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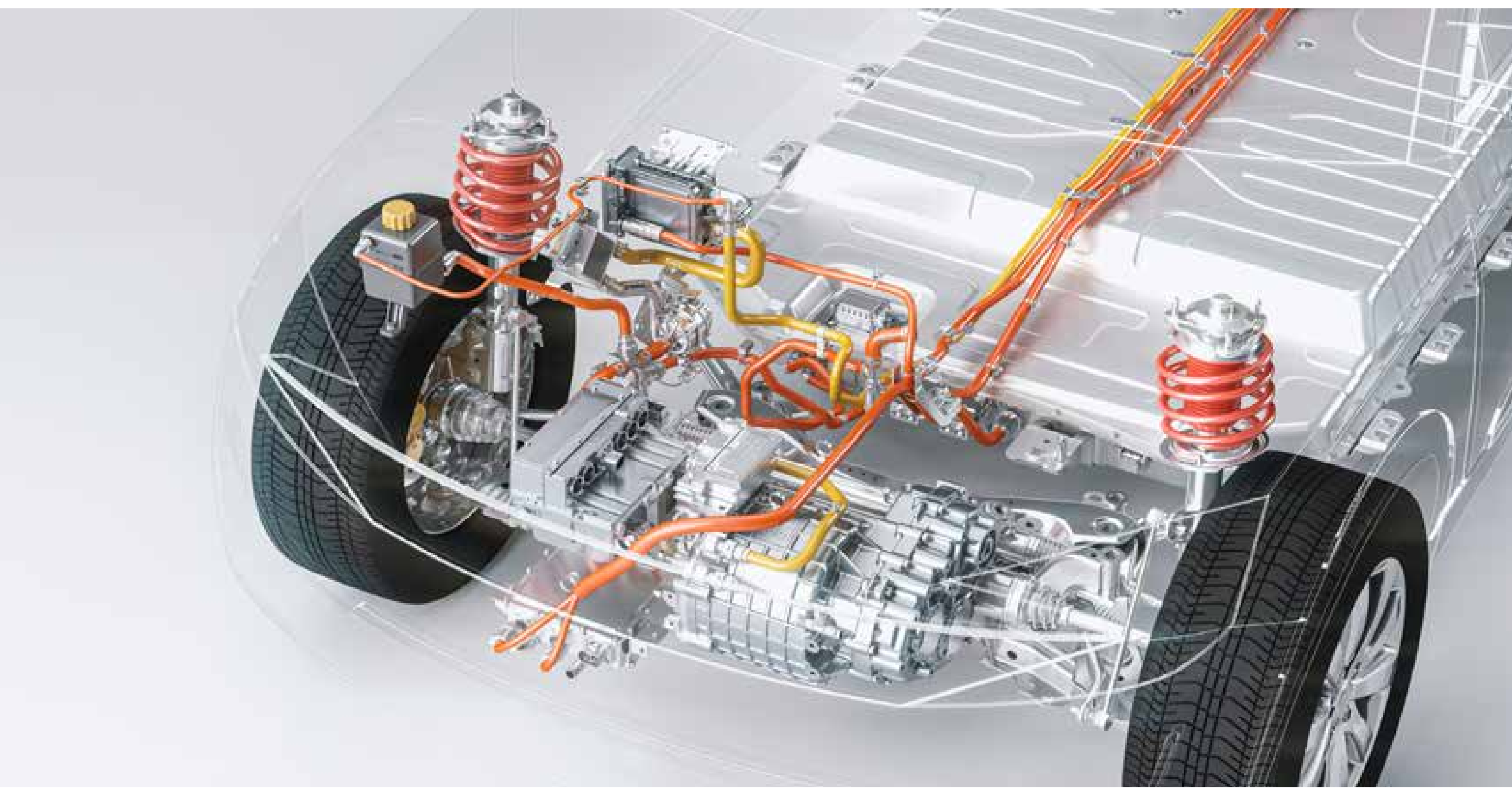
How to drive winning battery-electric-vehicle design: Lessons from benchmarking ten Chinese models

Chinese OEMs use existing concepts and manufacturing technologies, as well as off-the-shelf components and a high level of modularization, for battery electric vehicles.

by Mauro Erriquez, Philip Schäfer, Dennis Schwedhelm, and Ting Wu



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Many automotive OEMs and suppliers in Europe, the United States, and Japan are starting large-scale launches of battery electric vehicles (BEVs) in their core markets. But in China, a rapidly growing BEV market and ecosystem have already emerged.

To help global automotive OEMs and suppliers truly understand the major challenges and opportunities of the Chinese BEV market, we analyzed ten BEVs that are popular in China in depth. We covered a large portion of the market, looking at vehicles from both incumbent OEMs and new players, including Buick, BYD, GAC, Geely, JAC, NIO, Roewe, SAIC, and Weltmeister. The companies included in our analysis cover 45 percent of the market with their complete BEV and EV portfolio.[1] The benchmarking consisted of a detailed technical analysis, as well as a cost estimate down to the level of individual components.

Our research on the Chinese market and our analysis of the benchmarked BEVs yielded the following insights:

1. The Chinese BEV market—dominated by Chinese OEMs, which had a market share of approximately 85 percent in 2019—is growing not only as a result of subsidies and regulations but also the increasing attractiveness of these products to customers.

2. For first-generation BEVs, many Chinese OEMs are focusing on low capital expenditures (capex) and a fast time to market , together with an ecosystem dominated by local suppliers. They use existing concepts and manufacturing technologies, as well as off-the-shelf components and a high level of modularization for pre-assembly. This approach creates a potentially profitable business case for at least some of the benchmarked BEV models.

3. Differences among e-powertrain designs (including e-drive,[2] power electronics, and battery systems), electrical/electronic architectures (E/E), and pricing models of the benchmarked BEVs indicate that there are still significant design- and cost-improvement opportunities.

1. China—the world's largest automotive profit pool—is quickly moving toward e-mobility

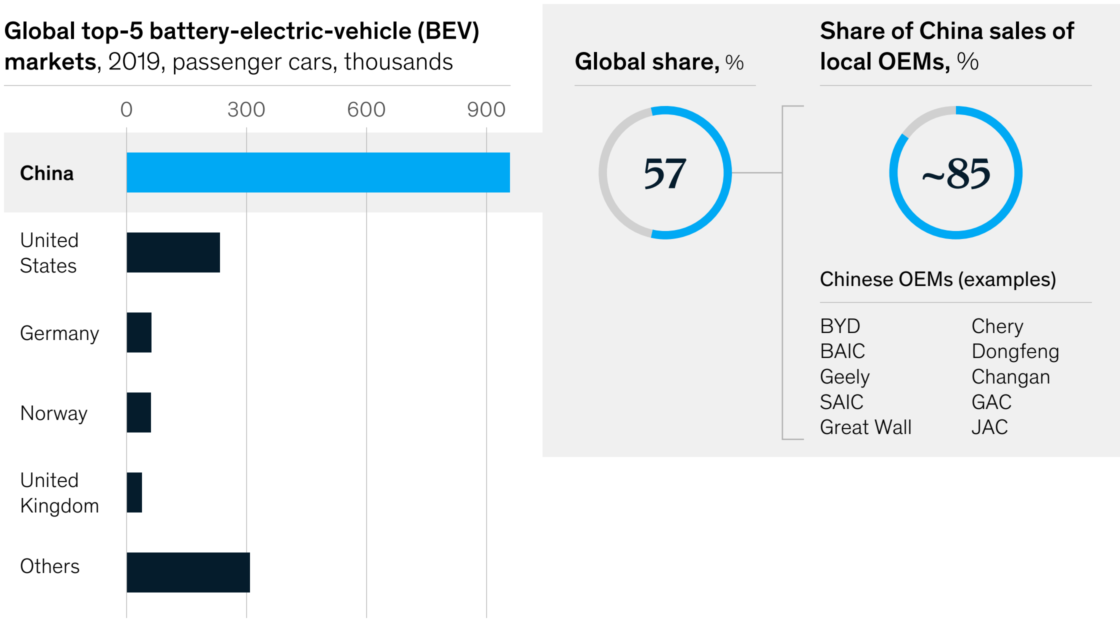
The Chinese automotive market is the world's largest automotive profit pool, accounting for one-third (about $40 billion[3]) of the global total. The market is now shifting toward e-mobility. From 2014 to 2019, BEV unit sales in China increased by 80 percent a year. With more than 900,000 units in 2019, 57 percent of the BEVs sold throughout the

In China, a rapidly growing battery-electric-vehicle market and ecosystem have already emerged.

[1] Calculation of total battery-electric-vehicle market share in China is based on EV-volumes.com's wholesale unit sales figures for China in 2019.
[2] An e-drive includes the e-motor, transmission, and inverter.
[3] This figure is derived from McKinsey's proprietary automotive-profit-pool model.

Exhibit 1

The Chinese BEV market, mainly controlled by local OEMs, is the world's largest, with a share of global volumes of more than 50 percent.



Note: Numbers are based on wholesale volume (similar to CAAM), which have generally been higher than the corresponding retail insurance volumes.

Source: EV-volumes.com; McKinsey analysis

world were sold in China, making it the world's largest BEV market. A look at OEM market shares reveals that Chinese OEMs dominate the market almost completely. International OEMs had a mere 15 percent of annual BEV sales in 2019 (Exhibit 1).

Looking back over the past few years, we see that BEV growth in China was triggered primarily by two factors:

— *Subsidies, quotas, and regulations facilitated production and adoption— and will continue to do so.* Early subsidies, along with the mandate that OEMs increase the share of BEVs in their portfolios, have been a significant driver of the greater availability and adoption of BEVs in China. In 2019, the reduction of subsidies slowed growth in demand, but China's CAFC[4]/EV credit rules still point to a percentage of EV penetration—mostly of BEVs—in the mid-teens by 2025.[5] Regulations on ride hailing and government fleets, as well as restrictions on traffic in city centers, will also keep up BEV demand.

— *The value proposition of BEVs is increasingly attractive to consumers.* Even though the decrease in BEV sales to individuals in 2019 showed that public policy still drives most of the demand for these vehicles, consumer-sentiment analysis shows more promising trends. The general perception of BEVs is exceptionally good regarding safety, performance, connectivity, and brands. Consumers know the

[4] Corporate average fuel consumption.
[5] See Robin Zhu, Luke Hong, Xuan Ji, *China EVs: Unique detail on Chinese EV sales by province and city, and buyer type*, Bernstein, February 13, 2020, bernstein.com.

financial and environmental advantages, and the driving experience stands out as the largest benefit of BEVs. Still, lingering concerns limit demand. Availability of charging infrastructure, cited by 45 percent of respondents, was the most significant concern.[6]

Many new models designed with Chinese consumers in mind have contributed to the acceptance of BEVs, which had a consideration rate of 80 percent in 2019.[7] Customer-sentiment analysis of the ten benchmarked vehicles shows that with an average approval rating of 85 percent, all OEMs have been able to tailor their products to the needs of customers (Exhibit 2).

All benchmarked vehicles perform like comparable European, US, or Japanese BEVs in absolute range or power but outperform them in range-to-price ratios (Exhibit 3). The tested Chinese BEV range is

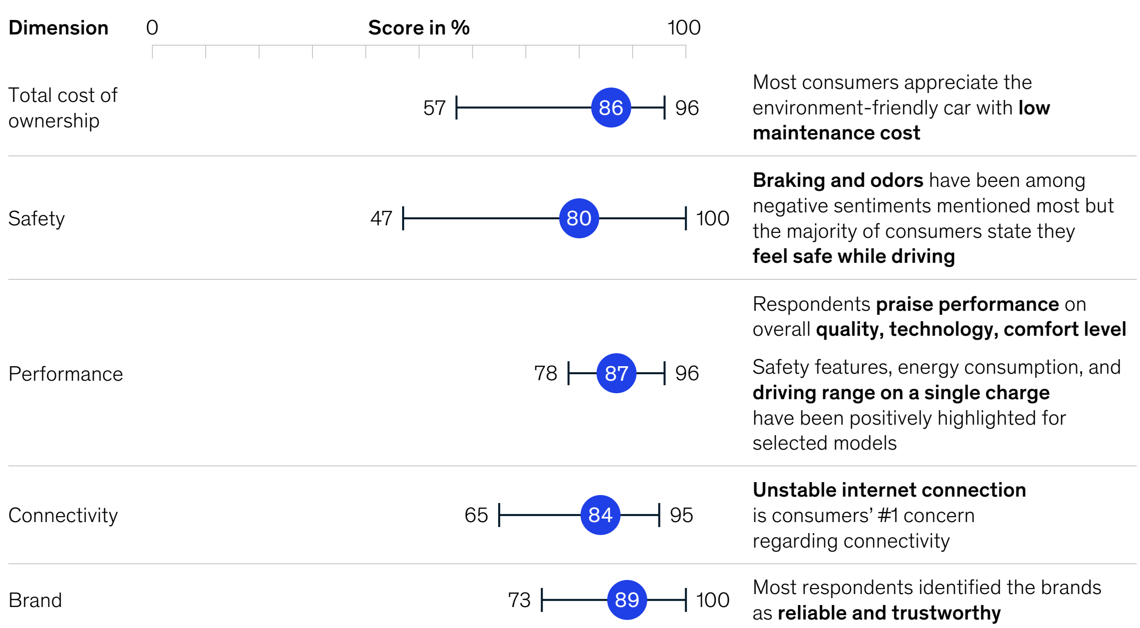
[6] See findings from the McKinsey electric-vehicle consumer survey 2019, published in Thomas Gersdorf, Russell Hensley, Patrick Hertzke, Patrick Schaufuss, and Andreas Tschiesn, *The road ahead for e-mobility*, January 2020, McKinsey.com.
[7] Ibid.

Exhibit 2

Consumers largely acknowledge the performance of the ten benchmarked battery electric vehicles.

Consumer sentiment analysis, % of positive rating

Average rating of responses

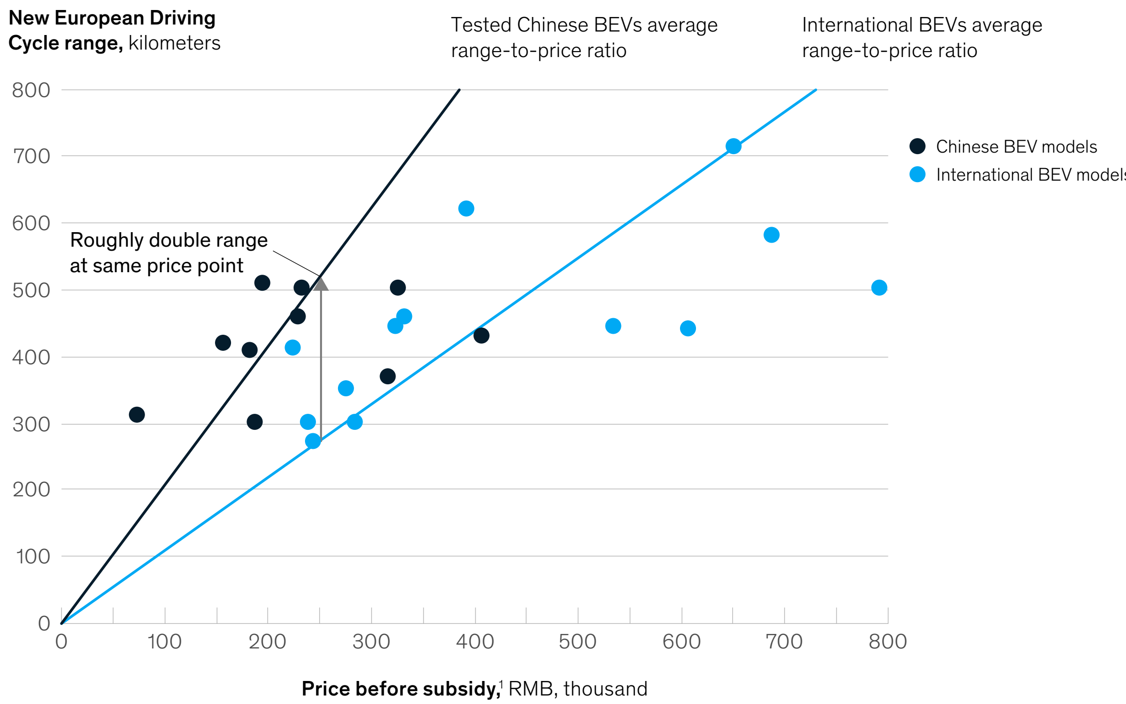


Source: McKinsey analysis

Exhibit 3

Compared with BEVs from established global OEMs, many Chinese models offer better range-to-price ratios.

Comparison between Chinese and international battery electric vehicles (BEVs)



[1] Due to launch timing and availabilities, prices of Chinese models are from official Chinese websites before subsidies whereas prices of international models are based on average Western markets.

Source: OEM website; press research; McKinsey analysis

nearly double that of international models at the same price points.

The outlook for the market is promising: BEV penetration in China is expected to grow from 3.9 percent in 2019 to 14 to 20 percent in 2025—a sales volume of roughly 3.8 to 5.0 million vehicles.[8] With the COVID-19 crisis affecting global BEV markets, China's central government decided in March 2020 to extend purchase subsidies by two more years to fuel BEV sales. Therefore, we expect that after stagnation in 2020—compared with the double-digit growth before COVID-19—the BEV market will pick up again, both absolutely and relatively, in 2021.

2. Chinese BEV producers are on the verge of becoming profitable, given sufficient volumes

Several BEVs have the potential to be profitable, as their product cost structures benefit from several unique characteristics of the Chinese market. The reuse of existing internal-combustion-engine (ICE)

[8] Figures are derived from McKinsey's proprietary Mobility Market Model and Sustainable Mobilty xEV Model.

platforms decreases time to market, and off-the-shelf components and a high level of modularization keep down capex. These design principles and their effects are supported by an ecosystem of local suppliers with long-established expertise across electronics and batteries.

Our bottom-up estimate of materials and production costs, based on more than 250,000 data points, reveals that nine out of ten vehicles may achieve a moderate to solid contribution margin of up to 50 percent. However, we estimate that a lower share may actually achieve a positive operating margin when we take into account warranties; selling, general, and administrative costs; R&D; and capex (Exhibit 4). The high variance in fixed costs can stem from various factors, such as the depth of integration and differences in sourcing strategies or the overall volume of OEMs.

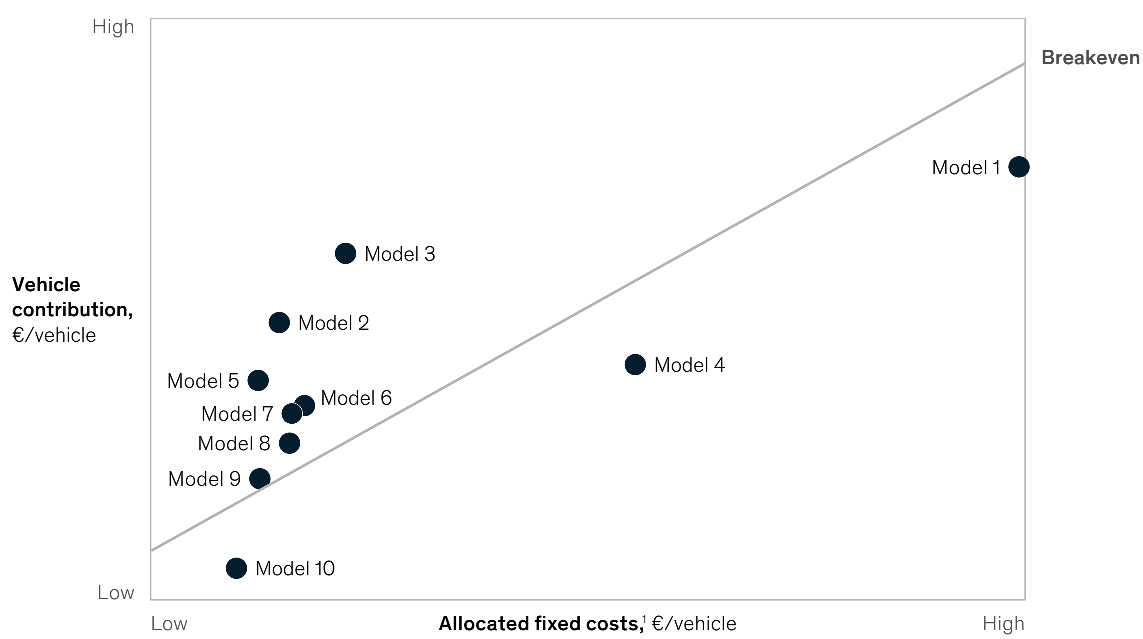
New market entrants in particular need to deal with structural challenges and low overall vehicle volumes. Together with further efforts to excel in R&D, the optimization of capex through flexible manufacturing and strategic value-chain positioning could help more OEMs turn a profit with their BEV models.

To offer a wide range of BEV products and models quickly, most Chinese BEV OEMs manufacture these cars by modifying their existing ICE platforms or using multipurpose shared platforms. We compared the designs of the vehicles during the physical teardown, leveraging our 3-D digital-

Exhibit 4

Battery electric vehicles from our benchmark set may be profitable after they ramp up to full volume.

Estimation



[1] Excludes any ramp-up cost.
Source: McKinsey analysis

twin/virtual-reality software. This work showed that nine of the ten benchmarked BEVs share features such as battery shapes, battery positions, and floor shapes. That indicates the reuse of an ICE chassis and thus a modified or shared ICE platform (Exhibit 5). Likewise, the use of similar designs facilitates industrialization, since existing blueprints for processes and manufacturing technologies can be leveraged. Industrialization takes up a significant share of the product-development process, so this approach is essential for achieving short time to market.

In addition, we observed OEMs implementing a segment-focused design, focusing on existing concepts and manufacturing technologies, and using off-the-shelf components. These allow for reduced capex and rapid industrialization (Exhibit 6).

High modularization and outsourcing promote capex–efficient manufacturing. Once modularized, content can be pushed toward preassemblies and suppliers to increase the level of outsourcing, which permits a less complex mainline assembly process. In particular, we observed a high degree of assembly flexibility in three out of ten models: the e-drive and further power electronics (DC/DC-converter and onboard charger (OBC)) are preassembled on a subframe as one module. Moreover, the battery system can be built into the vehicle at any time

Exhibit 5

Body-in-white designs indicate the use of modified internal-combustion-engine (ICE) or shared platforms.

Most likely platform type from observation ■ Observed ■ Not observed

	Battery-electric-vehicle (BEV) native platform	Multipurpose shared platform					Modified ICE platform			
Indicators of ICE chassis reuse	Model 1	Model 2	Model 5	Model 6	Model 3	Model 9	Model 10	Model 4	Model 7	Model 8
Transmission tunnel at battery hold	Not observed	Not observed	Not observed	Not observed	Not observed	Not observed	Observed	Observed	Observed	Observed
Floor shape characterized by ICE components	Not observed	Observed	Observed	Observed	Not observed	Observed	Observed	Observed	Observed	Observed
Battery shape adapted to the layout of body-in-white	Not observed	Not observed	Not observed	Not observed	Not observed	Not observed	Observed	Observed	Observed	Observed
Lower **battery position** at side without body-in-white protection	Not observed	Observed	Observed	Observed	Observed	Observed	Observed	Observed	Observed	Observed

Source: McKinsey analysis

Exhibit 6

Many players use preexisting steel body-in-white, so the share of lightweight components is low.

Type of body-in-white		**Descriptions**
State-of-the-art aluminum body	Model 1	Full aluminum body with mostly nonthermal joining methods as well as usage of carbon-fiber reinforced polymer parts in trunk of vehicle
Modern steel body	Model 2, 5, 6	Fully automated body-in-white with aluminum share in closures and usage of, eg, high-strength steel for improved crash performance and reduced weight
Steel body optimized	Model 7, 8, 10	Full-steel body with mostly traditional joining methods (weld spots), but usage of optimized material concept (eg, hot-formed steel)
Traditional full steel body	Model 3, 4 9	Simple steel body using manual welding operations (especially in low-capacity lines)

Source: McKinsey analysis

Exhibit 7

The ten benchmarked battery electric vehicles used a variety of assembly-modularization approaches.

■ Modularized ■ Partially modularized ■ Individual component level

<table>
<tr><th>We see different archetypes of assembly modularization</th><th></th><th>E-drive (including axle)</th><th>Power electronics</th><th>Battery</th><th>High-voltage harness and tubing</th></tr>
<tr><td>Type 1
The front-axle integrator
Widely spread modularization across key car components to simplify main-line assembly</td><td>Model 4, 8, 10</td><td colspan="2">Preassembled module (on subframe)</td><td rowspan="2">Fully independent module (flexible integration throughout assembly process/ late integration possible)</td><td>Preassembled to main line with various connectors</td></tr>
<tr><td>Type 2
The electronics integrator
Modularization of different electronics components</td><td>Model 1, 2, 5, 7</td><td rowspan="2">Self-supporting axle with simplified assembly rack; additional components assembled separately</td><td>Integrated module (eg, 1-box design)</td><td>Fully preassembled complete electronic module, 1-connector assembly in main line</td></tr>
<tr><td>Type 3
The component assembler
Low level of modularization; complex assembly resulting in high capital and operating expenditures</td><td>Model 3, 6, 9</td><td>Single-component assembly</td><td>Early integration in assembly main line required</td><td>Individually assembled on main line</td></tr>
</table>

Source: McKinsey analysis

during assembly, providing for late integration and making assembly more flexible (Exhibit 7). This, in turn, further reduces capex demand.

Regarding fast industrialization, the current supplier ecosystem speeds up time to market. China's long-established expertise in electric machine production, semiconductors, electronics, and, especially, batteries makes it possible for local companies to supply all components of the e-powertrain (Exhibit 8). Depending on the level of vertical integration, OEMs source 45 to 100 percent of e-powertrain components from local suppliers.

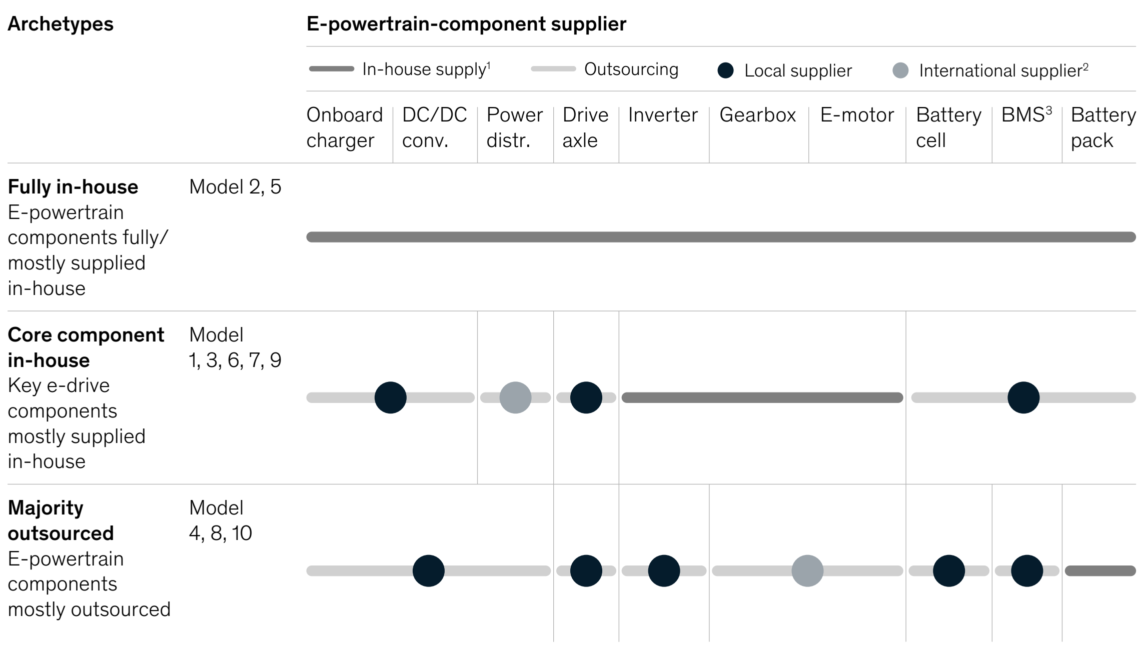
However, in the broader context—providing production equipment and setting up manufacturing lines—global players remain involved. The know-how of Western manufacturing-equipment OEMs enables Chinese suppliers to deliver the quality needed for the entire value chain, in paint shops, for example.

3. Substantial variety in design and technology remains—the game is far from decided

Local OEMs have demonstrated a position of strength in the Chinese BEV market, but a deeper look at the technology reveals that substantial differences across OEMs remain. Variations in three aspects of vehicles will influence the development of next-generation BEVs and may provide an opportunity for others to gain a foothold in the market.

Exhibit 8

Chinese OEMs rely heavily on local suppliers, with three archetypes of module integration.



[1] By OEM internally or by JV/subsidiaries supplier of OEM.
[2] Including joint ventures with international suppliers.
[3] Battery-management system.

Source: McKinsey analysis

E-powertrain. The benchmark revealed a large variety of concepts throughout the e-powertrain, such as the battery layout, the thermal management design and routing, and drivetrain-module integration. Our 3-D models show that half of the benchmarked models use grid and row layouts for the battery pack, increasing the utilization of space and, potentially, lowering module-production costs thanks to a lower level of packing variety than multiple-sized battery modules would require (Exhibit 9).

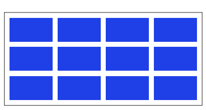
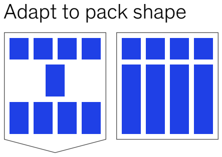
In addition, the degree of physical integration varies. Only three models show a high level of it: electric components and the e-drive are physically integrated, and the thermal management spans all components. Two models show the same level of physical integration, but the thermal management is separate for the e-drive and for the battery. The remaining models use less integrated components: separate electric modules and separate thermal management. Of these, three models use passive air cooling, which limits the charging speed when compared with the other models, which use liquid cooling of the battery (Exhibit 10).

E/E architecture. The benchmark shows that the weight of low-voltage wiring and harnesses differs among models with similar functionalities. That suggests significant design and cost-improvement opportunities in the E/E architecture. Similarly, OEMs of the benchmarked BEVs chose different ADAS[9] functionalities, use different designs for the electronic control unit (ECU) integration,

[9] Advanced driver-assistance system.

Exhibit 9

There are three designs for battery-pack module layouts, with implications for pack-space utilization and module packaging.

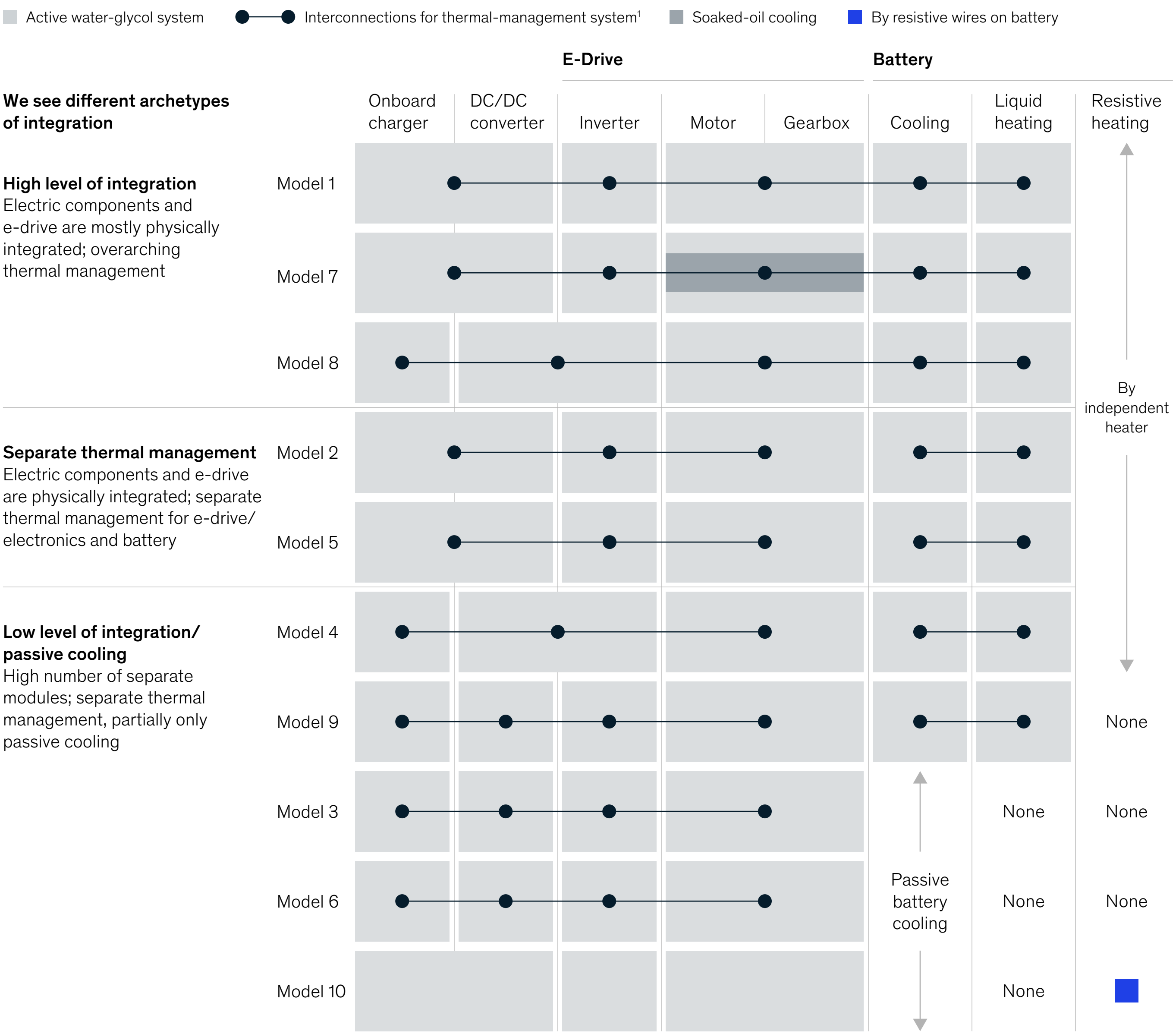
Module layout	Description	Test vehicles	Examples
Grid 	Identical sized and shaped module Layout in equally spaced grids	Model 1, 3, 9	Model 1 
Row 	Mostly identically sized and shaped modules Layout in equally spaced row	Model 2, 5	Model 5 
Adapt to pack shape 	Mostly multiple-sized and -shaped modules Arranged according to pack shape/varied module distance	Model 4, 6, 7, 8, 10	Model 7 

Source: McKinsey analysis

Exhibit 10

As with Western battery electric vehicles, there is no convergent powertrain design among Chinese BEVs—yet.

Comparison of powertrain and thermal management design



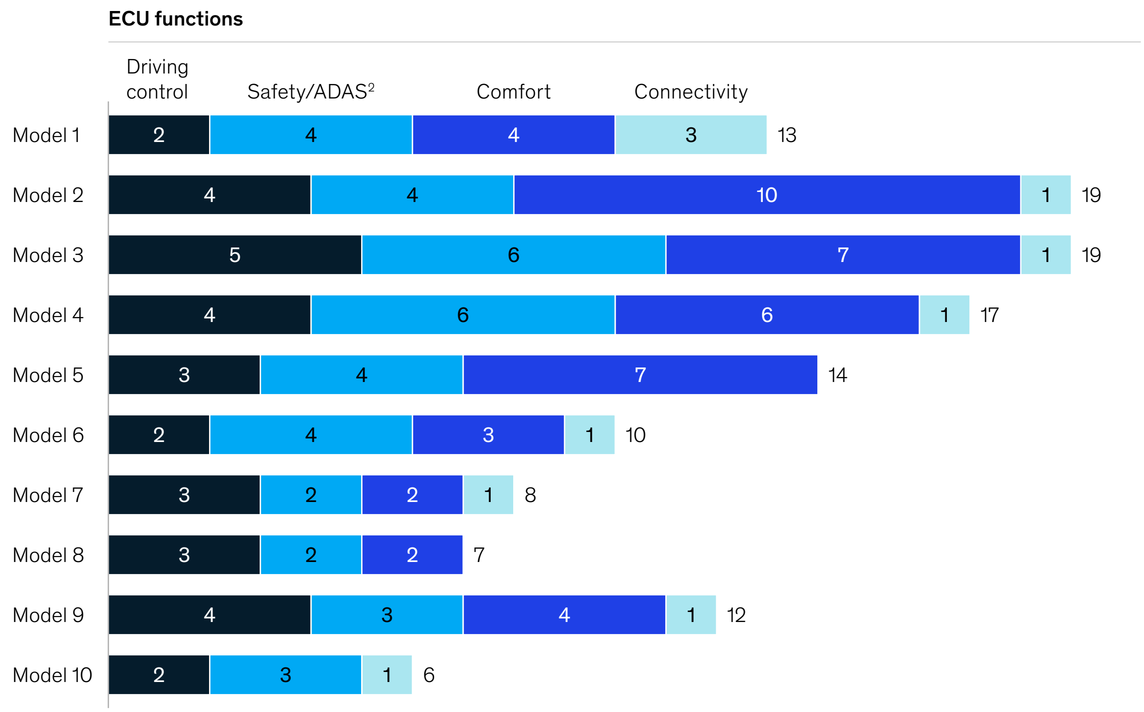
[1] Direct cooling jacket/pipeline/evaporator/heat exchanger connection.

Source: McKinsey analysis

Exhibit 11

Electronic-control-unit (ECU) usage is roughly correlated with design features, and some OEMs integrate ECUs in more sophisticated ways.

Low-voltage (LV) ECU function distribution, number of ECUs[1]



[1] ECUs of high-voltage system and chassis excluded.
[2] Advanced driver-assistance systems.
Source: McKinsey analysis

and differ in the number of ECUs used. The benchmarked BEVs have six to 19 decentralized ECUs (Exhibit 11). One potential direction would be to integrate all functions in one vehicle controller, as a BEV player in the United States does. That might increase performance at a relatively low cost but calls for substantial R&D investments and advanced internal software-development capabilities.

Trim packages. Chinese BEVs offer two to four trim packages on top of the base model. That reduces complexity and costs compared with the larger portfolio of options common among Western OEMs.

Seven out of ten benchmarked models therefore have a price spread of less than 50 percent between the base models and the fully loaded ones (Exhibit 12). Five out of ten offer battery or motor upgrades independent of the trim package, and three offer priced exterior options, such as color and wheels. Consequently, there might be untapped revenue potential in pricing strategies or non-hardware revenues, such as over-the-air software updates. Overall, global automotive OEMs may use our findings as a signal to simplify their portfolios or as a point of differentiation, especially when they think about entering the Chinese market.

4. Several strategies can help companies be successful in the market

Given the dynamic environment, succeeding in the Chinese BEV market presents significant uncertainties. Yet international OEMs and suppliers cannot afford to miss out on the Chinese BEV market in the long term, considering its sheer size and opportunities. In contrast, Chinese players will need to secure their dominant position and continue to focus on profitability.

The insights gained through the benchmark indicate several trends in the Chinese BEV market, each pointing to an associated strategic action or opportunity.

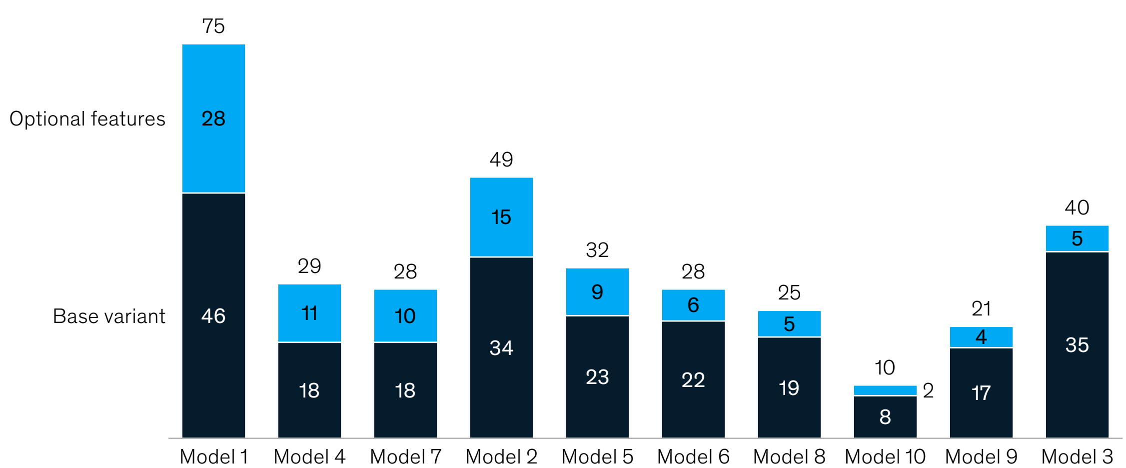
Development cycles are accelerating. To increase profitability and achieve a competitive advantage, OEMs are speeding up the development cycles of their BEVs. For current (and mostly first-generation) models, OEMs have cut time to market by reusing or modifying existing ICE platforms and relying on off-the-shelf components. But it is expected that for the next generation of BEVs, time to market will continue to fall as more OEMs develop dedicated BEV platforms and produce higher volumes. In addition to reducing time to market, the higher volumes will convey cost and design advantages.

The market composition will probably change. There are now around 80 BEV brands in China owned

Exhibit 12

Battery electric vehicles have a low price spread between the base and the fully loaded model.

Price of vehicle base variant and optional add-up, € thousand



	Model 1	Model 4	Model 7	Model 2	Model 5	Model 6	Model 8	Model 10	Model 9	Model 3
Additional price for fully loaded model compared with base variant	61%	61%	53%	44%	38%	30%	27%	27%	23%	15%

Source: McKinsey analysis

by about 50 companies. Of these, twelve are start-ups, with a market share of approximately 7 percent in 2019.[10] However, start-ups—especially if they haven't started production yet—will find that market conditions become increasingly unfavorable to them as a result of their cost structures. In particular, high fixed costs at low volumes burden these companies, so any start-up that cannot scale up quickly will disappear. By contrast, international OEMs will aim to capture additional market share, since they must extend their penetration of the BEV market to adhere to regulations, such as dual-credit policies.

E-powertrain technology will standardize. The observed technological variance in batteries, power electronics, E/E, and e-drives is expected to decline. The market will converge on just a few standardized designs, as happened with ICE powertrain designs. This presents a significant opportunity for suppliers that can deliver integrated platform solutions for the powertrain, especially if they have a competitive capex base through synergies and economies of scale.

Native BEV platforms will gain higher shares. The benchmark shows that Chinese OEMs have realized short time to market by using shared or modified ICE platforms. However, as noted earlier, we expect more OEMs to develop dedicated BEV platforms to satisfy demand—a trend that will reduce time to market while also conveying design and cost advantages. Moreover, it is expected that BEVs will increasingly be produced on dedicated production lines instead of (at present) flexible, shared ICE/BEV production lines.

Non-Chinese OEMs will need to leverage their assets, such as an exciting brand image, superior engineering expertise, and state-of-the-art production facilities, to differentiate themselves from their Chinese competitors. Simultaneously, they must simplify their portfolios to offer fewer but highly targeted and locally adapted options, supported by

International OEMs will aim to capture additional market share, since they must extend their penetration of the BEV market to adhere to regulations.

[10] Number of start-ups and their market share were derived from calculations using production data for electric vehicles from IHS Markit, Light Vehicle Powertrain Production Forecast, April 2020. Please note that while the production data are from IHS Markit, the classification into start-up and incumbent, as well as the calculation of the start-ups' market share, were developed by McKinsey and are neither associated with nor endorsed by IHS Markit.

Exhibit 13

Our insights give an idea about potential actions for players to drive winning battery-electric-vehicle design in China.

	International	Local
OEMs	Adapt a **customer-centric-design** philosophy and prioritize features and functions valued most by customers	Intensify **design-to-cost practices** to unlock potential cost savings
	Leverage assets—eg, brands, state-of-the-art production, and superior engineering; innovate using **design-to-cost** concept rigorously	Leverage **knowledge of consumer preferences** to differentiate offerings and to expand into **new revenue models**
	Reduce portfolio and adopt agile product development to **shorten time-to-market**	Solidify **brand image** to differentiate products from existing and new competition
	Expand into **new revenue models**—eg, software updates and maintenance	Further enhance **customer experience**
Suppliers	**Partner** with Chinese OEMs to advance engineering maturity and to help maximize cost savings	Select **long-term strategy** and develop **integrated solutions** for key modules
	Strive for **innovation leadership** in highly valued fields, potentially through strategic partnerships	**Broaden OEM customer** base and experiment with innovative business models

Source: McKinsey analysis

additional revenue streams through software and other technologies. In contrast, Chinese OEMs should continue to increase their profitability by focusing on cost savings while increasing their revenues through more differentiated offerings. Sophisticated pricing strategies and new revenue streams will be important.

For suppliers, partnerships will be crucial. Non-Chinese suppliers could leverage their engineering maturity to become leaders in innovation. Chinese suppliers might broaden their customer base by helping non-Chinese OEMs to gain a foothold in the market (Exhibit 13).

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