

FOREWORD

For more than 120 years, the car was a mechanical means of getting from A to B, an isolated system whose standout feature was the engine. That's not the case anymore.

Today, as with other products, most automotive innovations are electronic or software based. Cars have become "connected": customers expect to be "always online"; traffic updates are automatically beamed into their cars; and electric vehicles communicate with charging infrastructure. At the same time, features such as "parking by app" or "adaptive cruise control" are becoming increasingly common. In fact, the car is turning into a system within a system of systems. Soon, nearly all cars will be connected and part of the Internet of Things, requiring secure connections for updates and upgrades over the life of the car.

But there is a downside to this progress. The complexity of electronics and distributed software features has reached an unprecedented level that is proving difficult to handle. New hardware and software technologies have emerged to help untangle this complexity, but they are not without their own challenges.

For example, the automotive industry is leveraging advances in computing power to consolidate electronic control units (ECUs) into centralized computing platforms connected by the automotive ethernet. This greatly reduces complexity on the network level because of lower relative hardware costs, but greatly increases software complexity within these processors.

In addition, end-to-end software platforms promise to reduce software complexity by allowing the "plug-and-play" of new functions and lowering hardware requirements. However, not even basic software is completely independent of the chipset. Processor performance and possible parallelization of tasks must be considered when designing software platforms and applications, as well as in the electrical/electronic (E/E) architecture. The E/E architecture and the geometric architecture of the vehicle affect each other and cannot be designed independently.

These factors suggest a paradigm shift is required to fully address the complexity. Ultimately, future vehicle E/E architectures, software platforms and applications need to be designed around next generation processors – just as vehicles have always been designed with powertrain performance in mind. In short, electronics hardware and application software will become the major battlefield for differentiation and control of value creation.

This study is the first in a series on "computers on wheels" by Roland Berger's Advanced Technology Center. Each aims to address a different aspect of the transformational challenge facing the automotive industry, with the intention to create line-of-sight for our clients and other interested parties.

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4	Management summary
6	1 Introduction A "computer on wheels"
7	2 MADE to measure The key disruptive trends in automotive and their consequences for electronics and semiconductors
11	3 Power change Three big developments shaking up the electronics and semiconductor supply chain
17	4 Recommendations Four steps to tackle disruption in the electronics and semiconductor supply chain

Computer on wheels / *Disruption in automotive electronics and semiconductors*

The car of tomorrow – a computer on wheels – will deliver Mobility as a service, drive Autonomously, operate in a fully connected and Digitalized environment, and be powered by an Electric drivetrain – MADE. These macro trends are resulting in a significant increase in the role of automotive electronics and the emergence of the software-driven car, dominated by electronics.

The consequences will be dramatic with structural changes all along the automotive value chain:

- OEMs are taking more control over the value chain and critical functionality. They are expanding their capabilities by adding significant resources for module integration, software development and even semiconductor design.
- Semiconductor players, who frequently control the largest share of the electronics bill of materials (BoM) in software-driven cars, are moving towards functional integration of their chips (system-on-a-chip (SoC), system-in-a-package (SiP), etc). Additionally, they are expanding from hardware into application-level automotive software, as shown by the deal between Intel and Mobileye.
- Players in electronics contract manufacturing services (EMS, ODM) are expanding into engineering and integrated circuits (ICs), offering unparalleled scale advantages compared to other players.
- Software suppliers that were previously only minor players in the automotive market are now entering it all along the value chain, be it in middleware or at application level.

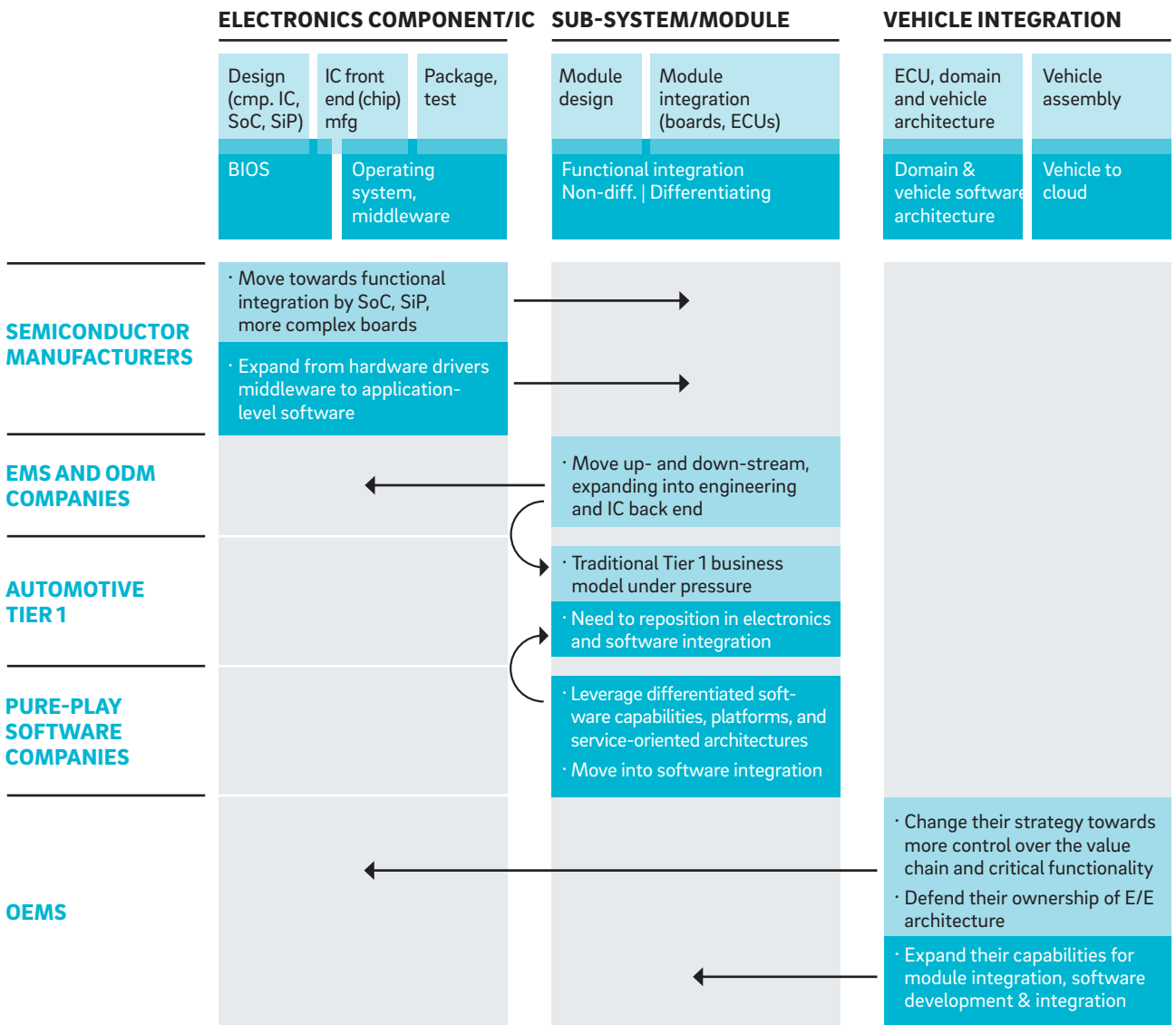
- Traditional Tier 1 E/E suppliers are under pressure from all sides. Their established business models are breaking apart and they risk becoming irrelevant. Furthermore, Tier 1s are at risk of getting stuck with traditional full front-line liability as an ECU and software stack integrator while losing control over multiple software components. → [A](#)

The result is that players along the automotive value chain are repositioning themselves, and profit pools are shifting. Semiconductor companies emerge as possible winners, able to leverage their SoC and SiP platforms to achieve strong growth in automotive applications.

Meanwhile, traditional roles in the supply chain are changing as new players move in and OEMs and Tier 1s expand or adapt their focus area to remain competitive. They are finding they have to understand the business drivers of semiconductor and pure-play software companies to identify suitable win-win positions and mitigate threats. Shorter product and innovation lifecycles are further pressuring them to adapt their organizational governance and engage in active lifecycle and innovation roadmap management.

A: Value chain reaction

The increased role of electronics and software will mean structural changes throughout the automotive industry, with Tier 1s particularly affected



Hardware Software

1 / Introduction

A "COMPUTER ON WHEELS"

The shift towards the car of tomorrow – a computer on wheels – is already happening, driven by several major changes in the automotive sector. First, electronic architecture is changing. It is becoming more centralized in terms of configuration of computing power with a stronger segmentation of hardware and software, giving rise to automotive software as a product. This means the role of all players along the value chain needs to be redefined.

Second, automotive semiconductors now combine more and more fundamental functionalities. This is hugely increasing complexity and development costs for embedded software, encouraging semiconductor companies to move downstream and capture value with higher levels of integration.

Next, power electronics are becoming the differentiator in new electric drivetrains. The technology and manufacturing base, especially for wide-bandgap semiconductors technology (e.g. SiC, GaN), are still maturing, while OEMs and suppliers need to acquire critical capabilities.

Fourth, the electronics bill of materials (BoM), the list of raw materials, components and parts needed to build a product, is expected to more than double for a premium semi-autonomous connected car with an electric drivetrain¹ when compared to a non-autonomous car with an internal combustion engine. Therefore, sourcing of electronics is becoming a critical capability when managing the automotive supply chain.

Lastly, large cross-OEM, cross-player consortia are forming to mitigate the increasing complexity, development cost, risk and BoM of future cars, especially for autonomous driving.

The result of these changes is a fundamental shake-up of the value chain. To address the challenges facing OEMs and Tier 1 suppliers, this study assesses recent

trends in automotive electronics and semiconductors, and makes several recommendations. It is part of a series by Roland Berger's Advanced Technology Center examining the car as a "computer on wheels". Future subjects will include software and IP management.

"The shift towards the car of tomorrow – a computer on wheels – is already happening, driven by several major changes in the automotive sector."

Falk Meissner

Partner

¹ Excludes battery and drive motor

2 / MADE to measure

THE KEY DISRUPTIVE TRENDS IN AUTOMOTIVE AND THEIR CONSEQUENCES FOR ELECTRONICS AND SEMICONDUCTORS

The car of tomorrow will deliver Mobility as a service, drive Autonomously, operate in a fully connected and Digitalized environment, and be powered by an Electric drivetrain. The so-called MADE trends will be the driving force behind the development of new automotive technologies.

Despite the proliferation of fleet-based, mobility-as-a-service vehicles that are autonomous, connected and most likely electrified, most cars produced in the foreseeable future will continue to be individually owned. Therefore, many of the advances driven by the MADE trends will occur incrementally via this mass market, and not via Uber or Waymo robotaxis.

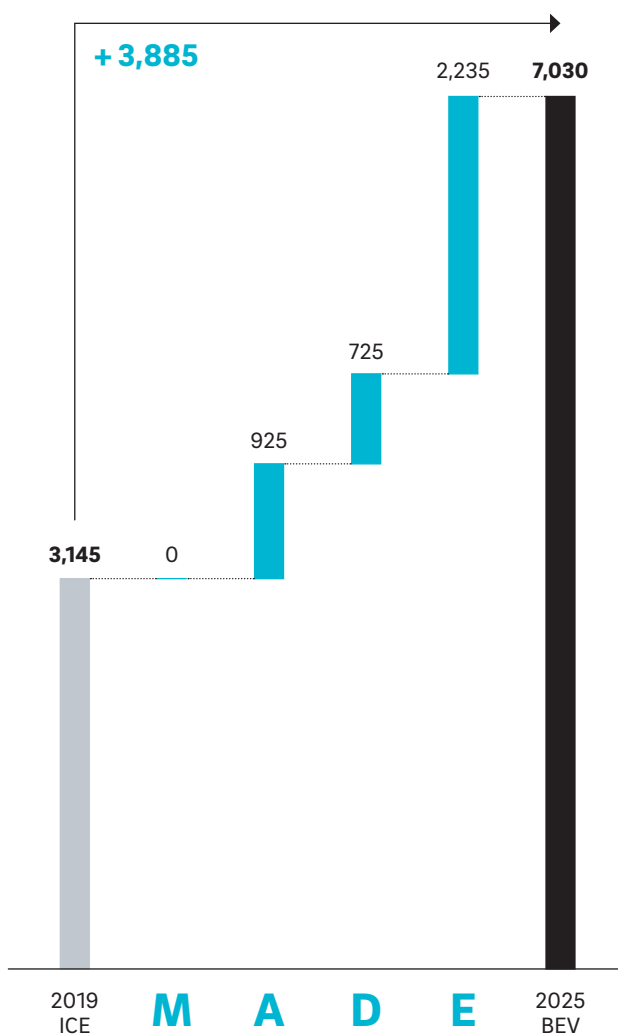
This spells disruption for OEMs and Tier 1 suppliers, who will need to prepare for the coming changes. In this chapter we take a closer look at what to expect from each of the MADE trends, and how they will affect the electronics BoM of future cars. For example, our research shows that the BoM cost of electronics (i.e. packaged electronics modules) for a mid-sized, premium battery electric vehicle (BEV) is expected to more than double to USD 7030² in 2025. This is compared to a similar standard internal combustion engine (ICE) car today, where the electronics BoM is USD 3,145. → **B**

MOBILITY – LET'S GO!

Fundamentally, Mobility is a paradigmatic shift from privately owned and individually operated vehicles to new business models and use cases. It is not a new vision – electric taxi cabs were introduced in New York in 1897. What is new is the potential for mass adoption, automation of vehicle operation, remote fleet management, and improved range and reliability of electric drivetrains. Electric vehicles are now shared and made available through fleets, for example, and cars are more tightly integrated with public transportation and

B: MADE to measure electronics

Breakdown by MADE factor of the electronics BoM of an ICE vehicle in 2019 and a BEV in 2025 [USD]



Source: Roland Berger Automotive Electronics Component Model

² Excludes battery and electric drive motor

the different means to complete the last mile of travel. Nevertheless, there is very little dedicated "mobility electronics" in cars; rather, mobility is enabled by technologies that are developed independently of it.

Electric vehicles (EVs) are undoubtedly the future of mobility, and three key factors are driving electric-vehicle-based mobility: a) simplification of recharging and maintenance; b) municipalities pushing for reduction of urban pollution; and c) regulatory requirements for average fleet fuel consumption. The latter push OEMs to sell electric vehicles into high-utilization applications, such as robotaxis, which can absorb the higher cost.

In addition, a significant part of the innovation required for mobility will be driven by policy makers, financial institutions and mobility platforms providing amenable business and regulatory environments. Customer interfaces, financing, payment infrastructure, insurance, fleet operation, and maintenance will be equally important.

AUTONOMOUS DRIVING – RISE OF THE ROBOTS

The automotive industry is moving from an era of manual driving to one of advanced driver assistance systems (ADAS) and autonomous driving (AD). This requires shifting from human decision making to artificial intelligence (AI), from memory to maps, and from senses to sensors. The transition relies on a seamless integration of different electronic components, from digitizing signals from analog sensors to power electronics for actuators and drive motors.

The biggest technological developments in autonomous driving, and therefore its biggest contribution to growth of the electronics BoM, will be in two areas – sensors and computing power. About half of the AD-driven increase in the electronics BoM (USD 925 in total) is attributable to sensors, such as cameras, LIDAR, radar and ultrasonic sensors. The actual figure will depend on the system architecture, pre-processing requirements, and the level

of required redundancy for the level of autonomy to be achieved. Tesla famously relies on cameras and does not use LIDAR (probably for cost reasons), but it remains to be seen if the industry follows or if LIDAR becomes more mainstream once the unit cost decreases with volume. → [C](#)

Autonomous cars rely on an AI-driven central computing unit that receives and analyzes all raw or pre-processed sensor data and determines the actions the car must take. These central computers contain multiple advanced chips (SoC ICs) and make up the other half of the AD-driven BoM increase. But while huge progress has been made on chip architectures with the advance of massive parallel processors as shown in chapter 2, challenges remain, especially to reduce power consumption.

DIGITALIZATION – ALWAYS ON

The car of the future is always on and always connected. Already, two thirds of new cars sold in the US have connectivity features. Connectivity puts the car (and the OEM that controls its architecture and data flow) right in the middle of the automotive IoT ecosystem, with features such as vehicle tracking, fleet management, maintenance scheduling, over-the-air software updates and remote access. It also powers autonomous driving, enabling data collection, algorithm testing, deployment, and interaction with driving infrastructure and other vehicles (V2X).

The automotive industry is moving towards functional integration to enable new features. In turn, this drives a growing need to reduce complexity and costs, and a fundamental change of the automotive E/E architecture. About a quarter of the rise in electronics BoM in future cars will be attributable to digitalization (USD 725).

ELECTRIFICATION – THE NEW DRIVETRAIN

As noted in Mobility, the automotive future is one of electric vehicles in one form or another, with several factors driving this forward. Regulations tend to push

towards electrification. In addition to national and state-wide emission standards, an increasing number of municipalities are banning vehicles with internal combustion engines. And it appears customers are increasingly demanding EVs due to their specifications, lower operating cost and environmental concerns. On the technical side, higher battery capacities and energy densities are allowing longer driving ranges, while lower cell costs are reducing the price of EVs. OEMs are jumping on the trend by launching large ranges with electric/hybrid derivatives of existing models, dedicated EV models and, in several cases (Daimler, Volvo, GM, Volkswagen), even announcing they will stop combustion engine development. The impact of high-voltage power electronics on the electronics BoM is significant. More

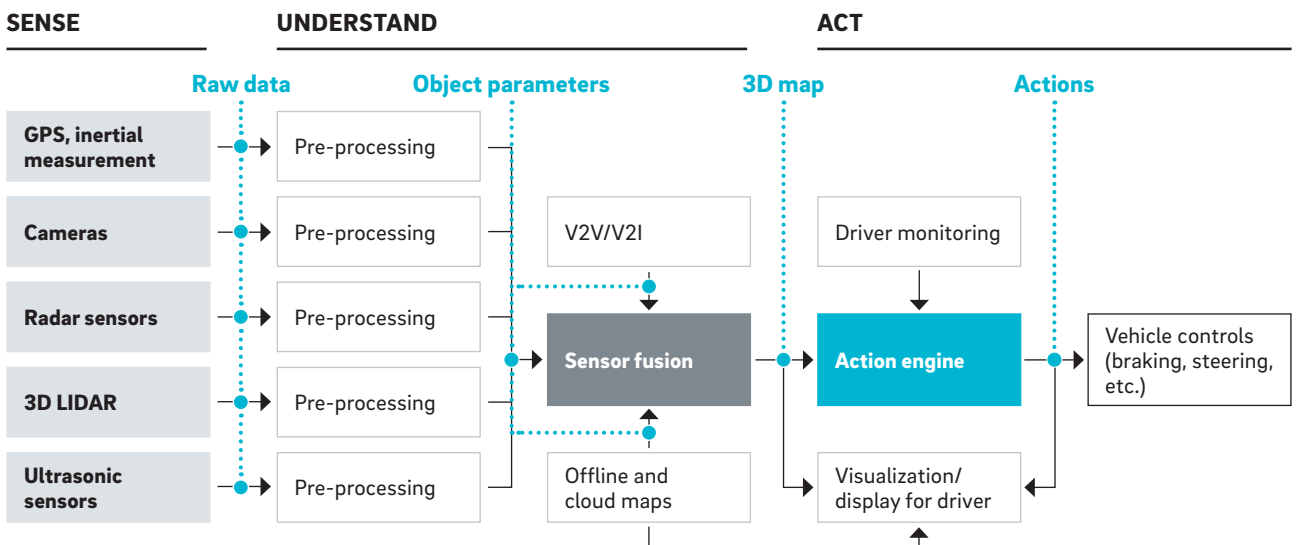
than half of the cost increase between the ICE and BEV car is driven by powertrain electrification (battery management, on-board chargers, converters and powertrain inverters), a total of USD 2,235.

MADE'S OVERALL EFFECT

Our research indicates that the share of electronics on the overall vehicle BoM will increase from about 16% for the ICE car to 35% for the BEV, which includes 12% of powertrain electronics. We estimate that the share of semiconductor components within the electronics BoM will rise from ~25% to ~35%. This will be driven by the increased complexity and higher integration of semiconductors, as well as an increase in more expensive power electronics. → [D](#)

C: Driving up costs

Autonomous cars rely on a system of sensors and data processing to replace human drivers and make them safe



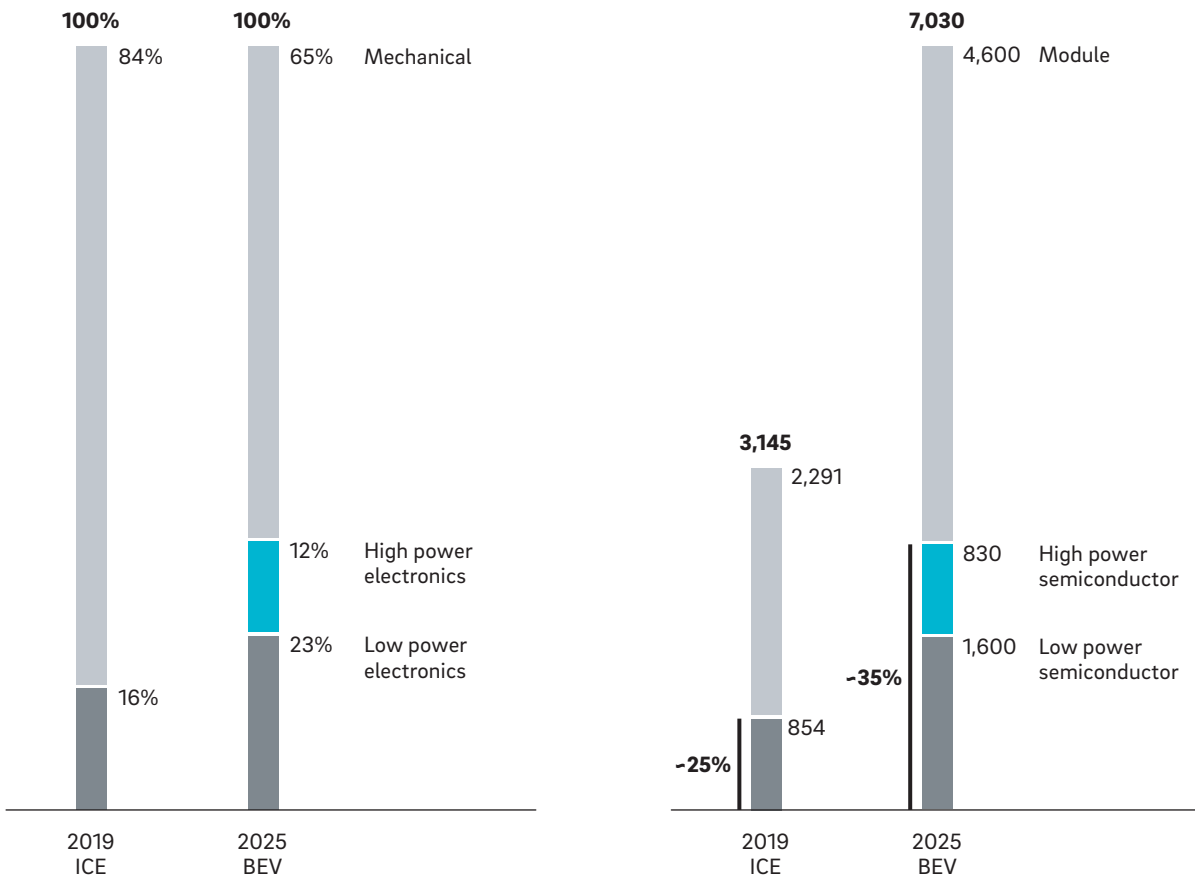
Source: Texas instruments, Roland Berger

D: Electrifying costs

Electronics as a share of total BoM in a 2019 ICE vehicle and 2025 BEV; and cost of semiconductors as a share of electronics BoM in the same two vehicles

SHARE OF ELECTRONICS BOM IN COMPARISON TO TOTAL VEHICLE BOM FOR A PREMIUM VEHICLE [%]

SHARE OF SEMICONDUCTOR CONTENT IN TYPICAL ELECTRONICS BOM [USD]



Source: Roland Berger Automotive Electronics Component Model

3 / Power change

THREE BIG DEVELOPMENTS SHAKING UP THE ELECTRONICS AND SEMICONDUCTOR SUPPLY CHAIN

It's clear from chapter 2 that the MADE trends will have a significant impact on the electronics BoM of future vehicles, especially when it comes to electrification. The technical developments behind these trends are too numerous to cover in this report. But to provide a snapshot, in this chapter we look at three key developments that will have a significant impact on the electronics BoM – new E/E architectures, autonomous driving chips and new powertrain materials – and describe their implications.

NEW E/E ARCHITECTURES

Automotive E/E architectures are set to be simplified and consolidated. Rather than comprising up to 120 separate electronic control units (ECUs), they will become less distributed and more centralized. At first, in the next few years, architectures will be arranged into so-called domains, consisting of several different computing groups fused together. In the longer term, they will be further centralized into zonal clusters of high-performance computers. Eventually, specific functions will be made cloud based for constant connectivity – the true computer on wheels. → [E](#)

Different OEMs are taking different approaches to domain fusion. In Germany, for example, it appears that premium OEMs are focusing centralization on five domains: power train & chassis; advanced driver assistance systems (ADAS) & safety; infotainment; comfort; and connectivity, in addition to the central gateway (the central computing platform or central application server). Development priorities include enabling new features, ensuring scalability and improving efficiency to reduce costs.

Over in the US, Tesla has taken a different route. It has split its E/E architecture into four safety-oriented domains: autopilot; central information display (CID); instrument cluster; and drivetrain and energy storage. The CID and instrument cluster are combined and communicate directly

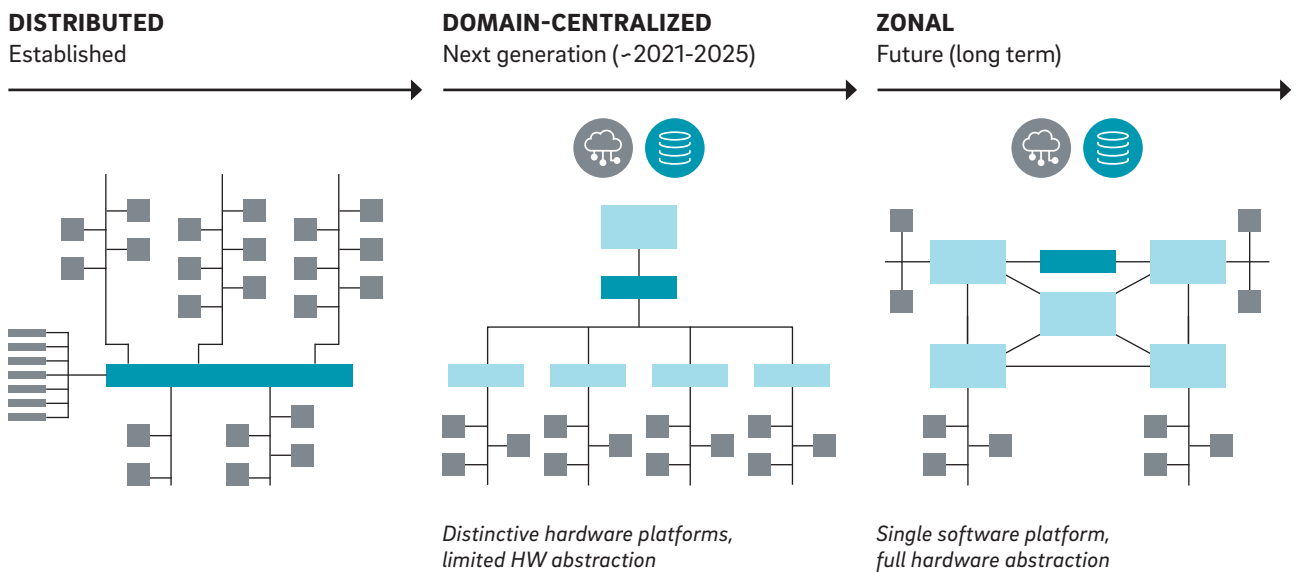
with each other. The CID module includes connections for 5G and other data sources. A central gateway provides a communication channel that allows the OEM to securely exchange data remotely. This is also used as an interface to the powertrain and energy storage.

Domain fusion and the later step-by-step evolution towards a more centralized vehicle computer have several implications for OEMs:

- Domain fusion will be subject to further functional integration to minimize cross-domain communication. A split into safety-critical and non-safety-critical functions at the ECU or core level could also emerge.
- Domain controller units (DCUs) will evolve into centralized computing units. This will increase the complexity and cost of the underlying semiconductor content.
- Fully and near-fully autonomous driving will require centralized holistic decision making to navigate real-time traffic situations. This is already visible in the available autonomous driving concepts.
- The new architectures shift complexity from hardware to software. Applications and functional software will be increasingly separated from electronics, computing hardware and operating systems via standardized interfaces and software such as AUTOSAR.
- Hardware will also become more standardized (and commoditized), with the result that automotive software will become a product (see our "Computer on wheels/ Software enabled vehicles require software enabled OEMs and suppliers" study to come). Security of in-vehicle, vehicle-to-vehicle and cloud communication is therefore a key issue that needs to be addressed by OEMs.
- New software and electronics engineering capabilities will be required by all players in the ecosystem, in addition to new (agile) management processes and organizational structures that mirror the high speed of development cycles in software engineering.

E: Centralized solution

The increasing integration of E/E architectures will cut costs and enable new features



TECHNOLOGY

- 80-100 ECUs
- Multiple CAN, LIN, Ethernet, Flexray, MOST communication links

- 4-5 high-performance DCUs
- Multiple sensor/actuator ECUs
- 1 CAN bus per zone
- 1 Ethernet backbone

- Cluster of high-performance computers
- Multiple sensors/actuator ECUs
- 1 CAN bus per zone
- 1 Ethernet backbone

CHARACTERISTICS

- Distributed control
- Many nodes
- Inter-communication via central gateway

- Dedicated domains
- Consolidation of functions in DCUs
- Routing between DCUs handled by advanced gateway

- Virtualized functions executed in high-performance computers
- Zone-dependent sensors/actuator ECUs (domain-independent, scalable)
- Routing complexity handled by advanced gateway

■ Gateway ■ DCU ■ ECU

Source: Elektrobit; Roland Berger

AUTONOMOUS DRIVING PROCESSORS

The development of centralized computing architectures for autonomous driving has led to big leaps in the functionality of automotive semiconductors. Automotive control ICs, which were once mono-functional microcontroller units (MCUs), are now powerful, integrated autonomous driving processors containing multiple processing units (central, graphical, tensor processing units: CPUs, GPUs, TPUs) and dedicated neural processing units (NPU) with AI accelerators. → [E](#)

This rapid evolution has several implications for automotive players:

- Semiconductor producers such as Nvidia, Intel, Apple, ARM and startups like Intuition Robotics, Hailo Tech and China's HiSilicon are becoming innovation drivers as they develop new AI-based architectures.

- From reference designs to applications, software is becoming an integral part of semiconductor offerings. OEMs will therefore increasingly collaborate with semiconductor players, which are traditionally Tier 2 suppliers.
- Advanced manufacturing nodes for AD processors (SoCs) are escalating development costs. This means Tier 2 semiconductor players must recoup their development costs across many OEMs. As a result, only a few will survive as suppliers for AD chips. → [G](#)
- Large development ecosystems are emerging to manage the complexity and share the cost and risk of AD chip development. These collaborations typically have one or more OEM and a semiconductor player at their center with Tier 1 and software suppliers adding additional capabilities.
- Managing the semiconductor supply chain will be

[E](#): Hard to process

Automotive control chips have evolved from simple microcontroller units to advanced AI engines

16 BIT AUTOMOTIVE MCU

Legacy product – 1990s (e.g. ST Micro ST10)

- Single core
- 180nm manufacturing node¹
- 144 pin package²
- <10 USD³ typical
- Monolithic – single task applications

32 BIT AUTOMOTIVE MCU

Next Generation MCU – 2000s (e.g. Infineon Aurix)

- Up to six Tricore CPUs
- 65 and 90nm
- 80-516 pins²
- 10s of USD³
- Wide application range: e.g. domain control, chassis, safety, engine, ADAS

64 BIT AI ENGINE

AI engine – 2019 (e.g. Tesla FSD chip)

- 12 CPUS + 2GPU + 2NPU
- 14nm
- 2,116 pins
- 100s to 1000s of USD⁴
- L4/L5 autonomous driving

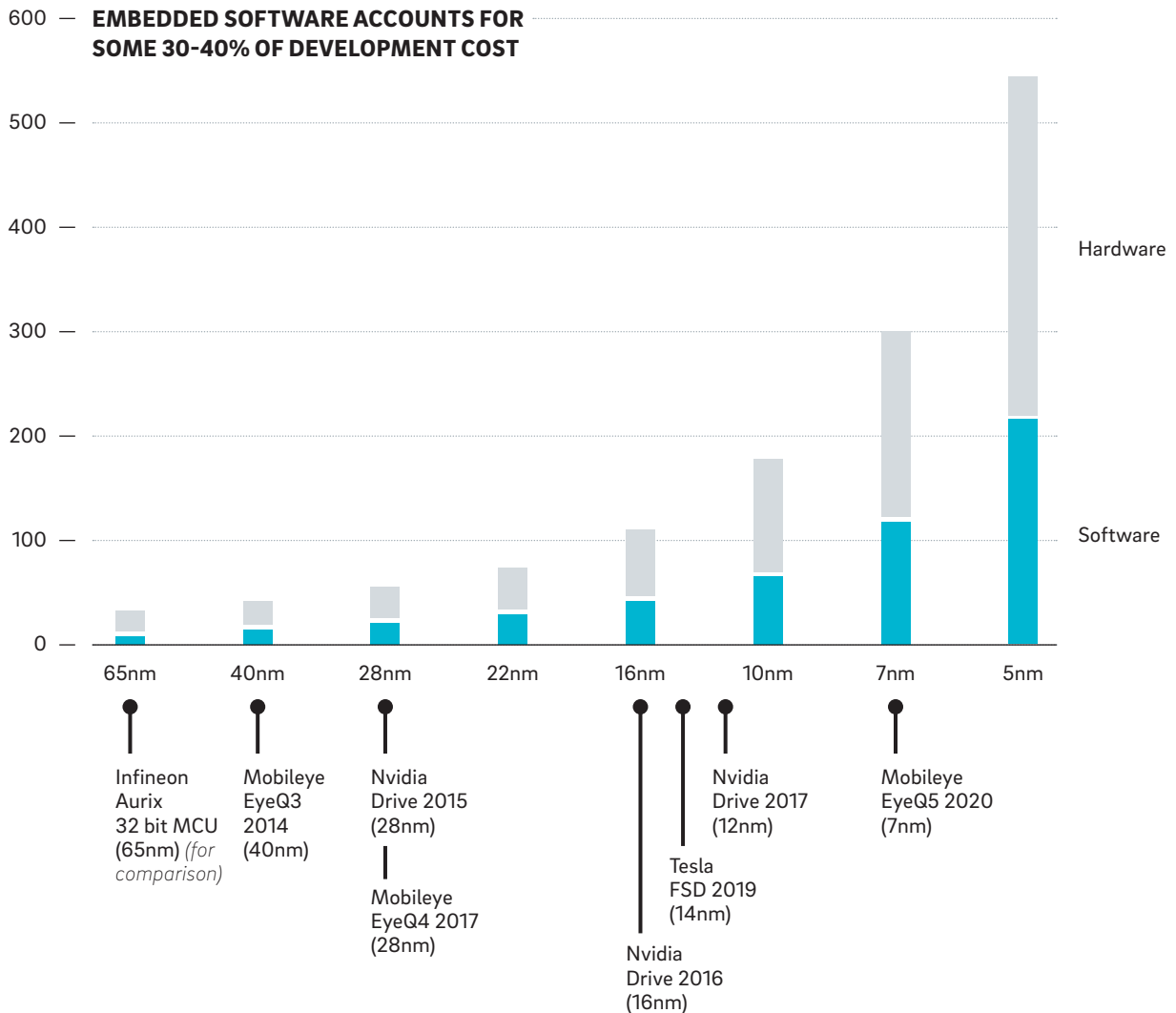
INCREASING RANGE OF APPLICATIONS, COMPLEXITY OF ARCHITECTURE, MANUFACTURING AND COST

¹ Feature size of manufacturing node in nm (nanometers) within the semiconductor structure ² Depending on version ³ Depending on version and volume ⁴ Estimate

Source: Company information, data sheets, desk research, Roland Berger

G: The chips are up

The smaller the manufacturing node (measured in nanometers), the higher the total development cost of the processor (SoC) [USD m]



Source: Darpa CRAFT, IB5, Gartner, company websites

critical for OEMs and Tier 1 suppliers. Semiconductor components cannot be purchased like conventional automotive components, they need to be designed into the system. OEMs and Tier 1s therefore need to rethink their long-term position in the electronics value chain.

NEW POWERTRAIN MATERIALS

Powertrain electronics, which cover the operation of the battery and electric motor in EVs, are developing rapidly, with several competing technologies available and no industry standard. For example, to enable more powerful electric drivetrains and faster charging at reduced currents, the industry is moving towards higher voltages. The 800V module in a Porsche Taycan, for instance, can be charged to 80% in less than 30 minutes, much faster than the 200V Toyota Prius device.

To enable these higher voltage and power requirements, silicon carbide (SiC) and gallium nitride (GaN) technologies have emerged as potential replacements for those based on silicon alone (Si IGBT: Silicon Insulated Gate Bipolar Transistor). Compared to silicon, SiC offers higher power densities, higher efficiency and smaller component size, albeit at significantly higher cost. → [H](#)

However, managing the high power densities, currents and thermal loads in these electric powertrains requires not just rapid development in semiconductors. Module assembly technology, such as copper bonding, sintering and liquid cooling of components, must also be enhanced, in addition to precise current measurement and control.

Automotive applications will be the growth driver for the high-power silicon and SiC markets in the future, where they will compete with renewable energy applications. It is expected that automotive applications will represent about 50% of the SiC semiconductor market in 2024, which is forecast to grow at ~30% CAGR to about USD 2 billion at that point. However, this rapid

growth means there is a risk that high-power Si and SiC semiconductor capacity becomes a bottleneck for the wider adoption of electric vehicles.



To prevent this, leading SiC players are making significant investments in the technology. Most notably, the US firm Cree/Wolfspeed recently announced a USD 1 billion investment in production capacity expansion. But these investments come with their own risks. Market growth is highly dependent on the adoption rate of SiC technology in the automotive industry. Technology breakthroughs in Si-based technologies may mean that it continues to compete with SiC. The industry may settle on Si-based technology for mainstream applications due to the cost advantage and the availability of existing Si production capacity. GaN technology is the wild card in the game, but still has to overcome key physical challenges.

This uncertainty means OEMs, Tier 1s and semiconductor suppliers face a series of pain points in the adoption of high-voltage power electronics, and SiC technology in particular:

- SiC semiconductor costs are 10 times higher than Si-based technology.
- There is insufficient manufacturing capacity. If SiC emerges as the favored technology, existing SiC capacity cannot meet the growing demand for EVs. The release of Tesla's Model 3 alone led to shortages. As an additional complication, the manufacturing assets for Si and SiC are not interchangeable. Therefore Tier 2 semiconductor players are reluctant to commit significant investment without volume commitments from OEMs.
- The electronics industry itself has limited capabilities in the handling and manufacturing of the materials, and Tier 1s lack skills in the design of the power systems.
- The power electronics industry is a virtual oligopoly with Infineon, Mitsubishi and Fuji dominating Si-based technology, and Cree/Wolfspeed and Robin

H: Raw power

Comparison of the three main types of semiconductors, identified by their key raw material, used in advanced powertrain electronics

	SILICON (SI) IGBT¹	SILICON CARBIDE (SiC)	GALLIUM NITRIDE (GAN)
	<ul style="list-style-type: none"> • Cost-competitive current standard • Capacity can be repurposed from other semiconductor segments 	<ul style="list-style-type: none"> • Higher switching speeds & power density for overall higher efficiency/reduced losses • Better thermal stability and conductivity • Enables fast charging & longer range • Reduces package size, weight and cost 	<ul style="list-style-type: none"> • Comparable switching speeds to SiC, potentially more cost effective than SiC • Lower package size and higher electron mobility compared to Si • Compatible with existing Si manufacturing base
	<ul style="list-style-type: none"> • Least heat resistant; most power loss • Limited switching frequency 	<ul style="list-style-type: none"> • Significantly higher cost • Greater handling & manufacturing difficulty; limited expert pool • Insufficient SiC manufacturing capacity 	<ul style="list-style-type: none"> • Not yet technically mature • Use in defense applications prevents partnerships between int'l suppliers • High cost with no industrialized manufacturing base
LONG-TERM OUTLOOK	Likely to prevail in lower-power hybrids – Potential use for low-end, low-cost EV	Likely to become mass-market solution once capacity is built up and volumes drive down cost structure	To be determined – Market still highly immature

Source: Roland Berger, desk research

¹ Silicon Insulated Gate Bipolar Transistor

ruling SiC-based technology. This limits the supplier base. China is attempting to develop a domestic supply base, but it is yet to produce significant results. High quality standards, requirements for reliability and longevity, intellectual property restrictions and capital intensity bar most startups from market entry.

- The importance of SiC- and GaN-based semiconductors for military applications has placed political restrictions on the export and exchange of technology, know-how and IP. This could potentially disrupt automotive supply chains and limit the consolidation of the industry, as seen with the blocked takeover of Wolfspeed by a non-US company.

- The industry has not yet reached a level of stability, maturity or technical capability to suggest the lowering of prices in the next 5-10 years.
- Tier 2 semiconductor players are increasingly working directly with OEMs, thereby threatening Tier 1s position in the value chain.
- Investment is likely to stagnate until one of the technologies emerges as the clear winner. This means strategic partnerships are crucial to accelerate the development and adoption of high-voltage powertrain electronics, and to enable investment in capacity expansion.

4 / Recommendations

FOUR STEPS TO TACKLE DISRUPTION IN THE ELECTRONICS AND SEMICONDUCTOR SUPPLY CHAIN

With so much disruption expected in the automotive electronics and semiconductor supply chain, no player can afford to sit still. But the complexity of the challenges facing them makes it difficult to navigate a path to calmer waters. Most importantly, which value chain position should they take to create sustained competitive advantage? Which partnerships and critical capabilities need to be built up? And what is the best approach to sourcing electronics hardware and software, and especially semiconductors?

In this chapter we provide some answers to these questions, as well as making a specific recommendation for Tier 1 suppliers, who have the most to lose if they fail to adapt to the new reality.

1 DEFINE YOUR VALUE CHAIN POSITION

The first step for any stakeholder in the automotive electronics and semiconductor value chain is to seriously reflect on their core value proposition. They must identify differentiating technology capabilities, as well as product and service offerings that will remain relevant in the long term. In addition, they must choose to defend or expand a competitive position against the increasing capabilities of incumbents and new entrants, capture sustainable profit pools, and decide whether to outsource or rely on partners.

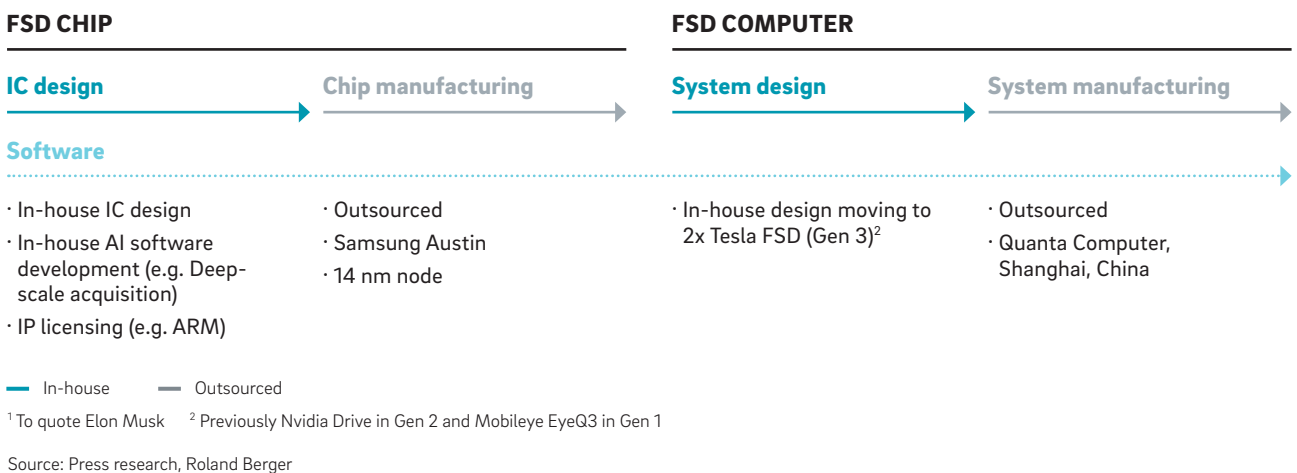
Not every player will arrive at the same conclusions. For example, Tesla has chosen to go it alone with an extreme vertical integration approach to its fully self-driving capabilities, from the overall system development all the way to a proprietary semiconductor chip (designed by an automotive OEM!). Even here, Tesla focuses on the differentiating capabilities in electronics and semiconductor design, while leaving the manufacturing to contractors. →!

OEMs and suppliers will have specific considerations when assessing their core value proposition. Depending on their starting position, examples include:

-▶ Is ADAS truly differentiating or will it be too highly regulated?
 -▶ How can we defend a Tier 1 position against new platform providers like Nvidia or Mobileye?
 -▶ Is the electric powertrain a differentiator and do we need to move powertrain electronics in-house?
 -▶ Do we need to control the entire software stack or only the customer-facing applications?
 -▶ Do we need to design our own semiconductors?
 -▶ Do we build in-house electronics manufacturing capabilities?
 -▶ How do we make money from software as a product – or will software remain an enabler for hardware sales?
-

I: The "best chip in the world"¹

Tesla's in-house-designed AI engine for autonomous driving



2 BUILD CAPABILITIES IN ELECTRONICS, SEMICONDUCTORS AND SOFTWARE

No single company can develop the expertise to manage all the elements in the electronics and software supply chain, or bear their costs. This is especially true when developing complex systems for autonomous driving, whose hardware and software requirements, as we have seen above, are highly demanding.

As a result, the automotive industry is experiencing a period of large-scale partnerships and consortia between rivals. These aim to create a complex ecosystem of diverse skills, reduce risk, build capabilities and share the development costs of autonomous driving. Currently two groups are leading the pack: one consortium involving BMW, FCA, Audi and Intel/Mobileye, and another with Toyota, GM and Nvidia.

When developing in-house capabilities, the starting point is to leverage existing core competencies. Comparing these competencies against best practices and/or technology requirements will determine gaps and areas for potential investment. Electronics, semiconductors and especially software have an accelerated development lifecycle, as well as their own development processes. This means they require the structure, agility and processes of a high-tech organization.

When establishing partnerships or joining a consortium, participants need to identify the right partners to close specific capability gaps. They must also decide which partnership option, for example license, joint development, JV or acquisition, best mitigates the implementation risks, and balances time-to-market with cost, quality, supply security, and the required investment.

OEMs and suppliers will have specific considerations when developing capabilities or establishing partnerships in automotive electronics and software. For example:

- Do we need a central platform development team and how do we structure it? What scale is needed and how do we achieve it?
 - Do we need separate technology/software organizations with a separate budget? How do we find, attract and retain the right talent?
 - How do we manage electronics and software development versus traditional automotive development and longer automotive lifecycles?
 - How do we engage with semiconductor players (like Nvidia or Intel/Mobileye) if they are already locked into partnerships? Should we join one of the existing consortia, for example, for self-driving technology?
 - Which startups should we partner with and what is the best partnership model? How do we leverage these relationships to build internal capabilities?
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3 TAKE A STRATEGIC APPROACH TO SOURCING

Stating the importance of strategic sourcing in the automotive industry seems self-evident. But the sourcing of electronics and semiconductors in automotive is particularly challenging and costly, for several reasons. First, quality and production standards are significantly higher than in other market segments. Automotive electronics components have to undergo extensive and time-consuming (i.e. expensive) qualification,³ and component manufacturing must adhere to strict quality processes validated by supplier audits.⁴ Suppliers, especially those with a consumer electronics background, often do not have the right mindset, qualification or processes to accommodate this.

Second, automotive volumes are small in comparison to other consumer and professional electronics market segments. Despite a high per-car electronics content, additional stock-keeping unit (SKU) fragmentation is driven by relatively low automotive platform volumes, complex E/E architectures with many different components and a lack of standardization. Unit volumes are also small in comparison to the semiconductor industry. For example, a 5-million-unit production run for a standard automotive MCU with 30mm² die area, which would be considered high volume in automotive, corresponds to less than 2 hours of equivalent production capacity of a 300mm wafer at a semiconductor foundry. → J

Third, the required ruggedness and reliability is significantly higher for electronics than it is for consumer applications. Automotive components must be able to withstand extreme temperatures and humidity and co-exist without interference.

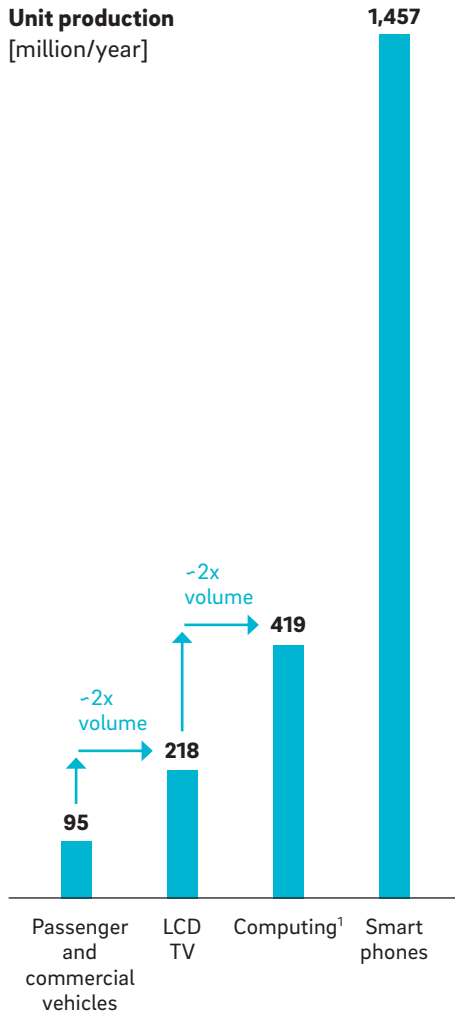
Lastly, the lifecycle for automotive electronics components is significantly longer than in other markets and can span 20 years. This is in stark contrast to the consumer electronics industry, where development and product lifecycles can be measured in months.

³ E.g. Early Life Failure Rate (ELFR), Power Temperature Cycling (PLC), Advanced Product Quality Planning (APQP), Production Part Approval Process (PPAP)

⁴ E.g. IATF 16949, AEC-Q 100, AEC-Q 200

J: Volume game

Unit production volumes in typical electronics markets show how semiconductor costs decrease as volume increases in 2018

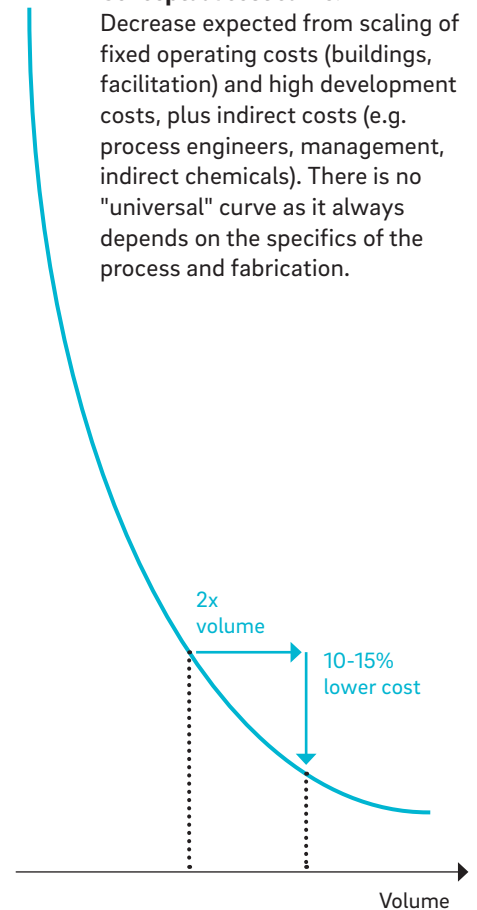


IMPLICATIONS FOR AUTOMOTIVE SEMICONDUCTOR

- Despite high per-car electronics content, additional SKU fragmentation driven by:
 - Relatively low automotive platform volumes
 - Complex E/E architecture with many SKUs
 - Lack of standardization
- Even in high-volume automotive production runs, unit numbers are small in comparison to other market segments

Conceptual cost curve:

Decrease expected from scaling of fixed operating costs (buildings, facilitation) and high development costs, plus indirect costs (e.g. process engineers, management, indirect chemicals). There is no "universal" curve as it always depends on the specifics of the process and fabrication.



¹ Tablets, laptops, desktops, servers
Source: Statista, Qorvo, Roland Berger

The solution? OEMs need to get directly involved with semiconductor suppliers when sourcing critical semiconductor components. Advanced procurement is required to build a competitive edge and enable significant cost savings in automotive electronics. This should take in supplier management, the optimization of supply channels and distributors, volume bundling, SKU reductions, thinking through minimum order quantities, inventory avoidance and push vs. pull manufacturing strategies. Equally important in optimizing the BoM are design for cost and value engineering, feature optimization, functional integration and platform strategies from the system level all the way to the chip level.

4 TIER 1 SUPPLIERS NEED TO RETHINK TO STAY COMPETITIVE

Traditional Tier 1 automotive electronics suppliers are under pressure from all sides. Their position is challenged by up- and downstream incumbents and the growing capabilities of new players. A growing market size and changing OEM sourcing behavior make the sector both interesting and accessible to global electronics players, or contract manufacturers with cross-industry scale. And as the electronics share of the BoM grows, OEMs' cost pressure will only increase and scale will continue to gain importance as a competitive advantage.

This leaves traditional Tier 1s with three options, each similarly challenging:

1 – Master complete systems, compete on system knowledge and optimize cost at the system level rather than component or ECU level. This path requires integrating system knowledge and design capabilities with competencies across electronics, software and mechanical components and architectures.

2 – Stay at the cutting edge of the technology to avoid competition on scale. Continuously realign the product portfolio to technology trends and make continuous significant investments in innovation.

3 – Dramatically increase scale to compete with global electronics giants. This path will likely require large-scale inorganic growth options.

“Traditional Tier 1 automotive electronics suppliers' position is challenged by up- and downstream incumbents and the growing capabilities of new players.”

Konstantin Shirokinskiy
Partner

Conclusion

With OEMs and both Tier 1 and Tier 2 suppliers redefining their role in the changing automotive electronics value chain, three overarching themes emerge.

- First, they need to clearly define their area of differentiation as part of a product and technology strategy based on specific electronics and/or semiconductor core competencies.
- Second, participation in the electronics value chain needs to be clearly aligned with these core competencies and the differentiation areas. Additional partnerships or acquisitions can help close capability gaps or improve business cases.
- Finally, all players can benefit from adapting their organization's skill set, tools, purchasing and development strategy. Electronics and semiconductor development and sourcing need to be value driven and strategic rather than transactional.

Such action may be the difference between future success in automotive electronics and semiconductors, and irrelevance.

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