, passengers will expect the infotainment system to integrate the kind of services that are currently typical of smartphones, e.g., virtual assistants, media consumption, and productivity SW. In another area poised for growth, energy management will be a prime target for further evolution with the proliferation of EVs.

All these developments must be enabled through a sustained effort in SW development and testing – programming more sophisticated functions, enabling interaction between SW modules, and extensive testing. Depending on the domain, ACES-trends-related factors are expected to contribute to the CAGR of the SW market with values between ~2 percentage points (infotainment) and ~15 percentage points (AD).

The necessity to expand the target functionality and customize the core SW for a broad range of vehicles is another important driver of the expected growth in the automotive SW market. As complex functions become mainstream, more and more vehicle platforms and variants will integrate them. This will lead to increased efforts from OEMs and tier-1 suppliers to customize and expand the SW. ACES trends will accelerate this need, as more vehicle platforms will be connected and require advanced energy management functions or AD features. We expect that by 2030 almost all vehicle platforms will have some form of data connectivity and incorporate ADAS features. For more “classical” SW domains (e.g., powertrain, chassis, body), the customization effort for different vehicle variants will remain an important multiplier for the costs of the base ECU SW.

Beyond function development and customization, validation and verification are the stages of the development process that ensure that the developed functions meet specifications and fulfill their purpose consistently and reliably. Validation and verification are expected to represent ~29 percent (USD 24 billion) of the total automotive SW market in 2030 (Exhibit 5). This significant share will be driven mostly by the need to verify safety-critical SW, e.g., ADAS, AD, security, as well as the OS deployed in the vehicles. The implication for automotive players is that they need to further invest in their capabilities to test and validate SW efficiently. For automotive players, this translates to adoption of more specialized tools and restructuring of teams to foster efficient validation and collaboration with HW teams.

Integration – at the system level – is the process of bringing together SW subsystems into a larger system. Estimated at USD 4 billion in 2020 and USD 10 billion in 2030, the integration’s 12-percent share of the overall SW market is expected to remain stable. Yet, for some areas such as AD, its share of development is likely to significantly increase (up to 30 percent).

The increase in labor costs will also contribute to the overall growth of the market. Depending on the skill set, salaries are expected to grow annually between 2 percent and 6 percent by 2030, with domain specialists and highly skilled developers at the higher end of the range.

The growth of the overall development effort in the coming decade is reflected in the growth of the sheer number of SW developers, totaling ~250,000 in 2030. The largest share of developers is expected to be concentrated in ADAS/AD and infotainment (~30 percent). As the number of SW developers increases, the market will likely see shifts in the distribution of the workforce. Specifically, organizations’ resources should be increasingly allocated to SW domains most impacted by ACES.

AD SW with highest yearly growth rate until 2030 due to increased complexity and integration effort

By 2030, AD SW (excluding ADAS) is expected to represent more than a quarter of the market value and grow at an average yearly rate of over 20 percent until 2030. Its growth exemplifies the key factors mentioned: increasingly complex functionality, increased validation and integration effort for AD functionality as it becomes integrated in more vehicle platforms, and growing labor costs for the highly specialized and scarce development resources.

AD is likely to be the automotive SW domain where most OEMs and tier-1 suppliers place their strategic bets. The value of the market is expected to grow to ~USD 28 billion by 2030. Increased functionality is one important driver. Elements such as sensor fusion or

environmental modeling will become more complex in the following years as AD-enabled vehicles will need to handle real-world situations. Especially for SAE Level 4 to 5, covering corner cases and ensuring the safety of the driver will become prohibitive after a certain point. For this reason, it is important to make critical decisions about what functionality is really needed. The market is expected to become more dynamic; thus specialized companies might seek to cover specific AD components.

Validation and verification as well as integration are also significant multipliers of the market value. We expect AD development costs to almost double due to validation and verification and integration. The reasons for this are the extensive testing and simulation that must be done to ensure safety, as well as the integration with different sensor configurations. This is likely to lead to increased collaboration between market actors to ensure integration is done efficiently, and costs are kept under control.

An important growth factor is the steady increase in labor costs for specialized SW developers and domain experts typically required for AD SW – we expect a CAGR of 4.5 percent given the profile mix. AD talent sourcing is likely to remain an important topic for all the market players and, in the short term, talent will continue to remain highly concentrated. However, as the market adapts and the technology and tools become better understood, we might see an increase in the available talent pool.

2.2 Electronic control units/domain control units: convergence of Electronic control units will open a new market for domain controllers

ECUs and DCUs with a market potential of ~USD 156 billion in 2030

ECUs within a vehicle are responsible for controlling the electrical subsystems. Examples range from simple ECUs that control the engine that electrically moves passenger seats to complex ECUs like those responsible for ensuring optimal engine performance based on the input from various sensors. DCUs are the next level of evolution of ECUs, consolidating the functionality of several individual ECUs into a single, more cost-efficient system. In this context, an ECU or DCU is not only defined as an integrated circuit but as the full “box,” including, i.e., the printed circuit board or input/output (I/O) connectors. The combined ECU/DCU market size is expected to reach ~USD 92 billion in 2020 and grow at a CAGR of 5 percent to ~USD 156 billion in 2030, as shown in Exhibit 6. As explained in Text box 1, to understand this growth, it is important to consider three factors: changes in vehicle production, ECU/DCU ASPs, and the number and distribution of ECUs/DCUs within each vehicle domain. First, vehicle production is growing at ~2 percent p.a., and second, ECU/DCU ASPs are declining at a rate of ~3 percent p.a. due to efficiency gains in ECU/DCU production. This effect is not compensated for by potential ASP increases due to performance or functionality gains. Third, there is a shift towards higher-cost ECUs/DCUs driven chiefly by ACES trends. Due to the introduction of DCUs, the number of control units per vehicle does not increase further (see next section for a discussion of architectural considerations) so that this is not a driver of growth. At the same time, consolidation into DCUs can reduce costs for OEMs due to less common components (e.g., power supply). Note that the calculated market sizes include costs for low-level SW below the OS or middleware stack layers but exclude costs for functional SW as the latter is covered explicitly in the automotive SW market model (see Section 2.1).

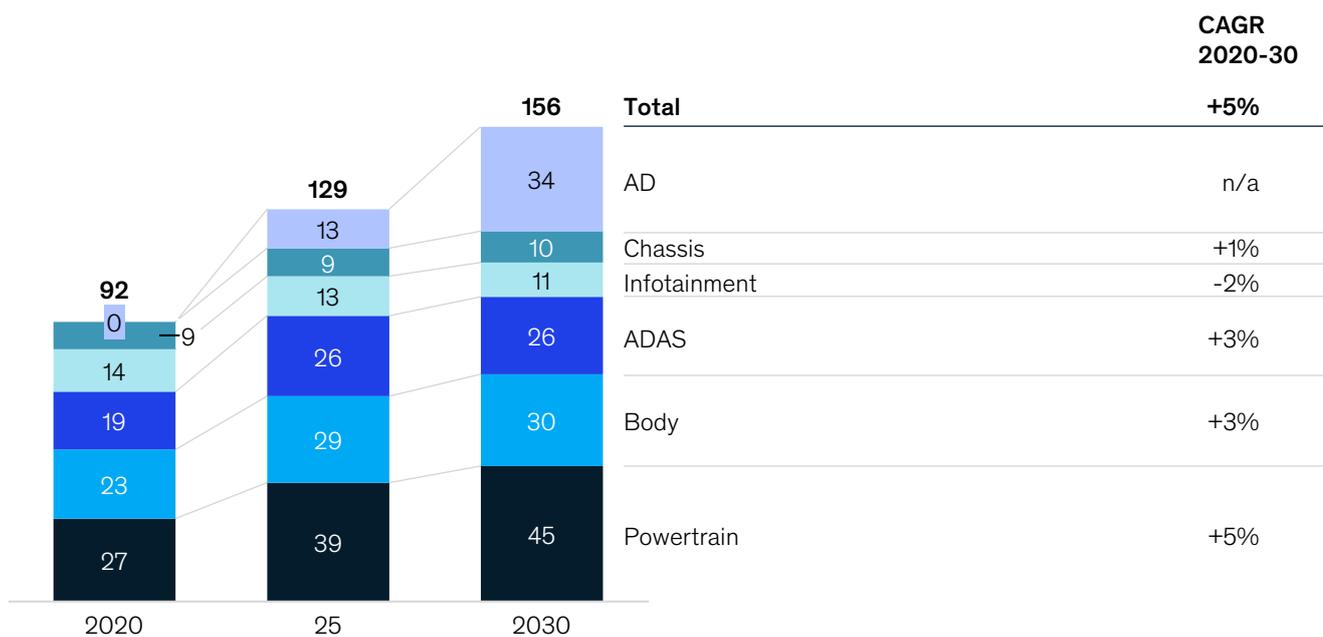
The following paragraphs detail the drivers underlying the varying market size changes per vehicle domain that are shown in Exhibit 6.

Powertrain domain

Within the powertrain domain, the expected market growth at a CAGR of ~5 percent is largely driven by a shift towards EVs (i.e., PHEV, HEV, BEV). This is because the ECUs of EVs have a large ASP, i.e., up to ten times higher than that of ICEs accounting for their complexity. ICE vehicles only make a minor contribution to ECU/DCU market growth in the powertrain domain, as the ASP of ICE ECUs will remain largely stable over time. Overall, the market size of the powertrain domain is the largest, because the take rate of powertrain ECUs/DCUs for

ECU/DCU market by domain

USD billions



SOURCE: McKinsey analysis

engine, transmission, or battery control is virtually 100 percent.

Chassis domain

ECUs/DCUs in the chassis domain are mainly used for controlling braking, suspension, and steering. The expected rather low market growth of ~1 percent is because the growth in the vehicle production at ~2 percent is partially offset by declining ASPs. Most innovation is expected to take place in the context of electronically controlled braking and steering where, consequently, ECU ASPs are highest. The remaining systems such as ABS/ESP are largely commoditized with low, quickly declining ASPs. The shift towards more expensive ECUs will all in all result in a small net market growth.

Body domain

The body domain consists of a multitude of separate systems, such as access control, lighting, HVAC, window lift, seat control, door control, or gateway. Moderate growth of the ECU/DCU market in the body domain at an expected ~3 percent is mainly driven by the shift towards systems with more complex and, hence, more expensive ECUs, such as advanced front lighting or gateway systems.

ADAS domain

The ADAS domain comprises ECUs/DCUs utilized for controlling systems such as airbags, collision warning, tire pressure, or e-call telematics. DCUs become a prerequisite for SAE AV Level 3 vehicles and above, because the complexity of multiple separate ECUs in an SAE AV Level 3 system would be too high. Some OEMs may use ADAS DCUs even for SAE AV Level 1 systems, e.g., in case time-to-market benefits are expected. Market growth at ~3 percent CAGR is largely driven by the growing incorporation of ECUs/DCUs that control ADAS and related functionality. Other ECUs, such as airbag or tire pressure control units, are largely commoditized and hence contribute little to overall growth.

AD domain

AD (SAE AV Level 4 to 5) represents a largely different segment in comparison to the aforementioned “traditional” vehicle domains. Given that the production of those vehicles in 2020 is virtually 0 and likely to reach ~6 million vehicles p.a. by 2030, AD DCUs are expected to grow significantly. Market size will likely grow from essentially 0 in 2020 to ~USD 34 billion by 2030, largely because of the expected uptake of SAE AV Level 4 and Level 5 vehicles.

AD DCU redundancy needs represent an additional factor leading to a large market size in 2030, i.e., the second-largest ECU/DCU market in 2030.

Infotainment domain

In the infotainment domain, ECUs/DCUs are primarily used for controlling primary instrument clusters, navigation systems, or the vehicle audio system. The infotainment ECU/DCU market size is expected to decline at an annual rate of ~2 percent. The reason for this is a strongly decreasing number of ASPs for instrument clusters, car audio, and navigation systems. There is a shift towards solid-state displays as instrument clusters that entails the need for more complex control HW at better performance. However, this shift is not strong enough to compensate the overall decrease in market size.

Convergence of architecture leading to major shift towards DCUs between 2025 and 2030

After 2020, we expect a major shift in vehicle E/E architecture. The architecture will change from one with numerous separate ECUs (~100 ECUs for complex vehicles) towards a more streamlined architecture with a few central DCUs covering one vehicle domain each, such as chassis or infotainment. DCUs consolidate the non-time-critical functionality of multiple ECUs and process data from multiple sources centrally. For example, in a traditional, non-DCU architecture, sensors such as cameras process captured data locally, and control actuators based on processing results. In a DCU-based E/E architecture, the data from multiple sensors such as cameras, radars, and LiDAR is processed centrally, e.g., for sensor fusion. Functionality that likely remains local, i.e., close to the sensor, is mainly related to the preprocessing of data to avoid congestion of the vehicle bus system. Also, latency-critical I/O functionality is expected to remain local.

The architectural shift towards a DCU-based architecture is induced by four key benefits:

- First, the transition to an E/E architecture based on few central DCUs leads to a reduction not only of HW but also of SW complexity. This is because a domain-based architecture allows for a clear functional split within SW modules where higher-level functionality (e.g., sensor fusion) resides in DCUs and lower-level functionality (e.g., data preprocessing) resides within remaining local control units, e.g., in sensors.
- Second, a clear functional split of SW reduces validation cost, as the SW for a single DCU can be validated separately without having to incorporate a complex network of ECUs and their respective SW in the validation process.
- Third, in a domain-based architecture with DCUs, SW upgradability is simplified, which is especially relevant in the context of over-the-air (OTA) updates.
- Fourth and last, consolidation of multiple ECUs into a single DCU delivers reduced HW cost even when the majority of ECUs will remain local at reduced functionality. Savings are expected to come not only from the reduction in ECU-related HW costs, but also from a reduction in secondary costs, e.g., the wiring harness.

The speed of transition from an architecture with separate ECUs to centralized DCUs differs by domain. The infotainment domain is fastest because ECU functionality is virtually neither latency- nor safety-critical, and there is the clear benefit of enabling relatively simple SW updates. Updates are not only a prerequisite for the security (and safety) of connected applications in the infotainment domain, they may also enable an improved user experience and, hence, have a directly monetizable customer benefit. In contrast, we expect a slower transition in the body domain due to a relatively large number of separate ECUs, e.g., for doors, windows, seats, or HVAC. Much functionality has already been consolidated in body control modules. At the same time, there is only a limited benefit of further consolidation, as there is comparatively little need for upgradability in the body domain.

We expect that the speed of transition is also driven by the adoption of higher SAE AV levels. Vehicles with SAE AV Level 3 and above require a HW architecture that supports a clear functional split and easy upgradability for the relatively complex ADAS and AD functionality. Especially the latter is important because it is safety critical to ensure that the most recent ADAS/AD SW version is running on vehicle systems at any time. Therefore, AD functionality is expected to naturally entail a domain-based architecture.

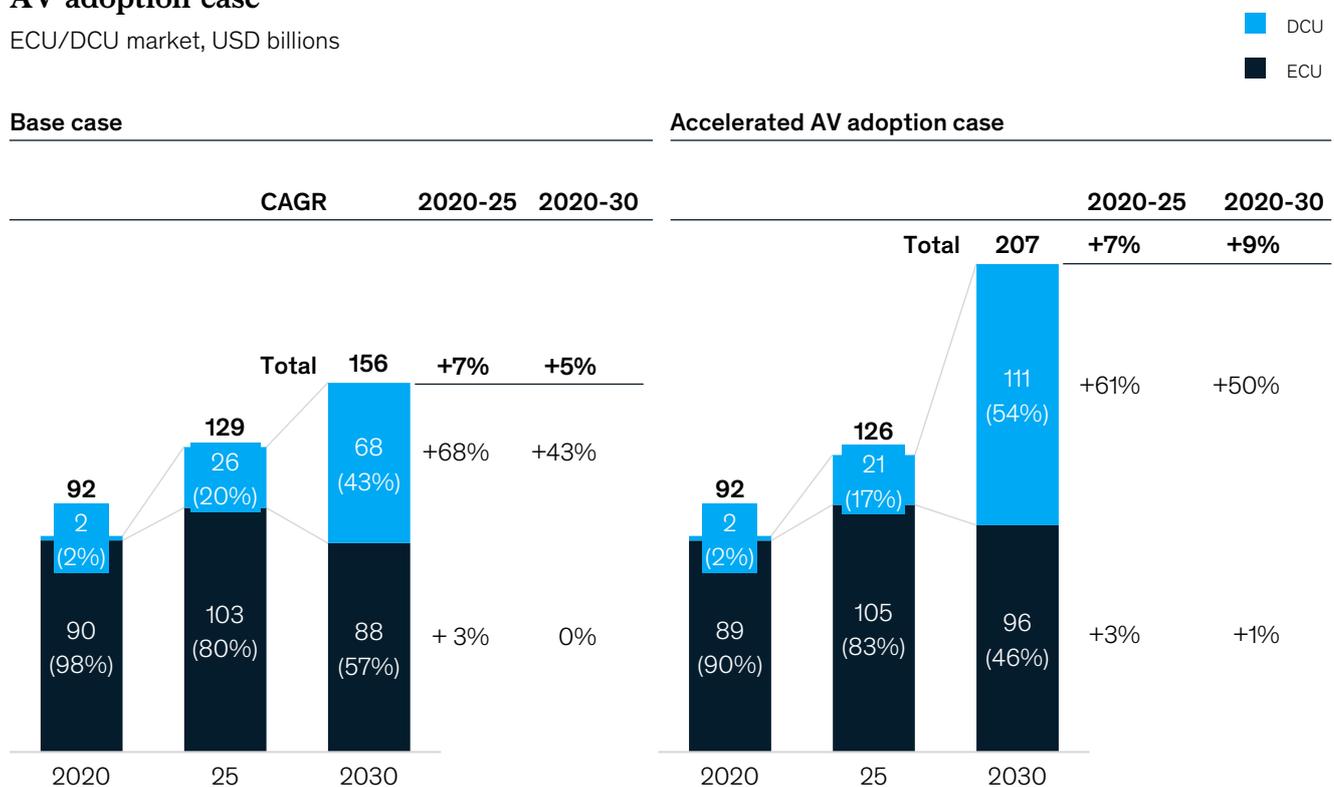
Specifically, between 2020 and 2030, the structure of the automotive market for control units is expected to shift from one that is almost entirely comprised of ECUs (98 percent) into one where DCUs represent ~43 percent of the market as shown in Exhibit 7. In the base-case scenario, the halfway point in this transition is expected to arrive two “car generations” from now in 2025, when DCUs will represent 20 percent of the control-unit market. In the accelerated AV adoption case (see Appendix 1 and the right-hand side of Exhibit 7), we expect a faster rate in the ECU-to-DCU transition than in the base case in the time frame 2025 to 2030. In 2025, the DCU share is likely to be ~17 percent and expected to increase to ~54 percent in 2030.

The differences between the base case and the accelerated AV adoption case are due to different assumptions in vehicle production and adoption rates of higher SAE AV levels, especially in the years 2025 to 2030. In the accelerated case, the number of SAE AV Level 4 to 5 vehicles is expected to be about twice as high as in the base case. Vehicles at higher SAE AV levels are assumed to have a higher DCU penetration due to a higher degree of freedom in architecture and the increased need to centrally process data from various sensors. The overall market size in the accelerated case of ~USD 207 billion in 2030 is higher than that of the base case of ~USD 156 billion in 2030 for two reasons. First, as previously discussed, the share of SAE AV Level 4 to 5 vehicles that need a costly AD DCU is higher. Second, the share of EVs requiring relatively more expensive engine and battery control units is higher in the accelerated case as well.

Exhibit 7

Change of split between DCU and ECU over time in base case and accelerated AV adoption case

ECU/DCU market, USD billions



SOURCE: McKinsey analysis

2.3 Sensors: autonomous driving will be the primary trigger for sensor demand

Most sensors are growing in line with overall automotive market growth. Sensors related to ADAS/AD are the single driver for the above-average expected growth in automotive sensors. An increasing adoption rate of ADAS and AD will be responsible for an overall expected growth rate of 8 percent in automotive sensors (Exhibit 8).

More specifically, this growth will most likely be seen in ADAS/AD systems starting from SAE AV Level 3 due to the near-full autonomy of the system and the higher requirements and costs (and introduced redundancies) regarding the sensors used at this level. The following is a description on a vehicle domain level of how the various sensor categories contribute to the overall growth trajectory.

Powertrain sensors

Powertrain sensors play a role in the operation of the engine, transmission, and alternator. The costs of these sensors vary greatly depending on the engine type (e.g., BEV, HEV, ICE, PHEV) with the number of required sensors decreasing with an increasingly electric engine. With the shift towards electrification, the volume of powertrain-related sensors is expected to decrease. On top of that, powertrain sensor costs in BEV vehicles are also lower. Together, the electrification trend and the commoditization of sensors are likely to lead to a shrinking market with a CAGR of -1 percent between 2020 and 2030.

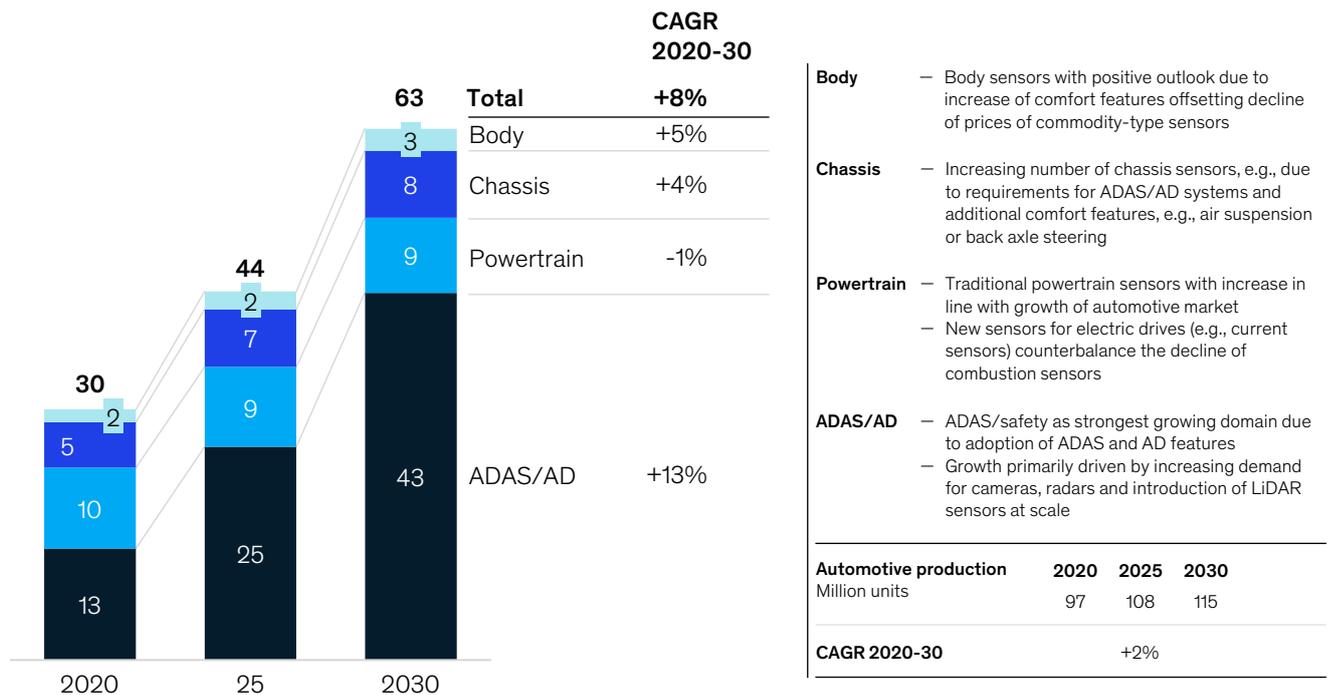
Chassis sensors

Chassis sensors monitor functions, such as braking, steering, and suspension. In general, innovation related to these sensors is quite low, and this leads to price pressure. These sensors are, however, integrated in ADAS/AD use cases, particularly when it comes to the safety redundancies implemented in the braking and steering features of SAE AV Level 3 vehicles. Together, these realities put the growth of chassis sensors slightly above the CAGR of the overall vehicle market at 4 percent.

Exhibit 8

Total automotive sensor market will outgrow automotive sales primarily driven by strong growth in ADAS sensors

Total automotive sensor market, USD billions



SOURCE: McKinsey analysis

Body sensors

Body sensors measure the state of the vehicle in ways less related to active performance than safety/AD sensors. For instance, body sensors capture and convey information regarding door/roof closure, seat occupancy, and the amount of sunlight/rainfall and can trigger alerts and basic functions of the vehicle body accordingly. Growth of this sensor type is expected at 5 percent CAGR, which is mainly due to growth of the vehicle market and additional body functionality and higher safety requirements for body functions in SAE AV Level 4 to 5 vehicles.

ADAS/AD sensors

ADAS/AD sensors include cameras, LiDAR, and radar. The sensors required for SAE AV Level 1 to 2, mainly a combination of camera and radar, are largely safety related. The safety functions required for 5-star NCAP drive the increasing demand for cameras and radars. Compared to lower SAE AV levels, ADAS/AD sensors used in SAE AV Level 3 and up come at a higher cost. As a prerequisite technology, LiDAR's high price point is the main cost driver at these SAE AV levels. The redundancy requirements starting with SAE AV Level 3 also require a higher number of sensors per vehicle. Robotaxis/shuttles are among the SAE AV Level 4 to 5 use cases with these significantly higher sensor requirements and costs. A CAGR of 12 percent is expected for these sensors, due to significant increases in production rates of SAE AV Level 1+ vehicles driven by safety regulations and safety tests (with emergency braking assists, in particular) as well as in SAE AV Level 3+ vehicles. Other sensors in the ADAS/AD domain, including airbag sensors, tire pressure sensors, and ultrasonic sensors, are growing with a 6-percent CAGR.

Sensor setup for autonomous cars

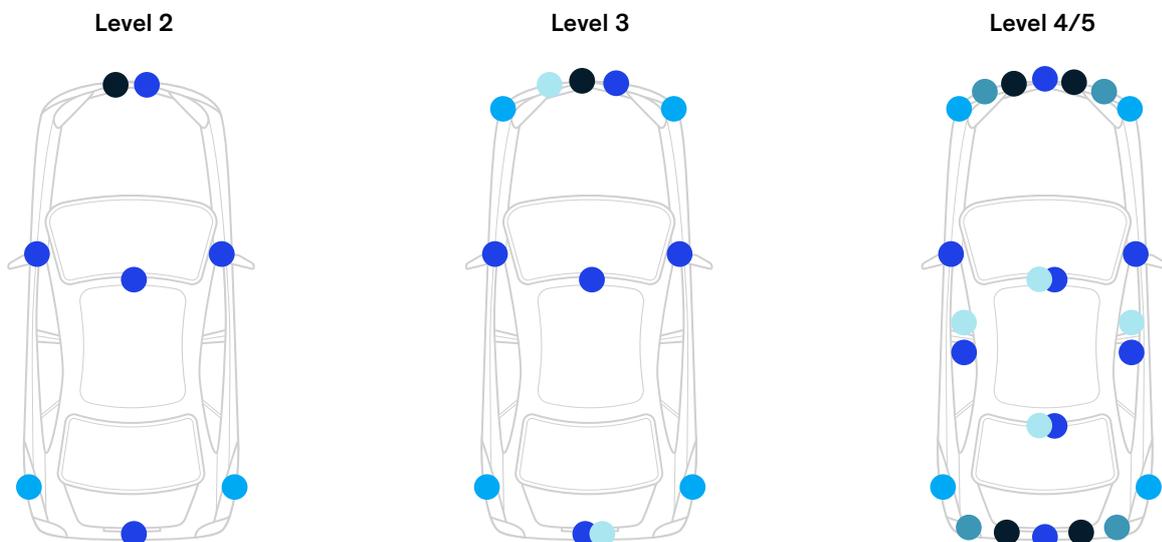
Exhibit 9 shows exemplary sensor configurations for different levels of autonomy. SAE AV Level 1 to 2 vehicles typically have one front-facing long-range radar sensor and one camera for adaptive cruise control, emergency brake assist, and lane departure warning/assistant. Two backward-facing medium-range radar sensors enable blind-spot detection. Up to four additional cameras and up to 12 ultrasonic sensors allow a 360° view for parking assistant functions.

In addition to the sensor set of SAE AV Level 1 to 2 vehicles, we expect SAE AV Level 3 vehicles to typically have one more front-facing long-range LiDAR for redundancy and for situations where other sensors reach their physical limitations, e.g., cameras at night or

Exhibit 9

Sketch of a vehicle and its sensor setup for AD

● Long-range radar ● Short- and medium-range radar ● Camera ● Long-range LiDAR ● Short-range LiDAR



SOURCE: Expert interviews; Waymo Safety Report; Audi press announcements; GM investor presentation

glaring sunlight. The LiDAR sensor is also characterized by a high resolution, wide angle, and high accuracy due to active distance measurement, which will be needed to detect and classify objects or track landmarks for localization. For highway pilot applications, a second, rear-facing long-range LiDAR sensor is typically used.

Additional short-range front-facing radars could improve the detection of vehicles cutting into the lane, while a backward-facing radar detects approaching vehicles on a highway. A driver-monitoring camera might be required to assess attention of the driver, who is required to take over the car if necessary.

SAE AV Level 4 to 5 vehicles usually require a 360° view with different sensor technologies to provide redundancy and to level out disadvantages of each sensor principle, e.g., camera detection to the side of the vehicle at night. To provide this 360° view, five to ten cameras, eight to 12 radar sensors, and five to 12 LiDAR sensors could be used (spinning, long-range LiDAR sensors could be replaced by several solid-state sensors in the medium term). Exhibit 9 shows a typical setup with eight cameras, eight radars, and four long- and four short-range LiDARs. With additional sensors, like microphones and ultrasonic sensors, the number of additional sensors for SAE AV Level 4 to 5 could easily reach 50 sensors or more. Unforeseeable innovations or breakthroughs in the sensor technologies could change the sensor setup for AD in the long term.

On top of these outward-facing sensors, there are additional sensors either required or optional for safety systems, e.g., acceleration sensors for crash detection and airbag release, rollover sensors, seat occupant sensors, night-vision and tire-pressure sensors.

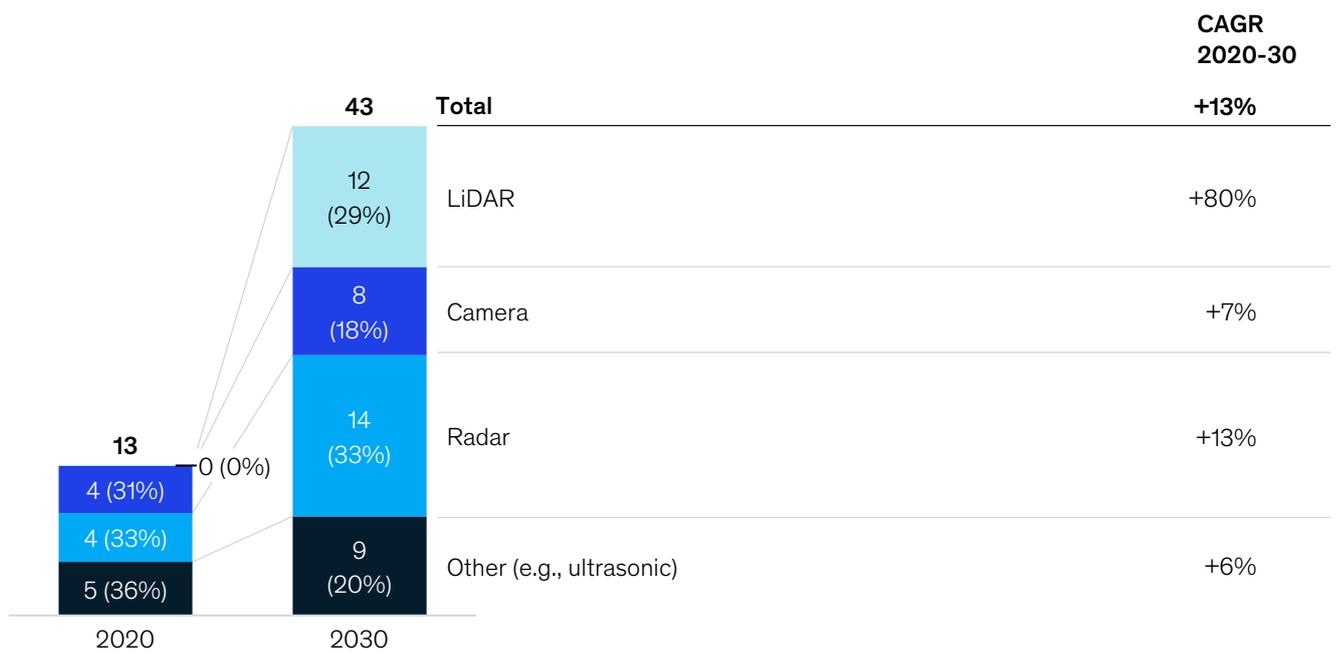
Price erosion and technological advancement to shape the ADAS/AD sensor market

The market for ADAS/AD sensors is expected to grow by 12 percent p.a. Exhibit 10 shows, that this growth will be mainly driven by the LiDAR market, which is hardly existent today but will likely take the ADAS/AD market to USD 13 billion in 2030. The radar sensor market is also growing by 13 percent p.a. and is likely to be the largest sensor market in 2030 with a market size of ~USD 14 billion. Other safety sensors are expected to grow with a CAGR of 6 percent p.a. driven by increased vehicle sales and increased safety requirements, especially since emerging markets are catching up with the stricter regulations in Europe and the US.

Exhibit 10

Split of market by sensor types in ADAS/AD for 2020 vs. 2030

USD billions



SOURCE: McKinsey analysis

The market for other sensors (e.g., ultrasonic) is expected to grow at 6 percent p.a. driven by, for example, the tightening of the Euro NCAP regulation, and likely to reach a market size of ~USD 9 billion in 2030.

LiDAR sensors are positioned for strong growth (an anticipated rate of ~80 percent p.a. through 2030). This technology is currently only in place in a limited number of vehicles, but these sensors will be key elements of the growing number of SAE AV Level 3+ vehicles.

“Mass market” as a force to shape LiDAR technology

Today’s testing vehicles for urban automated driving are usually equipped with mechanical LiDAR sensors with spinning parts. Once LiDAR sensors become available in the mass market in the early 2020s, however, we expect a switch to solid-state sensors. Initial solid-state sensors will come at a relatively high price point compared to cameras or radars, but the price is expected to drop rapidly due to an uptake in numbers, and they should be able to deliver higher robustness. Even after erosion, however, the price of solid-state LiDAR sensors is expected to remain higher than that of other environmental sensors.

As there is a lot of research going on in the sensor field, there might be unforeseeable technology changes. These new technologies could change the assumed number of sensors per car or price points per sensor. This would also lead to a different split between sensor technologies in the market.

Notably, the cost of LiDAR sensors will be added on top of the costs of the high-performance AD DCUs. This is a main reason for why urban AD is likely to be deployed first in robotaxis/-shuttles, where customers are not as price sensitive as private car buyers.

2.4 Power electronics and harnesses: transition to EVs will enable the formation of a new market

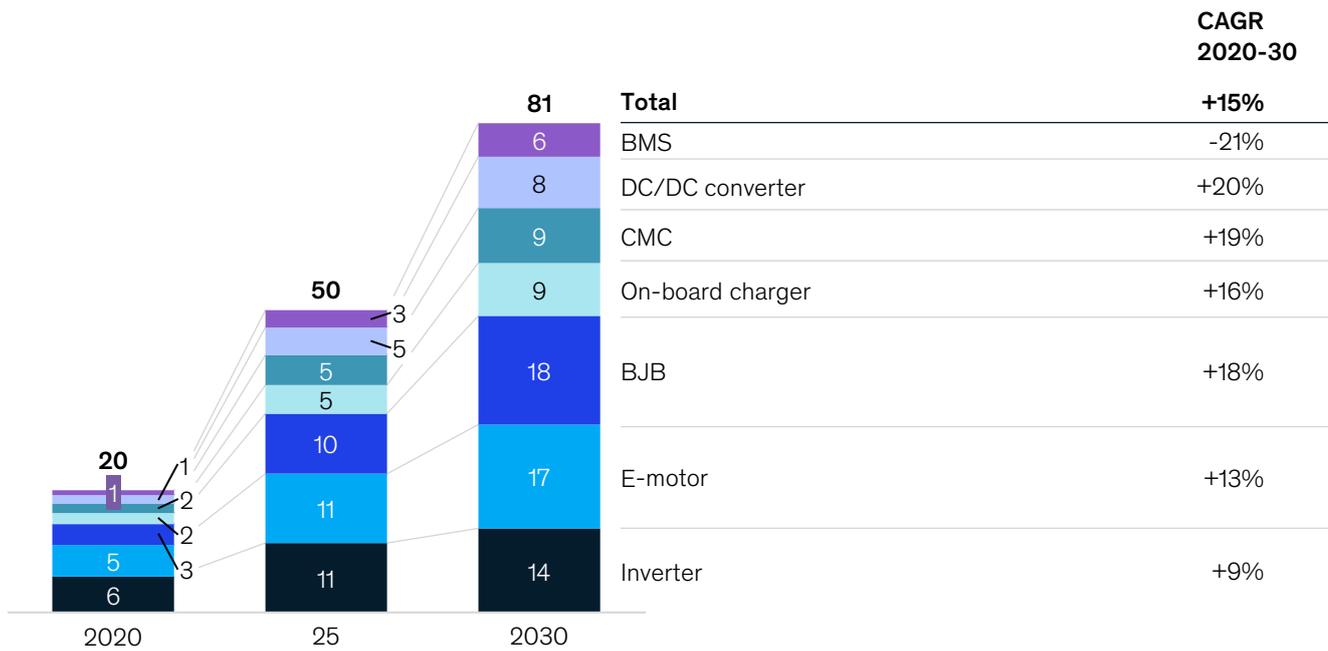
The power electronics market is expected to have the largest relative growth with 15 percent CAGR until 2030, not taking into account the battery cells (Exhibit 11).¹ This growth is primarily driven by adoption of xEVs, which require significant amounts of power electronics, as

¹ A more detailed analysis of the power electronics market will be featured in our upcoming publication “Reboost – a view on the changing powertrain components market and how suppliers can succeed.”

Exhibit 11

Power electronics market – breakdown of components

USD billions



SOURCE: McKinsey Sustainable Initiative Powertrain Model, McKinsey

well as introduction of mild HEVs to complement traditional combustion engines. Inverters are expected to represent the largest product category in 2020 due to their higher ASP than e-motors in the LV market segment, yet a multitude of components with different technologies compose the overall power electronics market. In the long term, battery junction boxes (BJBs) are projected to capture the highest market share.

The biggest driver and also biggest uncertainty for power electronics growth is the adoption rate of xEVs. This in turn depends significantly on the industry’s ability to decrease production costs of batteries to satisfy customer demands for range and expected sales price for vehicles as well as regulatory steering. This would be self-reinforced by an increase in production capacity, technological advancement, and competitive pressure, that will decrease the price per kWh for batteries further, again leading to higher EV adoption. An additional effect is a potential higher adoption of SAE AV Level 4 to 5 vehicles, especially robotaxis. As robotaxis are expected to have a relatively higher share of BEV powertrains than other vehicles, a higher growth will boost also the power electronics market.

Our growth projection includes two core effects: first and obviously, the overall automotive sales growth, including xEV adoption as described above. Second, standardization and commoditization of core product segments such as 40 to 150 kW inverters or 48 V systems, are likely to lower entry barriers for semiconductor tier-2 suppliers to offer more integrated systems and therefore increase competition and put pressure on system ASPs.

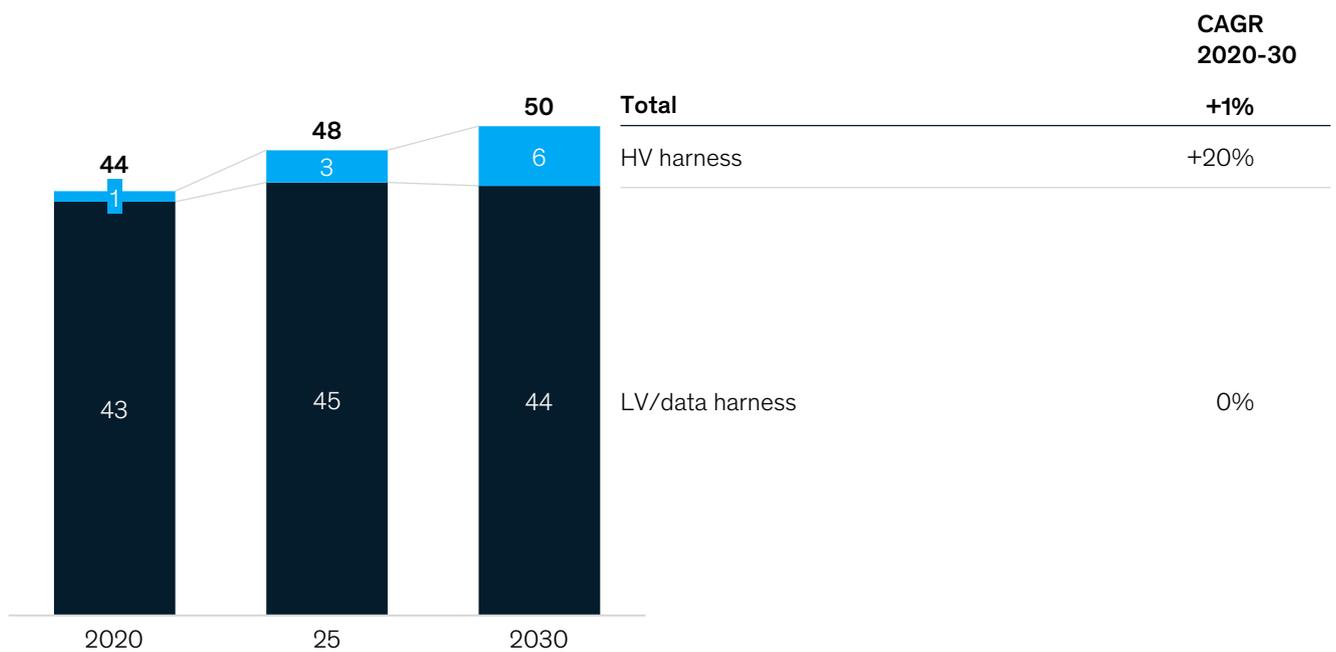
The harness is an additional key component of the vehicle for data and power transmission. The global automotive harness market is expected to grow at a moderate rate (Exhibit 12). The LV harness represents the majority of the market. There are two countering effects impacting the harness market. Combined, these effects are expected to have the net impact of giving the market a growth rate that, at ~1 percent p.a. from 2020 to 2030, is below the overall automotive sales growth.

Major growth driver for harnesses is the introduction of EV platforms. This will open a new, strongly growing market for HV harnesses that connect HV battery, charger, e-motor, and further HV components inside the EV. While current BEV models are mainly built on existing

Exhibit 12

Automotive harness market

USD billions

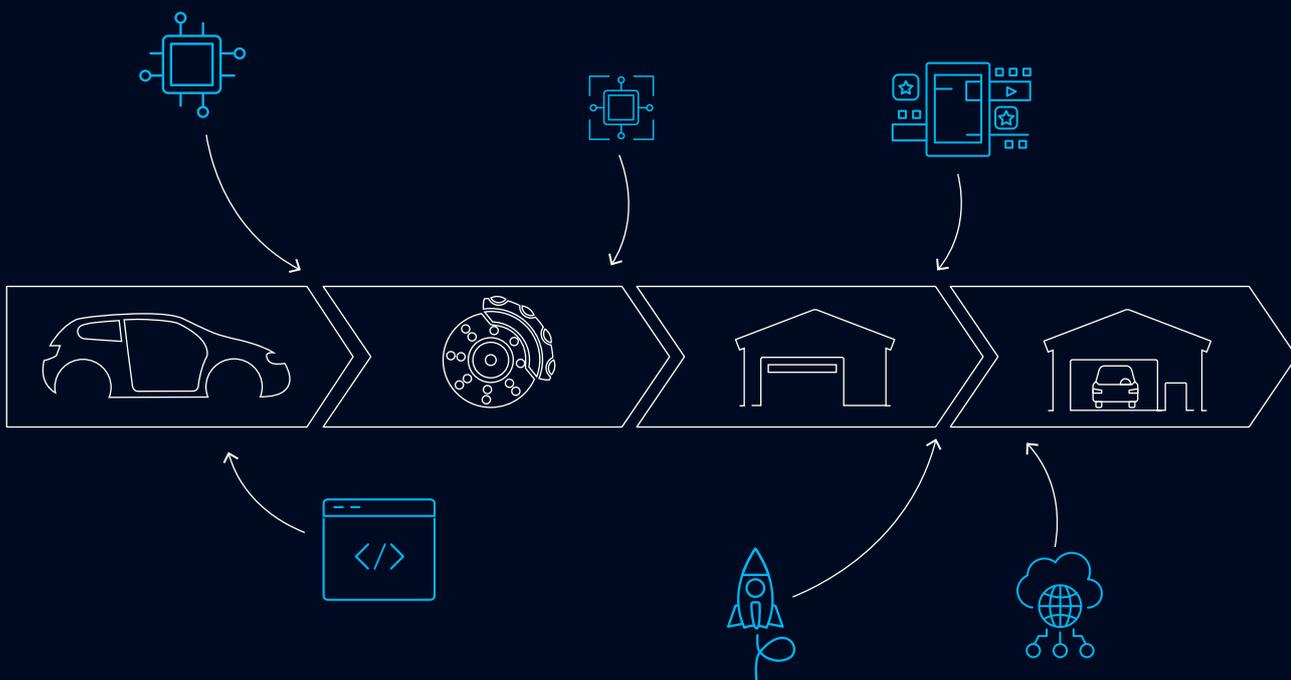


SOURCE: McKinsey analysis

ICE platforms and thus the harness is not fully efficient, native BEV platforms will have more efficient designs. This efficiency gain is exhibited by the difference in cable weight for the powertrain harness between the first and second generation of an EV between 2011 and 2017. The respective weights of 6.2 kg and 2.1 kg correspond to a weight reduction of 66 percent. Despite the ASP reduction of individual harnesses, the overall HV harness market is expected to grow significantly driven by increasing EV penetration.

On the other side, the LV harness segment is expected to shrink due to ASP reduction. Due to standardization, the introduction of ethernet, and the evolution of the E/E architecture, harness variation is expected to be reduced also as more functionality will be defined by SW. While consolidation of ECUs into domain controllers might lead to higher cable volumes, these are likely to have much less variance. While today's harness market in the high-price segment is primarily driven by customer-specific solutions, the standardization will enable (partial) automation of harness production. Therefore, the average value of the harness per car will decrease, leading to the overall shrinking LV market despite growth of the vehicle base.

3. Disruptive trends along the industry's long-established value chains



Beyond their impact on the business models and operational priorities of individual automotive players, the aforementioned trends will profoundly alter the market's core value chains and affect all players along the automotive SW and electronics value chain. In the following, we will discuss the key implications of the changes described above on existing stakeholders' value chains, threats and opportunities, and points of entry for new players from other industries and start-ups.

3.1 New technologies are breaking up the “power dynamic” of traditional relationships between OEMs and tier-1 suppliers

Traditionally, automotive OEMs have specified the high-level functionality requirements of individual components. Then, tier-1 suppliers (and the supply chain behind them) have delivered integrated systems based on those functional specifications. The technologies, know-how, and low-level specifications are unique to the respective tier-1 and tier-2 suppliers. The technology trends described above, however, are changing these roles, especially for electronics and SW components for a variety of reasons:

- First, OEMs and end customers can be expected to demand systems combining “best of breed” features, and no single supplier will be able to deliver a full, best-in-class system covering all technologies end to end in a competitive way.
- Second, capabilities required for new systems, especially for SW, do not exist at sufficient levels in the traditional industry structures. This creates opportunities for new entrants (e.g., SW companies) with the ability to approach the market with different collaboration models than incumbents.
- Finally, the growing complexity and cross-system integration of SW and electronics requires the collaboration of OEMs and their partners as early on in the process as the design phase. It also impedes traditional dual- or multisourcing paradigms, as long as standard interfaces/frameworks have not yet been established in the market (see HW-SW separation below).

These new realities may have specific implications for the relationship between OEMs and tier-1 suppliers. Namely, design specification is likely to be more of a codevelopment process. In this situation, OEMs and tier-1 suppliers will deliberately “lock themselves in” together for the duration of a project to handle complexity and deliver time to market. To maintain some level of independence, such approaches will more frequently be coupled with dual-sourcing to build-to-print or AD services (electronics manufacturing services, EMS) providers that get the right to only manufacture the system that had been developed within the OEM-tier-1-supplier partnership.

However, these models lack the single point of responsibility that was guaranteed by the classic tier-1 supplier business model. Therefore, it remains to be seen how much this will extend into the market and, in particular, which players, both on the OEM and the tier-1 supplier side, will build up the necessary capabilities to sustain this model successfully.

3.2 Separation of hardware and software is leading to new sourcing models

Currently, the majority of SW is combined with HW in a single “package” and sourced from a tier-1 supplier. This model is largely a result of the fact that most functionalities in vehicles currently are single-function devices with a relatively simple interface (such as CAN bus). However, new roles in the market and go-to-market strategies are also being created, including the model where OEMs source pure SW only, HW and integration combined, or even pure system integration engineering services.

Separating HW and SW, if successful, would create two main advantages for OEMs:

- First, it would reduce complexity as HW and SW can be sourced, scaled across classes/tiers, and innovated independently of each other.
- Second, separate sourcing would break the value pool of integrated system providers, lowering entry barriers for new entrants by, for example, allowing SW pure players access to automotive (see above). For the OEM, it would allow a standardized SW platform while keeping competition on the HW to avoid costs through lock-ins. This certainly threatens the value pools of established tier-1 suppliers, but an increase in competition among suppliers could be a benefit to OEMs.

There are other significant implications of a new sourcing model. Since SW is more about R&D costs (“zero marginal costs”) than unit costs, the traditional HW sourcing approach will make way for new realities. First, single-sourcing solutions and strategic partnerships will arise. Next, secondary factors, such as toolchain integration, development excellence (e.g., defect resolution time), and testing automation will become key differentiators, and buyers need to be able to judge those. Finally, the SW life cycle will extend beyond ten years after SOP. This means that finding the right strategic, contractual and operational sourcing approaches to optimize life cycle cost and customer delivery will be crucial.

3.3 New companies are entering the playing field in nontraditional and automotive areas

Based on the findings of our proprietary Start-up and Investment Landscape Analysis (SILA), we can paint a detailed picture of the evolving battleground in automotive. Every third automotive company in operation today was founded within the past two decades. Unsurprisingly, this number is fueled by automotive SW and electronics companies operating around ACES trends, especially providers of infotainment, connected services, and cybersecurity (44 percent of which were founded since 2000), and ADAS/AD system providers (38 percent of which are less than ten years old). In terms of headquarters, 34 percent of the new companies founded over the past ten years are based in the US and 28 percent in China, showcasing the innovative drive through start-ups in the US as well as the growing technology focus in China.

As can be seen from the SILA landscape and cluster analysis (Text box 2 and Exhibit 13), [1] OEMs, [2] tier-1, [3] powertrain/chassis and [4] power electronics suppliers are positioned in the middle of the network graph. These “traditional” companies, with a median founding year between 1964 and 1973, form the backbone of the network and provide the fundamental parts of a vehicle. Those clusters are highly integrated and show a strong interaction with other automotive players.

Text box 2
Start-up and Investment
Landscape Analysis: a big-
data tech-finding tool

McKinsey’s Start-up and Investment Landscape Analysis (SILA) tool reveals areas with the largest investment activity by using big-data algorithms and semantic analytics. It leverages inputs from comprehensive private and venture capital investment databases covering about 2 million companies. Furthermore, it analyzes developments over time and across regions and identifies implicit technological similarities between organizations.

This information helps to identify trends in the automotive landscape and to locate technology capabilities. Of course, it only takes into account the external investment view; it does not cover internal investments, such as R&D expenses.

Towards the edges of the graph, [5] battery, [6] semiconductor, and [7] infotainment, connected services, and cybersecurity suppliers are separated from the main network of core vehicle functions. These players are clustered together in a natural way as they provide unique, add-on technology solutions to tier-1 suppliers and OEMs.

The cluster for [8] ADAS/AD system suppliers, on the other hand, is spread out, indicating a difference in product and service offers. Hardly surprising, ADAS/AD system suppliers show similarities to [9] automotive sensor suppliers. This may be explained by the overlaps in their product portfolios, e.g., sensor suppliers might decide to introduce ADAS/AD systems and vice versa.

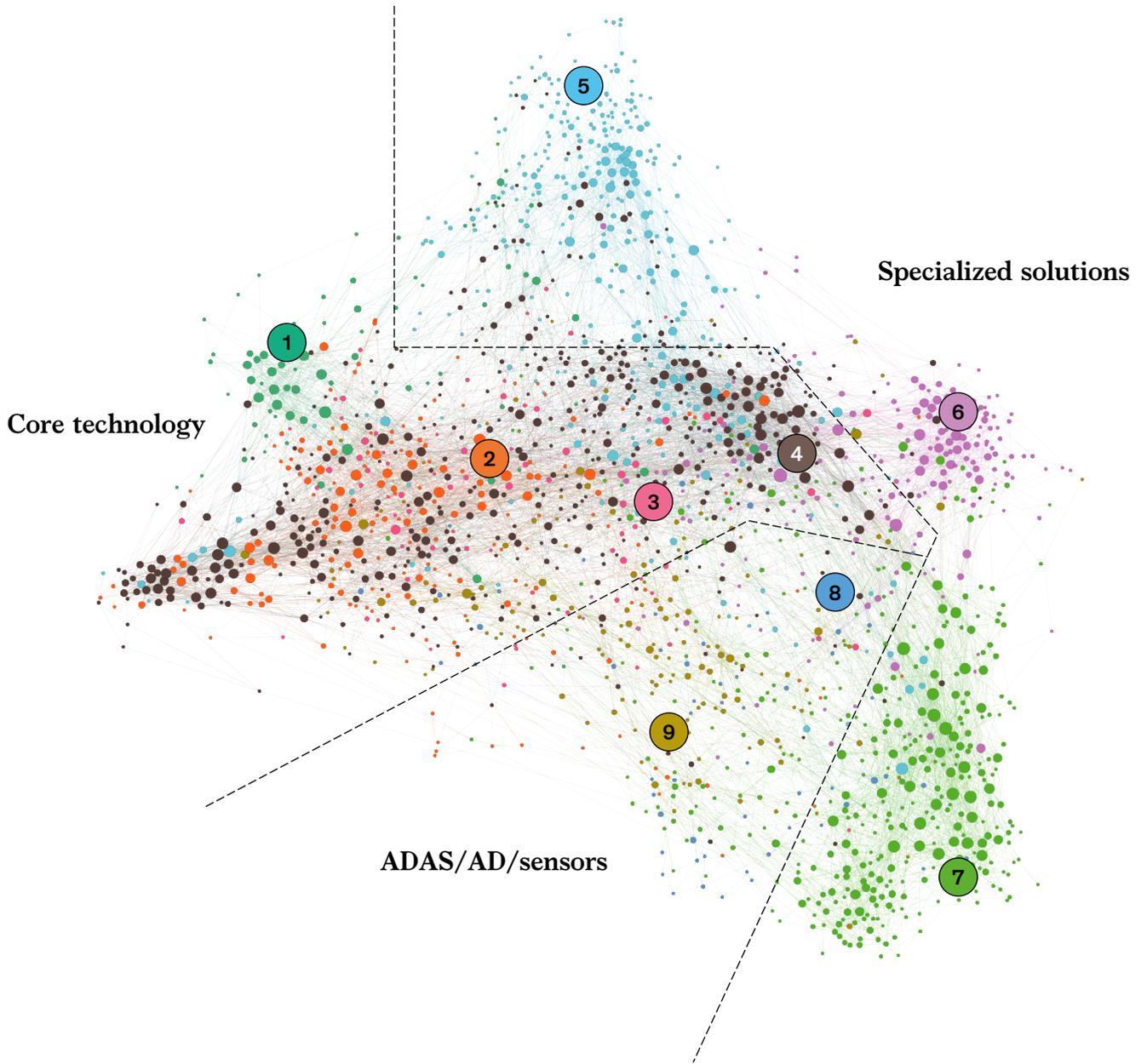
Shifting the focus to past transactions, most funding (in terms of number of transactions received) was provided to companies headquartered in the US, China, and South Korea. This is also true for five out of the nine product categories ([4], [5], [6], [7], [9]). For the clusters [1] OEMs and [2] tier-1 suppliers, companies headquartered in two out of the three countries were among the top three. In Europe, German companies were ranked among the top three in the categories [1] OEMs, [3] powertrain/chassis, and [8] ADAS/AD systems.

Looking at the different market players, it becomes obvious that traditional companies [1-3] received more than 80 percent of their transaction value through public offering. But [4] power electronics suppliers saw an equal number of transactions through M&A, private placements, and public offerings. Reasons for this may be related to the high specialization of power electronics companies and their comparatively smaller sizes and, consequentially, a lower share of publicly-listed power electronics companies.

On the other hand, nontraditional, emerging start-up companies ([5], [7], [8], [9]) that fuel the automotive revolution received at least 70 percent of their transaction value through seed funding/private placements or M&As. The transaction volume spent on M&As for [8] ADAS/AD system providers (43 percent of transaction value in this cluster) and [7] infotainment, connected services, and cybersecurity providers (38 percent) is especially high, showing the race and need for innovative SW solutions.

Automotive SW and E/E network map

● Individual company — Company similarity



Cluster name

- | | | |
|--------------------------------|-------------------------------|---|
| 1 OEMs | 4 Power electronics suppliers | 7 Infotainment, connected services, and cybersecurity suppliers |
| 2 Tier-1 suppliers | 5 Battery suppliers | 8 ADAS/AD system suppliers |
| 3 Powertrain/chassis suppliers | 6 Semiconductor suppliers | 9 Automotive sensor suppliers |

SOURCE: McKinsey analysis

3.4 New partnerships and cooperation models are emerging – primarily for software- and electronics-related topics

As the complexity and costs of new SW-driven functions, e.g., for AD or connected cars, are huge, we see increased cooperation to share costs or speed up development. Even close competitors, such as BMW and Daimler or GM and Honda, are now working together, especially in the field of AD, to share the high development costs. For EVs, Volkswagen announced their openness to share their EV platform with other OEMs. Also, tier-1 suppliers and OEMs are intensifying their cooperation and are building strategic partnerships. For example, engineers from Daimler and Bosch are working together, colocated in two locations to develop HW and SW for AD.

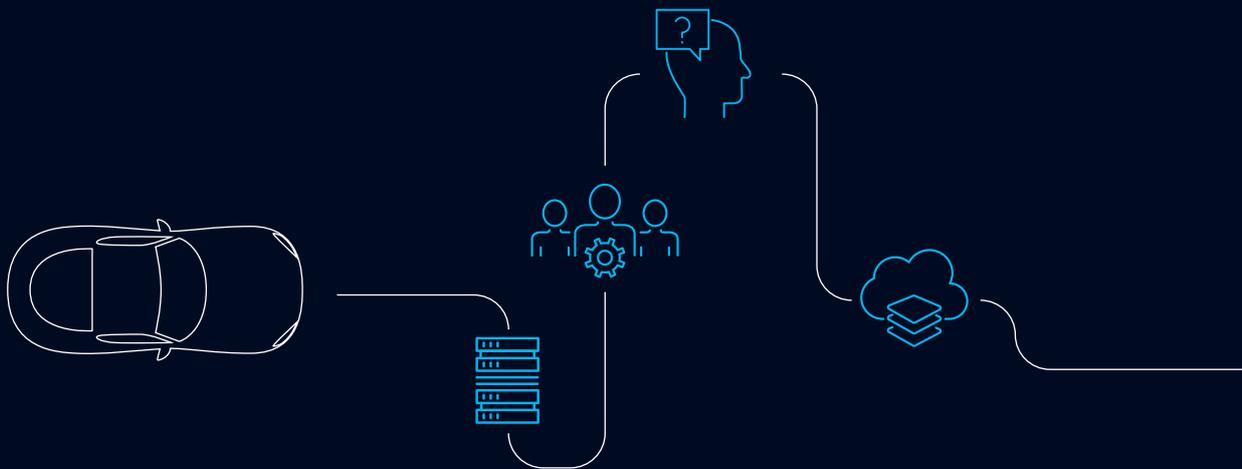
OEMs are also moving closer to strategically important tier-2 suppliers and tech companies and are using directed-buy or “direct buy” (by OEM) mechanisms for the sourcing of key components, and to gain access to IP, shape IP development, or secure critical supply. We see this, for example, for high-performance computing chips and other potential breakthrough technologies like LiDAR. These partnerships sometimes include financial investments by the OEMs. For example, for reasons stated above, Ford invested in the LiDAR company Velodyne. Also, tech companies are becoming a growing focus of OEMs. Volkswagen and Microsoft, for example, are building an automotive cloud platform together, a partnership that also signifies the move by players currently focused on consumer (electronics) into the automotive space. Besides Microsoft, Google has launched Google Automotive Services, including a partnership with and first deployment at Volvo¹, while Samsung has shown interest in entering the automotive space with the acquisition of Harman. Not surprisingly, those companies primarily aim at infotainment and connected services with a direct link to the customer, yet they might move further down into other domains over time.

We also see the formation of ecosystems with several players along the value chain working closely together. One example would be the close collaboration of BMW, FCA, Intel, Magna, Aptiv, Continental, LiDAR supplier Innoviz, and SW specialists TTTech and KPIT to jointly develop an AD platform. Baidu is trying to build an open platform for AD with its OEM, tier-1 supplier, tier-2 supplier, and research institution partners, sharing source code and data.

In summary, the traditional OEM-supplier relationship, especially in the fields of innovation in SW and electronics, is giving way to a variety of relationship models like strategic partnerships, directed-buy initiatives, minority and majority acquisitions, and different forms of alliances and joint ventures. These new forms of cooperation can be primarily observed in technology areas that are highly complex and/or characterized by deeply integrated systems, with value creation by different companies, impeding traditional sourcing mechanisms.

¹ <https://www.polestar.com/us/news/year-of-the-2-user-interface>, 23.01.2019

4. Building blocks for mapping your automotive software and electronics strategy



The emerging threats, but especially opportunities, resulting from the growing SW and E/E markets and their shifting dynamics call for action from most automotive companies and those who want to enter the industry. Due to fast-paced changes, it is imperative to map out and follow a clear strategy to ensure benefits from the disruptions in automotive and not be on the side of the disrupted. In the following section, we will describe emerging strategies by player type and provide an outlook on how companies can successfully navigate the landscape.

4.1 Strategic considerations for each automotive player archetype

The trends described thus far will significantly impact all aspects of the automotive industry. Not only will they influence the strategic positions and outlook of all players, but they will also shape the products and influence the end customers who buy them. In the following, for each of the player archetypes (OEMs, tier-1 suppliers, tier-2/component suppliers, semiconductor companies, tech companies outside automotive, and engineering agencies/3rd-party SW developers), we discuss the implications of the trends and provide an overview of the areas requiring an adaptation to the future landscape. We then offer a way for each player to imagine a shift in orientation that will enable them to act on a concise set of strategy- and operations-focused actions.

Automotive OEMs need to develop a strategic perspective on SW and electronics

For OEMs, we see four main strategic implications of the shift in automotive SW and electronics:

Mitigate rising per-vehicle HW and SW costs

The HW and SW costs per vehicle can be expected to increase significantly by 2030. As they will unlikely be able to completely pass these costs on to end customers, OEMs should find mitigation strategies to reduce the HW and SW development costs. Examples include creating economies of scale through partnerships with other OEMs, using supplier components for nondifferentiating components with higher economies of scale, increasing reusability of SW between platforms and models, or simplifying the E/E architecture.

Build SW development capabilities

In order to develop differentiating parts of the SW in house, OEMs should strengthen their SW capabilities. There are several ways to achieve this, including hiring additional experts, creating or acquiring dedicated business units or subsidiaries for SW development, or investing into development and validation tool chains.

Develop full-stack competencies

OEMs should increase their competencies along the full technology stack – i.e., across the elements of middleware, OS, HW abstraction layer, and cloud computing. This increased capacity will allow OEMs to specify the different technology stack elements in order to enable HW-SW separation and follow a best-of-breed sourcing approach.

Create a cross-functional development organization

By breaking up their domain silos in the development organization and moving decision-making power for SW and E/E architecture to central departments, OEMs can speed up time to market for new E/E architecture definition and sourcing decisions.

Tier-1 suppliers must react to the increased capabilities and changed sourcing behaviors of OEMs

In order to do so, tier-1 suppliers can redefine their SW and E/E strategy through three strategic moves:

Jointly define the E/E architecture

By becoming a thought partner, tier-1 suppliers can work with OEMs to cocreate a vision for the future E/E architecture and jointly shape the requirements. Tier-1 suppliers can seek to establish new partnerships or join existing ecosystems.

Invest in SW development and integration capabilities

Tier-1 suppliers can become significant players in this growth area by building the necessary SW-related capabilities. To do so, however, they will need to win the war for talent (see below). They can also create a dedicated development, integration, and validation tool chain to enable continuous integration and development.

Break down internal domain silos

As with OEMs, tier-1 suppliers also need to create a cross-functional organization to stay competitive in cross-domain offers and respond to their customers' changing engineering needs/sources.

Tier-2/component suppliers should think ahead and shape their space of differentiation

Increasingly centralized systems can favor larger tier-1 suppliers over specialized ECU providers. However, this and other market trends can also be a growth opportunity for tier-2 suppliers if they take action in two areas:

Claim their space

Due to functional differentiation on the SW level, many electronics components will be subject to commoditization, putting margins under pressure, especially for suppliers down the value chain. Tier-2 suppliers need to find an attractive niche and then scale within that niche.

Develop specialized SW capabilities

Specialized component suppliers have an opportunity to grow their business by adding certain SW capabilities (e.g., functional safety, artificial intelligence, or security capabilities) on top of their existing offering to larger tier-1 suppliers. They can even bypass them and supply directly to OEMs, or ensure that the OEM is directing the tier-1 supplier to use their components.

Semiconductor players are required to embrace the growing relevance of matters that were once only tangential

For semiconductor players, we see three crucial prerequisites for success:

Think beyond your direct customer

Understanding the technology shifts at the end customer (i.e., OEM) and deriving the implications for your own strategic position is needed now more than ever. Due to the technology shifts described above, many products will become commoditized or even obsolete (e.g., general-purpose controllers), while others' value will be maintained (e.g., specialized controllers) or even increase (e.g., power electronics). Semiconductor players need to understand this early, and they cannot wait for their direct tier-1 customers to tell them.

Understand the requirements

Before making any investments, semiconductor players need to understand the end customer product requirements. Those might be very specific and, in contrast to the last decades, will have an impact even on the lowest elements of the technology stack. For example, OEM preferences for certain OSs that enable the OEM to scale its application SW have direct implications for HW and SW design on the chip level. Also, the importance of tool chain and services will grow. This growing importance also includes other features that are not directly product related but that are critical to product market success nonetheless. Here again, understanding the end customer's requirements is crucial. For example, the OEM's reluctance to create lock-in (e.g., in certain development tool chains) and the desire to reduce integration effort and cost (e.g., through the use of supplier-developed tool chains) need to be carefully weighed against each other.

Place your bets wisely

While the opportunity in many segments is huge, so are, in many cases, the technology entry barriers or the competition. A realistic, objective assessment of a semiconductor player's own ability to compete is a prerequisite for commercial success. The risk of making huge investments into technologies that will be commoditized or turn out to have a different natural owner is significant.

That being said, the opportunity is huge, and those who approach it right have significant value to capture. Given the current early state of technology and market maturation, the future winners will have made the right choices today.

This similarly applies to engineering or (SW) development service providers and other tech companies from outside the automotive space. The technology borders between the automotive and the consumer electronics world will continue to be torn down. This will open up huge opportunities but also risks, for those who make efforts to enter the new markets.

4.2 First steps for all players in navigating the changing landscape

Without doubt, there is no one-size-fits-all approach to tackling the challenges that the disruptive trends described in this report present to various players in the automotive industry. Yet, independent of their individual starting position or location along the automotive value chain, we see a set of clear actions that all companies need to assess to successfully navigate the changing landscape of automotive SW and electronics:

Beef up your SW and E/E architecture capabilities and become part of early, shaping discussions

While the overall trends in SW and E/E architecture are clearly materializing, there is a lot of ambiguity and uncertainty. Players that involve themselves in early concept and design phases will be in a better position to shape the concrete technological solution, structure the integration of components, and, ultimately, set themselves up to own a competitive share of the market.

Be ready to experiment as there is no silver bullet yet

For most technological challenges and business models, solutions are not yet set in stone, for example, for AD. Players that want to be successful in the emerging technologies, especially SW and electronics for AD and next-generation infotainment/services, will need to embrace a test-and-learn culture and be ready to experiment and quickly iterate learnings.

Critically review existing control points and expand the view on establishing ecosystems

Control points that are relevant today might become commodities tomorrow. Players that want to successfully navigate the market need to continuously and critically review their control points along the technology stack. Furthermore, the dynamics of establishing ecosystems can quickly disrupt complete domains and reshuffle control points, requiring players to closely monitor and observe changing ecosystem landscapes.

Establish partnerships in an emerging ecosystem

The rising complexity of SW and electronics systems in the car required for AD and other functionalities of the future will make it impossible for a single player to develop and maintain the system end to end. In addition, high R&D costs, especially for SW, require a large base of vehicles to distribute the costs; otherwise, costs per car would be prohibitive, even for the largest OEMs. This leads to the necessity of players to work together more intensely than in the past with deeper integration than traditional supplier-purchaser relationships.

Appendix

Key aspects of the market models

The insights of this report were generated based on closely linked qualitative and quantitative research. Our qualitative insights come from external and internal sources. In terms of external sources, we conducted a series of interviews with executives in the automotive industry that not only helped us challenge and refine our perspectives on the three key questions mentioned above but also provided us with hands-on insights that fueled our quantitative analyses. In terms of internal sources, we combined the knowledge of key experts within our automotive practice to build a holistic view on how ACES trends and various more specific drivers will influence the automotive SW and E/E market.

For our quantitative market insights, we built bottom-up market models for each of the core components within the automotive SW and E/E market:

- SW development, integration, verification, and validation
- ECUs/DCUs
- Sensors
- Power electronics
- Other components (harnesses, controls, switches, displays).

For the first three of these market models we distinguish several automotive domains to ensure that we have the proper granularity within each model:

- Powertrain
- Chassis
- Body
- ADAS
- AD
- Infotainment.

At the highest level, each model, except that for automotive SW (see paragraph below for details), follows the same logic. The market size in a given year is calculated as the product of the number of components (e.g., the number of ECUs) per vehicle, their ASPs, and the number of vehicles produced in a given year. The calculation also takes into account differences, e.g., in take rate, price, between vehicle segments, OEM types, SAE AV levels (see “Definitions” on page 42 for details), and powertrain types. Specifically, for ECUs/DCUs, we have excluded the value of the SW content (OS, middleware, functions) from the model to avoid double counting.

The market value is comprised of the supplier value generation and components sold to the OEM. For DCUs, for example, this includes not only the integrated circuits but, among others, also the printed circuit board, memory, I/O connectors, thermal control, housing and the value add of development, integration, and component testing of the component at the tier-1 supplier. Next to the aforementioned sources of insight, we integrated findings from market research companies such as Strategy Analytics and IHS Markit as an additional validation.

The number of vehicles produced each year is provided by a separate model in which we incorporate data from the latest McKinsey Center for Future Mobility (MCFM) market outlook, the McKinsey EV market model, and the MCFM mobility of the future scenario analysis. We distinguish a “base case” with moderate growth in EVs and AVs by 2030 as well as an “accelerated AV adoption case” with a much steeper growth in both vehicle types, but lower

overall vehicle production due to cannibalization of private vehicles production through autonomous shared vehicles. Note that numbers presented in this article refer to the base case except where explicitly stated otherwise. In the vehicle production model, we differentiate production volumes by different categories, i.e., geography, OEM type (volume vs. premium), vehicle class, powertrain type, and SAE AV level. This differentiation is also present within the market models for each element of the automotive SW and E/E market. Hence, depending on the combination of the categories, such as SAE AV level and vehicle class, we assumed different values for the number of components and their ASP where appropriate.

Given the significant uncertainty around the emerging SW market and the core elements, such as price points, monetization, sourcing models, and value chain/value capture, the automotive SW market model follows a different logic than those of HW components. The model considers the workforce required to build, maintain, and upgrade individual SW functionalities over time as the key driver of market size, taking into account typical supplier margins for SW as well. The model factors in the number of vehicle platforms and variants across OEMs and tiers, as well as their temporal evolution, are used to obtain a realistic perspective on the market size. To ensure consistency with the other models for E/E components, the applicability of the various SW functions across powertrains and SAE AV levels is also considered. Distribution of the market between OEMs, tier-1 suppliers, and other companies (e.g., IT service providers, engineering service providers) is not taken into account. Due to the nature of this approach, the market already occurs during the development phase and not only after SOP as for the other models.

To pressure-test the results of our modeling, we conducted workshops with Global Semiconductor Alliance members in North America, Europe, and Asia. Based on workshop feedback we iterated the models towards the version presented in this report.

List of abbreviations

ACES	Autonomous driving, connected vehicles, electrification of the powertrain, shared mobility
AD	Autonomous driving
ADAS	Advanced driver assistance systems
ASP	Average selling price
AV	Autonomous vehicle
BEV	Battery electric vehicle
BJB	Battery junction box
BMS	Battery management system
CAGR	Compound annual growth rate
CMC	Cell management controller
DC/DC	Direct current to direct current
DCU	Domain control unit
E/E	Electrical and electronic
ECU	Electronic control unit
EMS	Electronics manufacturing services
EV	Electric vehicle
HEV	Hybrid electric vehicle
HV	High voltage
HW	Hardware
ICE	Internal combustion engine
I/O	Input/output
LiDAR	Light detection and ranging
LV	Low voltage
MCFM	McKinsey Center for Future Mobility
OEM	Original equipment manufacturer
OS	Operating system
PHEV	Plug-in hybrid electric vehicle
SOP	Start of production
SW	Software

Definitions

SAE AV levels¹

SAE INTERNATIONAL **SAE J3016™ LEVELS OF DRIVING AUTOMATION**

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	You are driving whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering.			You are not driving when these automated driving features are engaged – even if you are seated in "the driver's seat".		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety.			When the feature requests, you must drive.	These automated driving features will not require you to take over driving.	
What do these features do?	These are driver support features			These are automated driving features		
	These features are limited to providing warnings and momentary assistance.	These features provide steering OR brake/acceleration support to the driver.	These features provide steering AND brake/acceleration support to the driver.	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met.	This feature can drive the vehicle under all conditions.	
Example Features	<ul style="list-style-type: none"> • automatic emergency braking • blind spot warning • lane departure warning 	<ul style="list-style-type: none"> • lane centering OR • adaptive cruise control 	<ul style="list-style-type: none"> • lane centering AND • adaptive cruise control at the same time 	<ul style="list-style-type: none"> • traffic jam chauffeur 	<ul style="list-style-type: none"> • local driverless taxi • pedals/steering wheel may or may not be installed 	<ul style="list-style-type: none"> • same as level 4, but feature can drive everywhere in all conditions

For a more complete description, please download a free copy of SAE J3016: https://www.sae.org/standards/content/J3016_201806/

Vehicle classes

Although there is no Europe-wide formal characterization or regulation of vehicle segments, an EU document² mentions the following classes:

- A: mini cars
- B: small cars
- C: medium cars
- D: large cars
- E: executive cars
- F: luxury cars
- J: sport utility cars (including off-road vehicles)
- M: multi-purpose cars (including pickups)
- S: sports cars

¹ Source: SAE International J3016

² Regulation (EEC) No 4064/89 – Merger Procedure

Important notice

This report has been prepared by a McKinsey team based on public sources, extensive research, and proprietary information gathered both via in-depth interviews with industry thought leaders and from IHS Markit's Light Vehicle Production Forecast (2018).

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