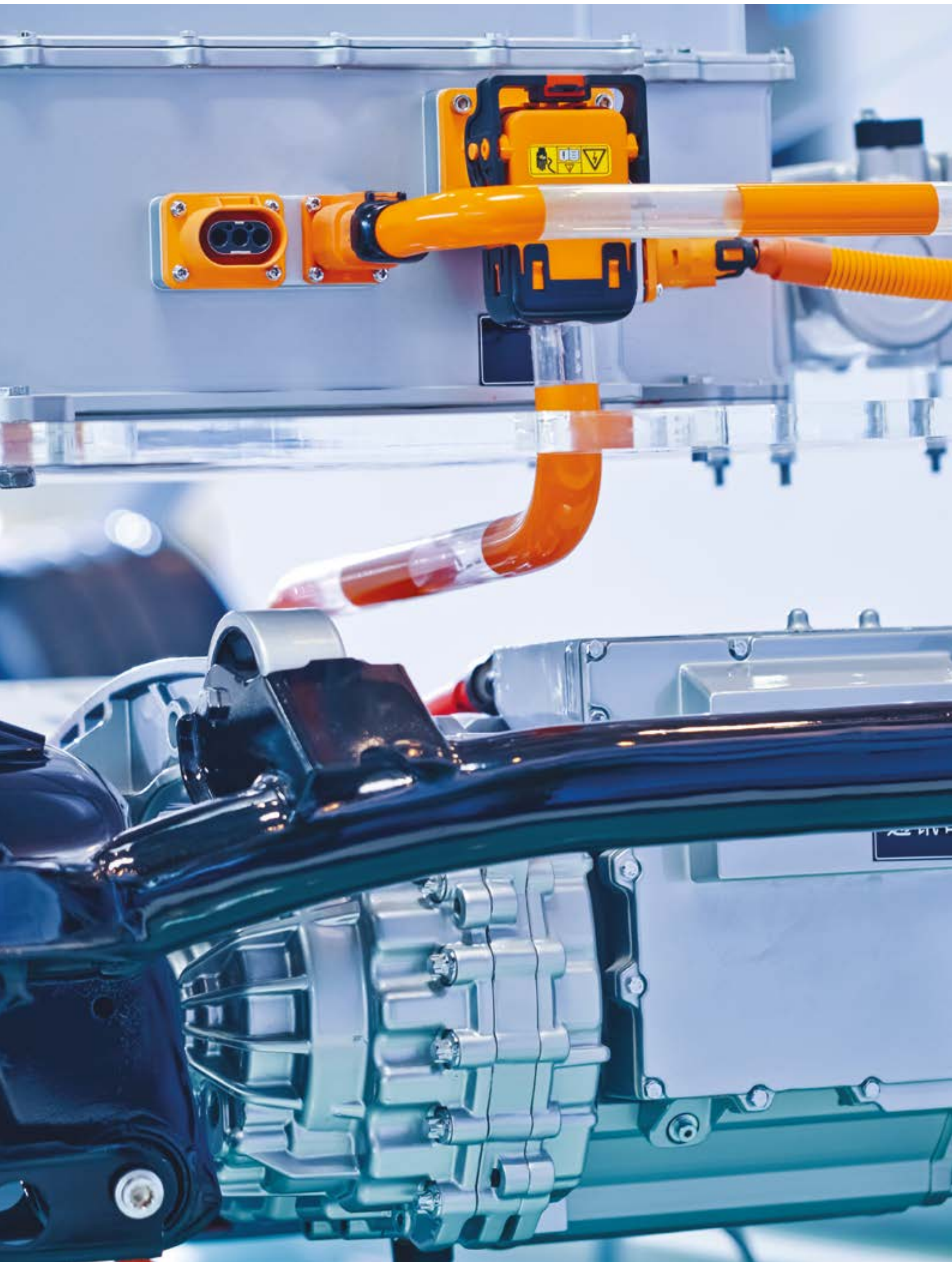
Trends in electric vehicle design
Issue No. 2

Insights on best practices for paving the road for mass-market electric vehicles



A2Mac1 Automotive Benchmarking

McKinsey&Company

MCKINSEY CENTER FOR FUTURE MOBILITY

Introduction

The race for mass-market EVs has begun

2017 possibly may be remembered as the year when electric vehicles (EVs) made the move to become mass-producible. Last year, roughly 1.3 million EVs were sold globally. While this makes up only about 1% of total passenger vehicle sales, it is a 57% increase over 2016 and there is little reason to believe this trend may slow down. Established OEMs have announced launches of over 100 new battery electric vehicle (BEV) models by 2024, further accelerating the automotive and mobility trends, potentially growing EVs' share of total passenger vehicle sales to 30 to 35% in major markets (20 to 25% globally) by 2030. Moving away from previous "niche roles" like high-performance sports or mid-range city cars, there will also be a sizable share of mid-size and volume-segment vehicles among the many new BEV models. A prominent, recently launched example is Tesla's new Model 3 with 450,000+ preorders.

What will help EVs gain market share is that OEMs have reached ranges with their EVs which allow them to focus on reducing price points, e.g., via further increasing design efficiency or reducing manufacturing cost to become affordable to more customer segments. As shown in Exhibit 1, we find that once the average range of our set of benchmarked EVs has surpassed 300 km (or 185 miles), OEMs seem to be able to concentrate on entering lower-price segments.

This indicates that the long-awaited EV volume segment – i.e., "mid-size EVs for the masses" – may be on the verge of becoming reality.

Despite different expectations regarding what makes for "good range" across the globe – i.e., ideas vary by geography and city archetype – average battery range seems to have gone above what the largest customer segments expect. Add to this a decrease in sticker price towards levels that more consumers will be comfortable with and the market for EVs may be close to a commercial tipping point.

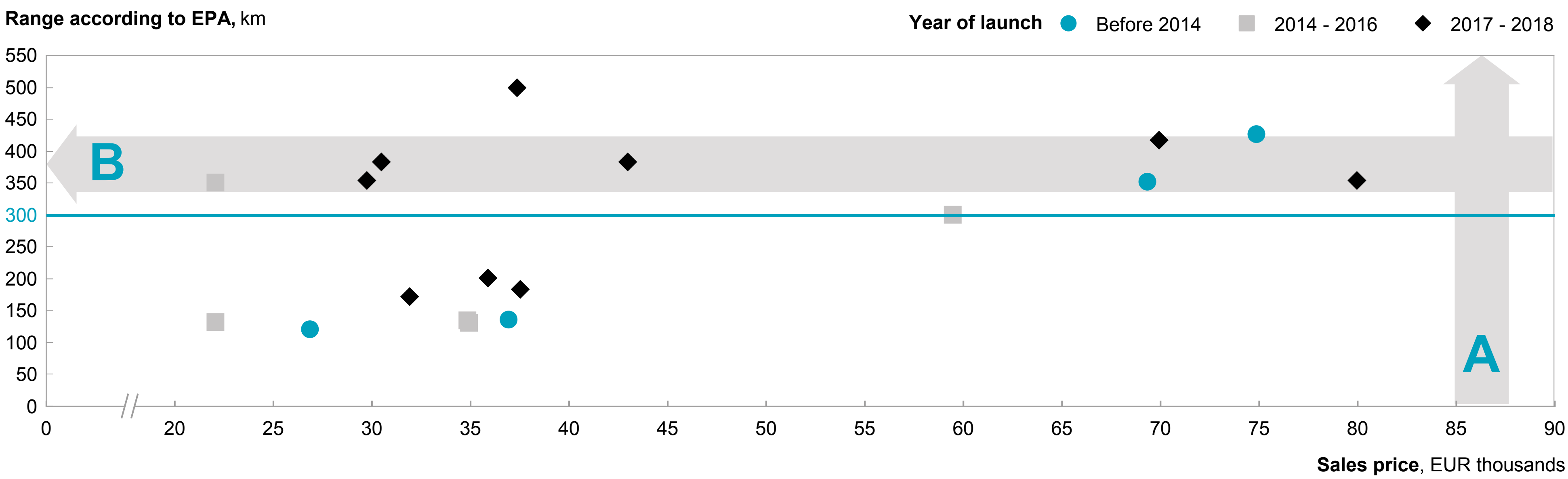
Whether an EV volume segment is (or will be) profitable for OEMs, is still a burning question among many in the industry. We estimate that many EV models in their base version, and potentially even including options, still may have low contribution margins, especially compared to current internal combustion engine (ICE) levels.

It is for this profitability question as well as the fast-paced technological advancements and new design trends in EVs that we have launched the second benchmarking analysis on "Trends in electric vehicle design" (see Text box 1).

In this issue, we describe success factors on the way to profitable serial production of EVs and discuss essential practices for paving the road towards the EV mass market. This includes four high-level commitments to design and development through the lenses of architecture, integration, technology, and cost that can help realize a positive business case for mass-market EVs.

Exhibit 1

The race for acceptable range seems to be over, the race for mass-market EVs has begun



Note: Where EPA data not available, NEDC or OEM data was used; sales prices based on German market OEM data

Source: A2Mac1; McKinsey; OEM web sites; press research

Text box 1

Our publication on trends in EV design

“Trends in electric vehicle design” is a joint publication by McKinsey & Company and A2Mac1. The series aims at discussing teardown- and benchmarking-derived insights on the most current trends in EV design.

The premier issue introduced key insights from a detailed teardown and physical and digital benchmarking of ten first- and second-generation EV models (see overview on EV models included in our current benchmarking pool at the end of this article). New issues, like this one, set out to expand on the learnings from our earlier EV benchmarking efforts – above all by including newly launched EV models in the benchmarking pool and introducing a perspective on a new EV trend. In this publication, we present consolidated findings – detailed insights from our work are available upon request but would exceed the scope of this article.

On the findings presented here: This publication provides observations based on a sample set of EVs. We make no claim to the generalizability of these findings. For individual points of comparison, we added outside-in research on other vehicles where relevant. Technologies are evolving quickly, leading to uncertainty, for example, when it comes to assessing the development of EV powertrain components across formats or chemistries.

On the differentiation of native and non-native EVs as used here: Entirely “native” or entirely “non-native” EVs can be understood as two ends of a range. In non-native EVs, most elements – besides the battery and specific EV powertrain components – are based on previous ICE models, following a logic of deriving the EV architecture from what an OEM has done in the past. Examples could be the VW e-Golf or the Chevrolet Spark. On the other end, we consider native EVs to be an entirely new development effort. Examples could be the Tesla models. As EV design advances quickly, it may become increasingly challenging to make such a clear differentiation.

Build a native and inherently flexible EV

Despite higher upfront investments – in the form of engineering hours, new tooling, etc. – native EV platforms have proven advantageous over non-native models in multiple ways.

Designing the vehicle architecture entirely around an EV concept, and without combustion engine legacy elements, means fewer compromises and more flexibility on average.

As native EVs have to compromise less, particularly in their architecture and body in white, they can accommodate a bigger battery pack, which in turn correlates with higher range. This is evidenced by the fact that native EVs have on average a 25% larger battery pack volume (relative to body in white volume) compared to non-native EVs. One reason is that the body structure can be fit around the battery pack and does not have to be integrated in an existing architecture. This additional freedom in design typically resulting in larger batteries also leads to other potential advantages such as higher ranges, more power or faster charging.

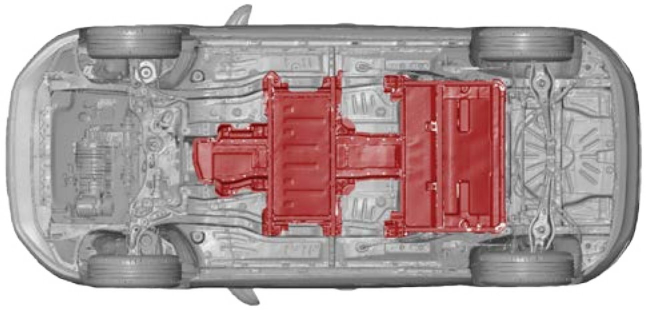
Further, as battery technology evolves quickly, allowing the newest EVs to have ranges which are not a bottleneck anymore, we see early indications that EVs are moving towards practices common in mass-market ICEs, e.g., offering powertrain options. The inherent flexibility of native EVs plays an important role in this as well. For example, battery packs can house a varying number of active cells while keeping the same outer shape, and variable drivetrain technologies can allow to produce rear-wheel, front-wheel, and all-wheel drive on a single platform.

While this may raise the idea that EVs will start moving towards modular strategies as we know them from ICEs, thereby moving closer to industry-typical mass-production approaches, we still do not see a clear convergence towards one standard in design solutions. Players will need to stay agile on their way to mass-market EVs.

Exhibit 2

Batteries of native EVs require less compromise and allow for higher flexibility

Non-native EV
battery pack architecture
(example)



Battery pack

Native EV
battery pack architecture
(example)

~25%
larger battery packs (relative to the vehicles' body in white volume) in benchmarked native EVs

3 of 11
benchmarked EVs already offer multiple range options; all of these are native EVs

Source: A2Mac1; McKinsey

Keep pushing the boundaries of EV powertrain integration

Our benchmarking has revealed a continued trend towards EV powertrain integration, with many parts of the power electronics moving closer together and being integrated into fewer modules. Yet, as players keep searching for additional design efficiency, the one "mainstream" EV powertrain design has not yet emerged – neither in terms of overall architecture nor the design of individual components.

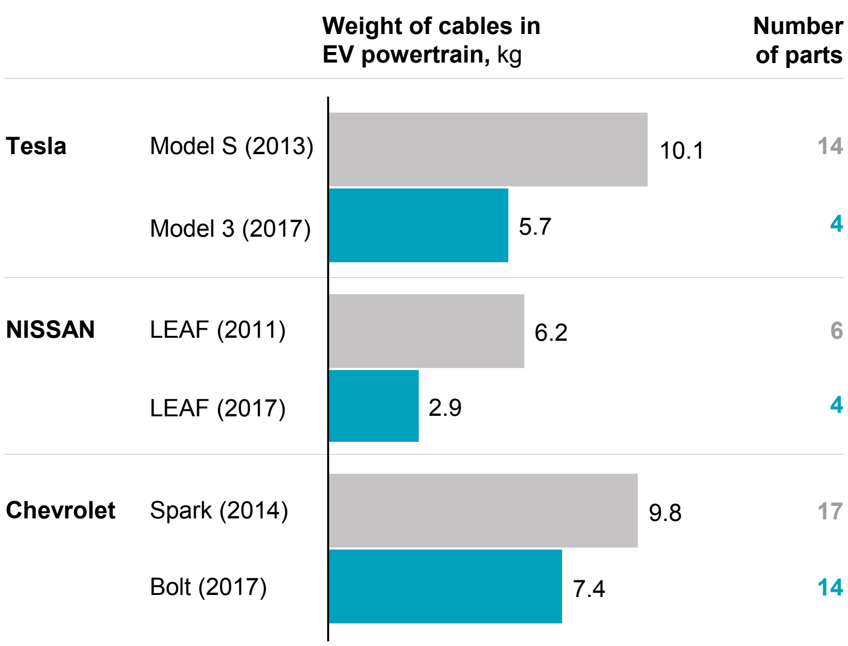
A good indicator for the increased level of integration is the design of the electric cables connecting the main EV powertrain components (i.e., battery, e-motor, power electronics, and thermal management modules). When looking at the weight and total number of parts for these cables across OEMs and their EV models, we observed a decrease in both cable weight and number of parts in the OEMs' latest models compared to earlier vehicles, which reflects the higher integration of more recent EV powertrain systems.

In addition to the physical integration of main EV powertrain components, we also observed a move towards more simple and efficient thermal management solutions across said components. However, while some OEMs are on a consolidation charge here too, others still rely on multiple systems, and we do not see a clear convergence of designs yet (see Exhibit 4).

Beyond the fact that technology is still maturing, the EV powertrain design variety may also be aided by its intrinsic, higher level of flexibility, as the components are generally smaller and the degrees of freedom based on available space in the underbody and front- and rear compartments are higher compared to ICE powertrains. To give just one example of different EV powertrain architectures: the Opel Ampera-e seems to leverage an ICE-like positioning of its powertrain electronics including ICE-typical body and axle components, whereas the Tesla Model 3 integrated most components on the rear of its battery pack and the rear axle directly (see Exhibit 5).

Exhibit 3

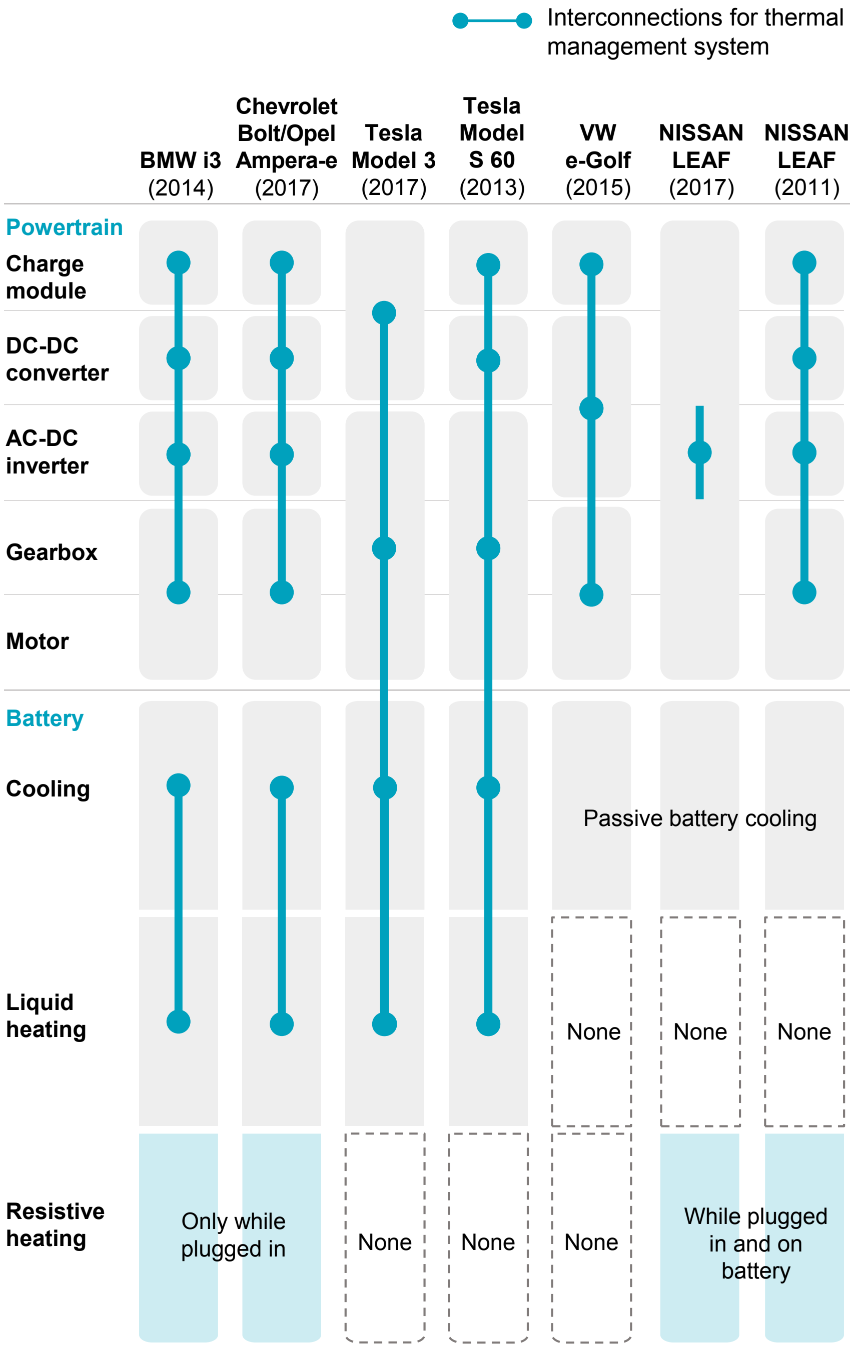
Weight and number of parts for major cables connecting EV powertrain components across example OEMs and models



Source: A2Mac1; McKinsey

Exhibit 4

Design approaches to managing EV powertrain and battery thermal management still vary widely among OEMs

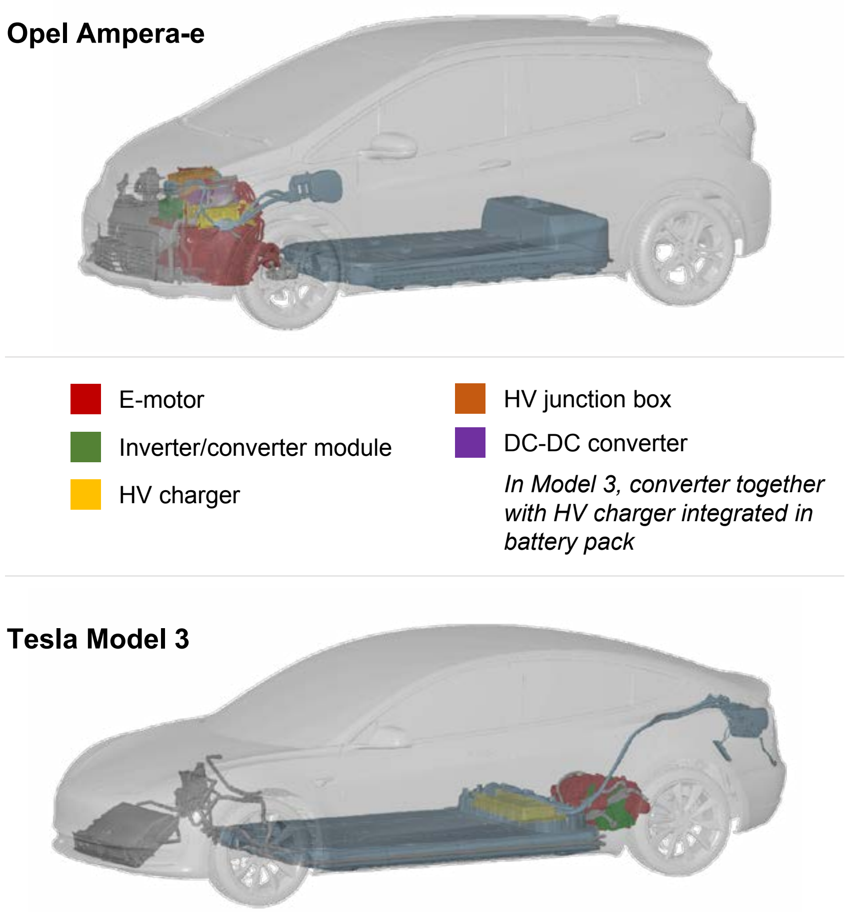


Note: Exhibit shows a simplification; detailed schematics can be requested from authors

Source: A2Mac1; McKinsey; Ricardo

Exhibit 5

EV powertrain architectures vary even among newest models



Source: A2Mac1, McKinsey

It is worth pointing out that such freedom in the positioning of components also gives more flexibility in overall features offered, e.g., choosing to have room for a bigger trunk, or superior driving performance due to a lower center of gravity.

In their ongoing pursuit of mass-marketability, EV players therefore may identify further opportunities in high-level integration of their EV powertrain systems, and could be able to capture potential benefits such as reduced complexity in development, lower material and assembly costs, and weight and energy efficiency improvements.

Stay ahead in the technology game

McKinsey research has shown that many EV customers are very tech-savvy. At the same time, new technologies are largely getting mature enough to be put into practice. Not only does this create a great testing field for new technologies which OEMs and other players hope to push into cars, it almost obligates EV manufacturers to equip their vehicles with the highest levels of technology around advanced driver assistance systems (ADAS), connectivity, and other trends that are redefining the driver experience and travel strategies to move from A to B.

Besides increasingly introducing ADAS technologies, OEMs are meeting the needs of their EV customers by enhancing the user interface and infotainment systems. Specifically, they are increasingly integrating the control of a wide range of interior functions into a more central, "smartphone-like" user interface (HMI). For example, controls move from buttons to continuously growing touch screens – a concept that was first tried in a few models of US car manufacturers in the late 1980s and now seems to have reached sufficient levels of technological maturity and customer interest. We observed EVs in our benchmarking which have only seven physical buttons in the interior, compared to often 50 to 60 in many standard ICEs.

Exhibit 6

Benchmarking of 12 ICEs and 8 EVs shows that EVs with latest ADAS technology move towards consolidating ECUs

	Equipped with ADAS technology	Number of ECUs per vehicle	Example vehicle
ICEs	Normal	2 - 6	VW Golf, BMW 3 Series
	Latest	11 - 14	BMW 7 Series, Mercedes S-Class
EVs	Normal	3 - 8	NISSAN LEAF, Opel Ampera-e
	Latest	3 - 4	Tesla Model 3, Tesla Model S

Source: A2Mac1; McKinsey

A key enabler of such advancements is the rapid rise in computing power. While traditional cars often show many decentralized and standardized electronic control units (ECUs), the latest EVs seem to rely on ever growing and increasingly centralized computing power.

ADAS technology, for example, requires a lot of computing power for the real-time signal processing of the various sensors. When putting the latest ADAS solutions, such as adaptive cruise control, autonomous braking, and potentially even autonomous driving capability, in the context of increased ECU centralization, it seems that EVs equipped with such ADAS technology further drive consolidation of ECUs in comparison to equally or less ADAS-equipped ICEs or EVs.

An OEM's decision for a centralized or decentralized ECU architecture can be a strategic question and will be driven by different factors. One reason for a centralized approach may be the choice to "own" a key control point in the vehicle by becoming an integrator. This could facilitate advanced software development and potentially may open up new revenue streams, e.g., from over-the-air updates.

Besides strategic considerations, the ECU architecture may also impact weight and cost. For example, centralization may optimize wiring and sourcing efficiency via increased bundling. Because they require simpler protocols and fewer connections compared to multiple, decentralized ECUs – thereby also reducing the number of operations that could go wrong – centralized ECUs can increase reliability. On the development side, more ECUs also mean more teams who must collaborate and communicate efficiently to ensure quality across systems. Fewer teams and simplified processes can result from centralizing ECUs, and this simplification can lead to shorter development cycles. Further, central, high-power ECUs may likely become the backbone of the growing work towards the development of fully autonomous driving, thereby equipping EVs to be ready for future mass-market characteristics and potential customer expectations.

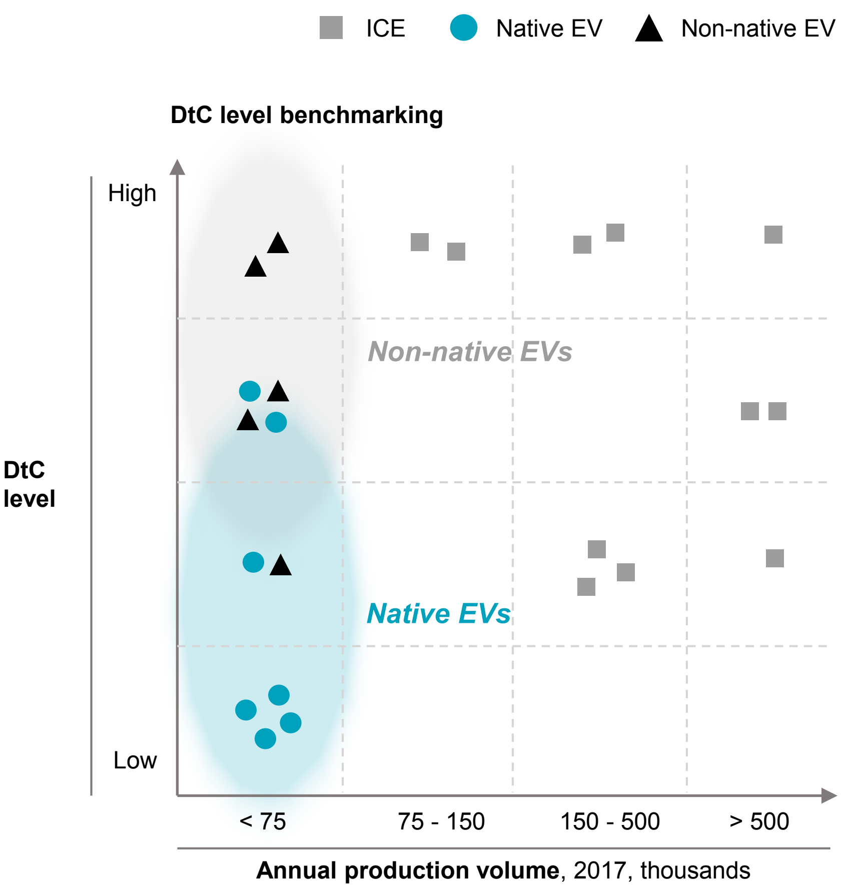
Ultimately, however, the ECU architecture choice will depend on the OEMs' individual strategy, and as centralization may require significantly building up additional skills in-house, it will always be an individual business case decision.

Apply design-to-cost levers

Achieving profitability is still a struggle for EVs, especially due to high powertrain cost. Since OEMs seem to have reached acceptable ranges by now, rigorous design to cost (DtC) will become more important to pave the road for EVs to successfully enter the mass market, i.e., achieve an attractive price point, without jeopardizing margins for the OEM.

Exhibit 7

Benchmarking of DtC levels across EVs and ICEs



Note: Assessment along typical DtC levers: integration and part reduction, switching to lower-cost material, sourcing industry standards, reducing specifications, switching to lower-cost machinery and reducing quality issues

Source: A2Mac1; McKinsey; IHS production data

Cost efficiency seems to be the home turf of established OEMs and suppliers, who may be in the best position to leverage their experience and knowledge in traditional DtC levers.

Therefore, it may come as little surprise that ICEs and non-native EVs seem to be more DtC-proficient than native EVs due to the makers' track record of continuous cost optimization and the possibility to carry over highly optimized components from previous models.

Yet, the latest native EVs may be able to quickly catch up. For example, due to advantages in battery pack advancements, native EVs seem to now switch from lightweight to more cost-efficient material solutions such as steel elements in the body in white, apply more rigorous despecification and decontenting (e.g., in controls and air vents on the instrument panel), and seem to invest into mass production processes, such as high-strength stamped steel instead of bent pipe seat structure designs.

As the move towards the mass market continues, EV experiments are increasingly becoming a serial production game. Non-traditional OEMs will likely study the DtC practices of traditional OEMs, including e.g., sourcing industry standard parts, to identify better ways to close the gap in cost performance and thus increase their profit margins from a product cost side. Nonetheless, achieving a superior cost performance might still be a competitive advantage for established OEMs and thus comprises an opportunity to step up against potential new market entrants.

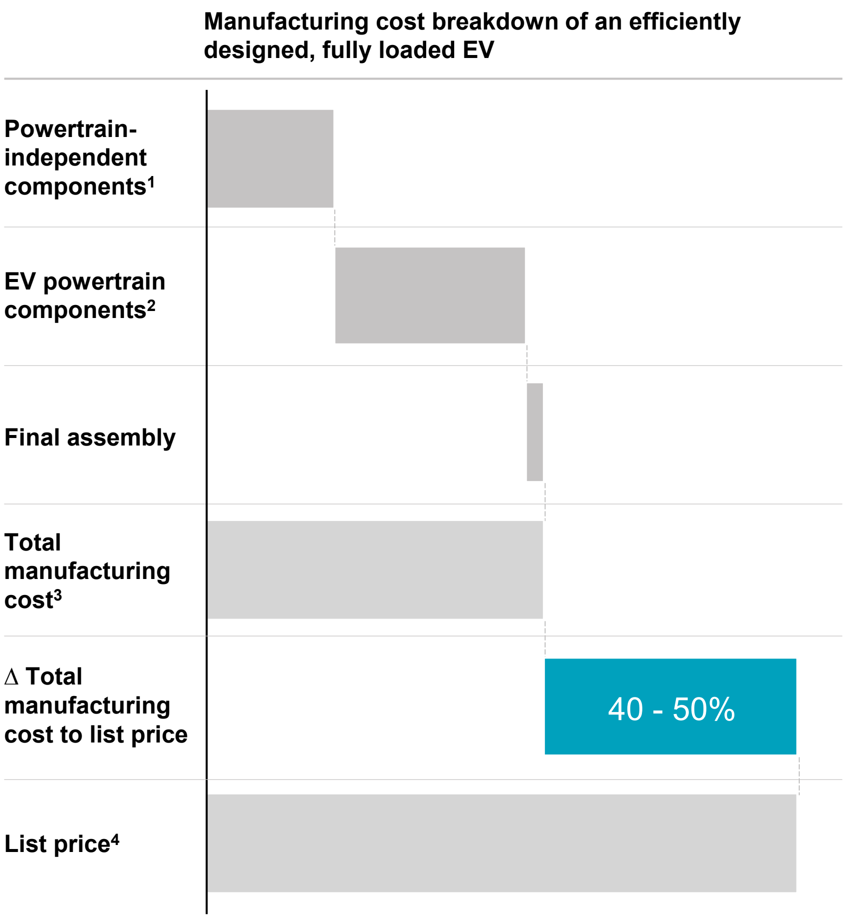
Outlook

Can OEMs make money in the volume EV market?

Most recently, EVs have gained a significant share in the new product announcements of many OEMs. At the same time, EV models individually have not yet offered much in the way of contributing to overall profitability compared to ICEs. As the global market share of EVs inevitably grows, their margins increasingly move into focus.

Exhibit 8

Sufficiently equipped EVs might reach 40 to 50% delta from total manufacturing cost to list price



1 Incl. body, driving and axles, electronics, interior, and others
2 Incl. battery and BMS, e-motor, power electronics, thermal management, transmission
3 Incl. material, production, and assembly cost
4 List price of sufficiently equipped EV: incl. hardware and software options such as non-standard color, range extension, and, e.g., different software settings

Source: A2Mac1; McKinsey

Taking the four steps in EV design outlined in this article into consideration may help OEMs to reduce the comparably high manufacturing cost (i.e., including material, production, final assembly) of EVs. With a focus on simpler and more flexible platforms along with a fresh approach to technology and design, we believe that a positive mass-market business case for EVs may exist.

In fact, based on our analysis, the delta from total manufacturing cost to list price for sufficiently well-equipped (i.e., including hardware and software options such as non-standard color, range extension, and, e.g., different software settings), mid-size EVs may potentially reach a level of 40 to 50%. While powertrain-independent components and final assembly appear very similar in their cost structure to ICEs, major cost drivers still lie in the EV powertrain itself and related uncertainties in the development of battery cost.

This also highlights that for an overall attractive business case, additional measures – for example, in optimizing offering logic and channel strategy – will still be necessary.

• • •

In summary, we may see an era of profitable mass-market EVs on the horizon – driven by design trends towards flexibility, integration, and customer-value-maximizing simplification, and under the clear governance of cost efficiency for mass-producibility.

As noted above, this publication presents only consolidated findings – detailed insights from our work are available upon request but would exceed the scope of this article.

Overview of EV models considered in the benchmarking

- NISSAN LEAF 2011, Japan
- Volkswagen e-up! 2013, Europe
- Tesla Model S 60 2013, United States
- Chevrolet Spark 2014, United States
- BMW i3 2014, Europe
- Volkswagen e-Golf 2015, United States
- BYD e6 Jingying Ban 2015, China
- NISSAN LEAF 2017, United States
- Chevrolet Bolt 2017, United States
- Opel Ampera-e 2017, Europe
- Tesla Model 3 2017, United States (new)

If you would like to learn more about our full teardown and benchmarking results, please contact us:

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The authors wish to thank the team including Alexander Kienreich, Alexandra Mathiolon, Amelie Pene, Cédric Weiss, Gaël Guilinger, Hans von Tiedemann, Kilian Zedelius, Klaus Ziemann, Markus Schweier, Maximilian Fischer, Patrick Schaufuss, Piotr Cependa, Rupert Lee, Stephan Fuchs, Stephan Mohr, Timo Möller, Tobias Geisbüsch, Wolfgang Günthner, and Vianney Palade for their contributions to this article.

The authors further thank the sponsors of this effort including Andreas Cornet and Nicolai Müller.