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Trends in electric-vehicle design

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What did we learn from a teardown and benchmarking of ten EV models?

Regulatory pressures on internal combustion engines (ICEs), combined with technological improvements in electric powertrains and batteries, are driving a surge of demand for electric vehicles (EVs). Most incumbent car manufacturers are rolling out models, joined by new entrants without ICE legacies. Worldwide sales of pure battery EVs (excluding hybrids) grew by approximately 45 percent in 2016.

With EVs becoming mass-market products, it is time for a detailed understanding of technology trends. In collaboration with A2Mac1, a provider of automotive benchmarking services, we conducted a large-scale benchmarking of first- and second-generation EV models, which included physically disassembling ten EV models: the 2011 Nissan LEAF, the 2013 Volkswagen e-up!, the 2013 Tesla Model S 60, the 2014 Chevrolet Spark, the 2014 BMW i3, the 2015 Volkswagen e-Golf, the 2015 BYD e6, the 2017 Nissan LEAF, the 2017 Chevrolet Bolt, and the 2017 Opel Ampera-e.

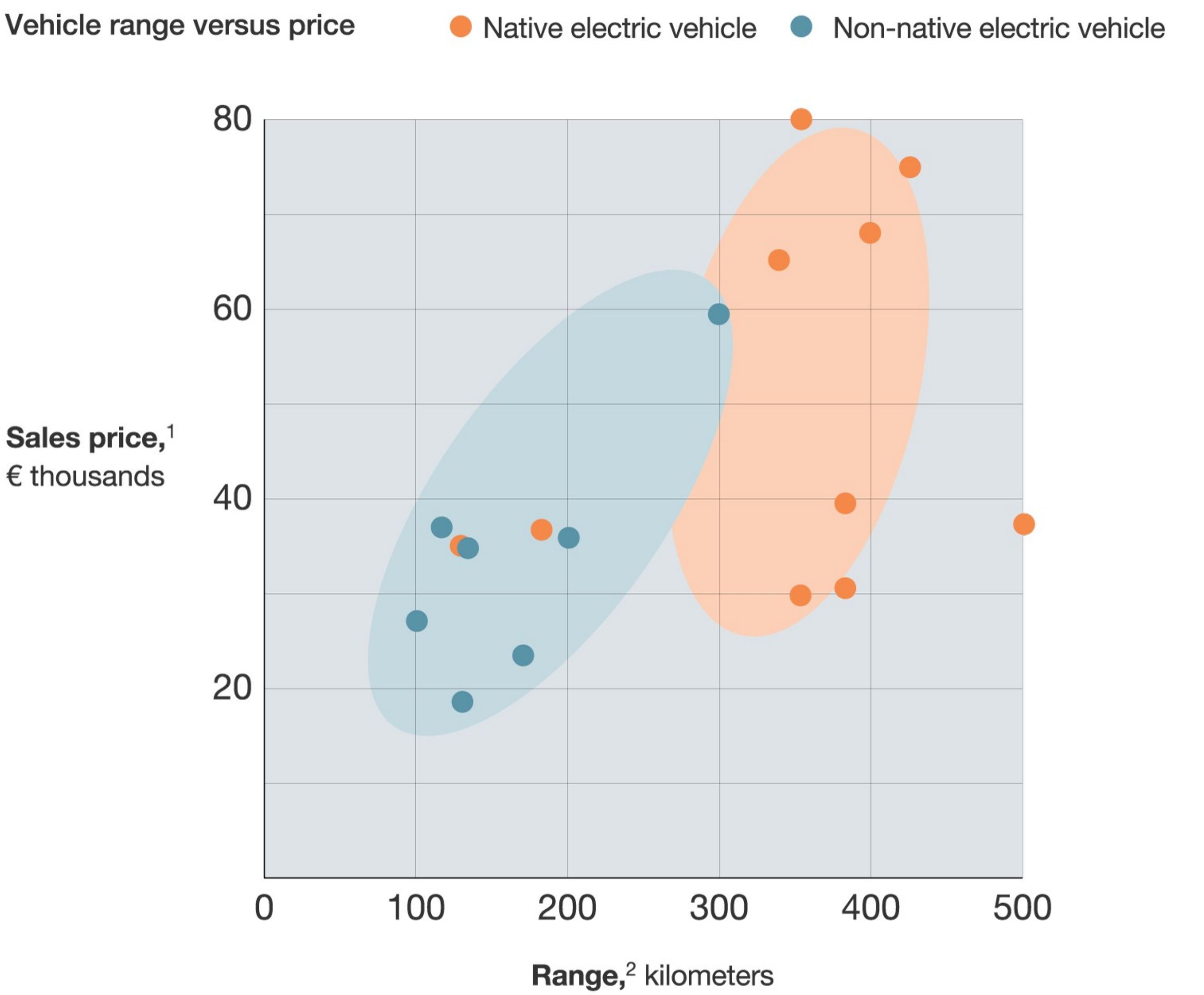
Together, these models account for about 40 percent of all pure-battery EVs ever produced. In addition to the ten torn-down vehicles, we analyzed publicly available information on additional vehicles and consulted independent subject-matter experts. The resulting analysis shows that successfully producing EVs requires radically different thinking. We identified five key insights:

Want a high-performing electric vehicle? Build a native platform

The benchmarking shows a clear gap in driving range and interior space between models with native EV platforms and those based on ICE. Native EVs optimize battery packaging; non-native EVs force the battery into the awkward footprint of the ICE platform, which limits the realized energy capacity. The native EV battery pack, by contrast, can take a simple, rectangular shape, giving native EVs up to twice the range—over 300 kilometers per charge and up to approximately 400 kilometers for the best performers, according to the Environmental Protection Agency—without forcing up the price (Exhibit 1). In addition, native EVs achieve a larger interior space (up to 10 percent by regression line) for the same wheelbase compared with not only non-native counterparts, but also standard ICE vehicles in the same segment.

Exhibit 1

Native electric-vehicle platforms offer range at competitive prices.



[1] Base price for German market (if German market price not available, US market price is converted to euros at €0.85 = $1).

[2] According to Environmental Protection Agency (EPA) data. If EPA range not available, OEM data used.

McKinsey&Company | Source: A2Mac1; McKinsey Center for Future Mobility

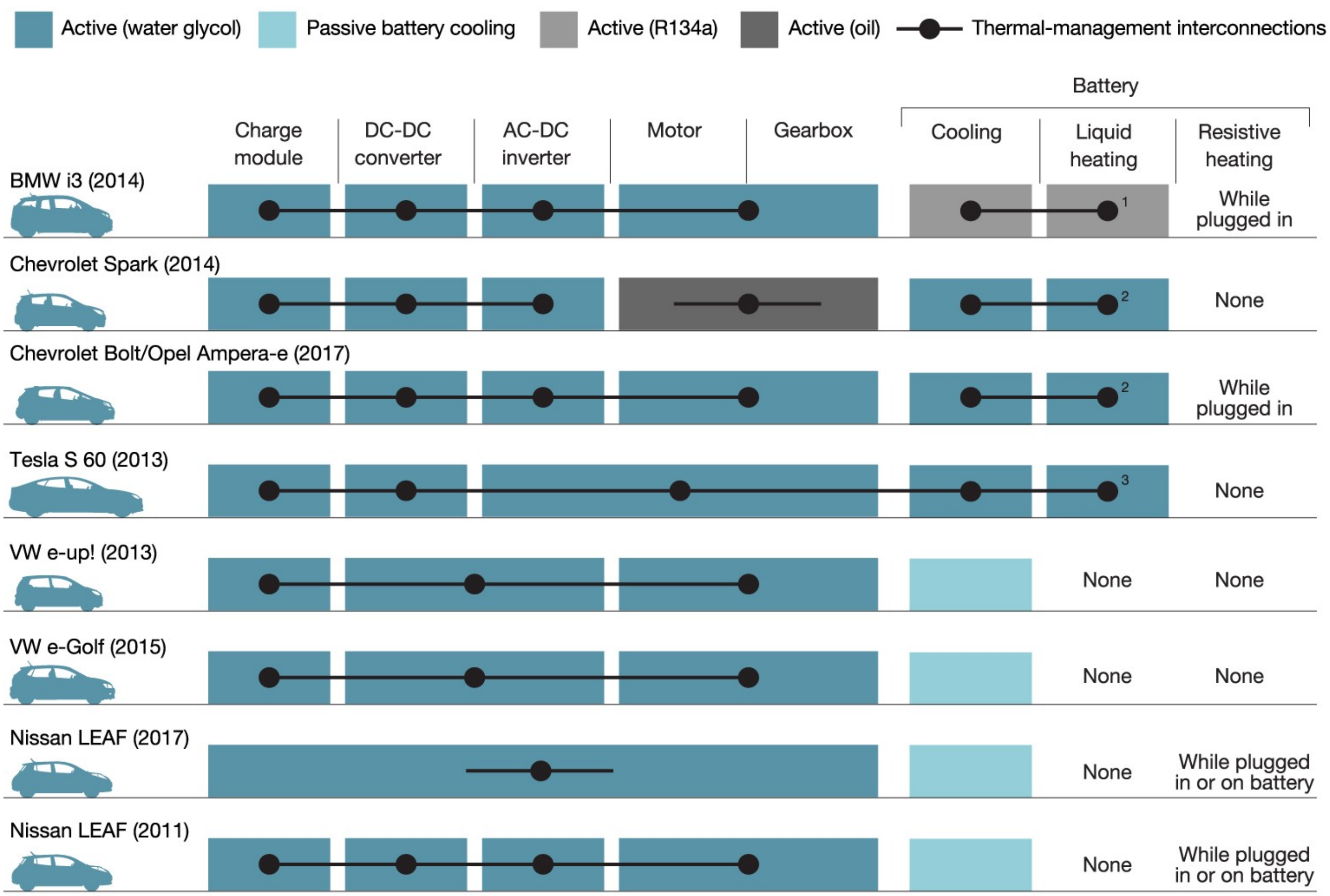
There’s no convergence yet on core EV powertrain design

The benchmarking included a teardown of the battery, the battery cells, and the thermal-management system. We found three battery-cell designs with different geometries (cylindrical, prismatic, and pouch), along with multiple chemistries. With each design having clear advantages and disadvantages, there is no winner on overall performance for mass-market EVs, as our benchmarking also revealed similar energy density increases of more than 30 percent over a period of seven years (2011 to 2018) across all designs. We also found a large variance in the design approach for thermal management with four battery-cooling solutions: passive (natural air cooling), active combined with powertrain, active but stand-alone dedicated to the battery, and active combined with the air-conditioning circuit. We also identified three archetypes of battery heating: none at all, waste heat from motor and power electronics or the AC system, and dedicated resistive heating integrated in the battery pack. Some dedicated resistive heating units use energy from the battery and work only when the vehicle is charging; others feature a combined liquid cooling/heating cycle using different heat sources, such as resistive heating outside the battery pack (Exhibit 2).

Exhibit 2

Design approaches to managing powertrain and battery thermal management vary widely.

Electric-vehicle manufacturers' powertrain and battery thermal management



[1] Combined heating/cooling with AC.
[2] Stand-alone battery heating/cooling.
[3] Combined heating/cooling with powertrain.

McKinsey&Company | Source: A2Mac1; McKinsey Center for Future Mobility

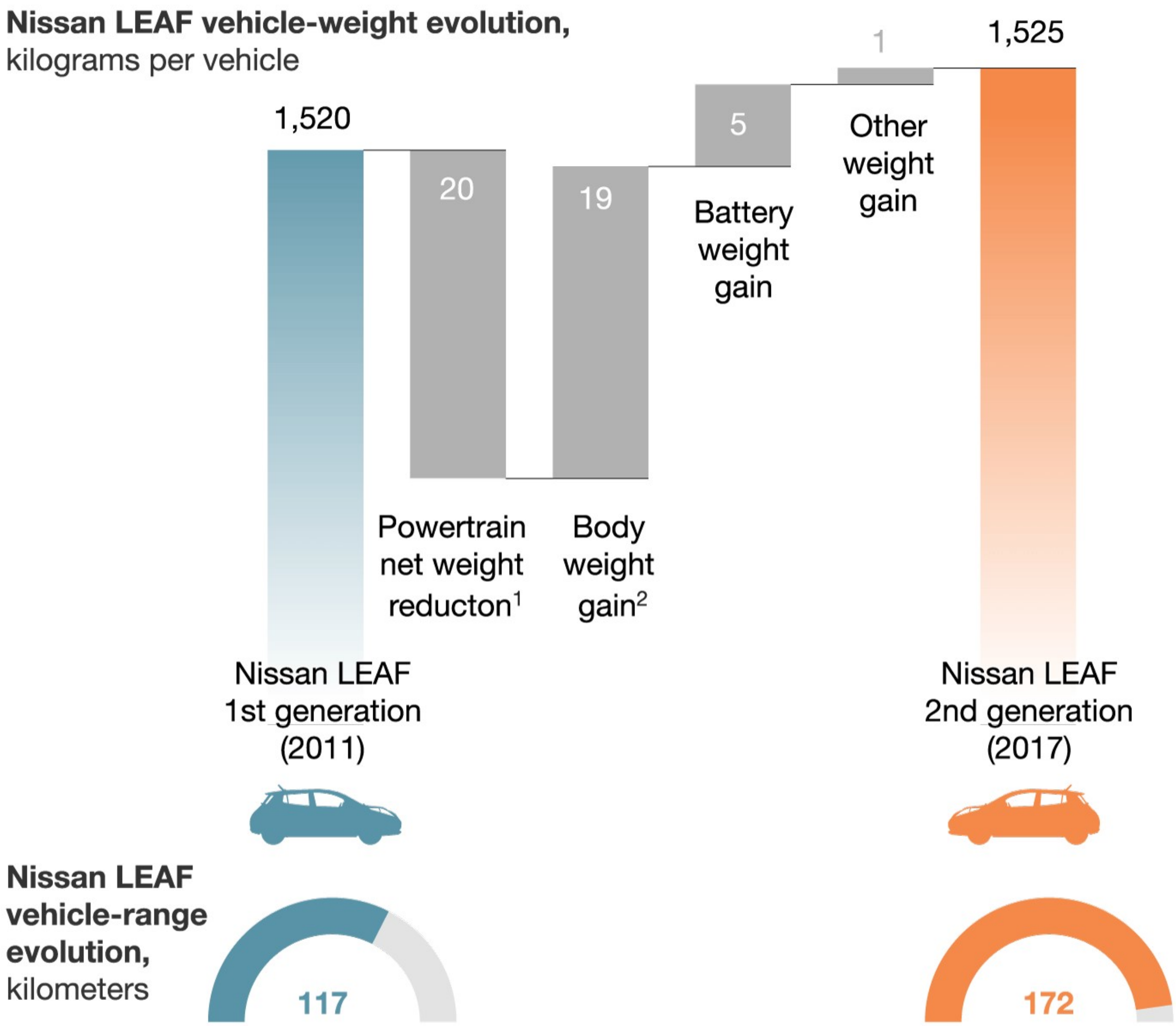
Taking the best performers on the market today, cylindrical cells have the highest energy density with approximately 245 watt-hours per kilogram (Wh/kg), followed by pouch cells with 195 Wh/kg—an astounding gap of approximately 25 percent. Prismatic cells have an energy density of approximately 160 Wh/kg. However, the required housing and thermal management evens up the score when looking at the net energy density of the battery pack: 132 Wh/ kg for cylindrical versus 138 Wh/kg for pouch and 104 Wh/kg for prismatic. As there is at present no convergence toward a unique technology or solution, OEMs will still need to invest in these areas to make optimal trade-offs on cost and performance in battery and thermal-management design.

Design to cost has already made its way into EVs

The benchmark reveals that OEMs have started consistently applying design to cost (DTC), in particular to the EVs' powertrain and body-in-white design, as the battle for performance and range has been won. This trend notably emerges in second-generation EVs. The DTC focus has been mostly on component integration in the powertrain area and smarter usage of lightweight materials in structural parts (Exhibit 3).

Exhibit 3

Design-to-cost efforts have focused on component integration and use of materials.



[1] Powertrain is motor, transmission system, and related electronics. Weight reduced through integration of powertrain components (inverter, converter, charger, and motor).
[2] Body weight gain from material change on doors from aluminum to steel.

McKinsey&Company | Source: A2Mac1; McKinsey Center for Future Mobility

Regarding weight, we analyzed major structural components of all ten vehicles to estimate their use of aluminum and composites. Some of the second-generation mass-market EVs use aluminum equal to only 5 to 10 percent of the total vehicle weight on these components, close to the average ICE (approximately 5 percent). In luxury EVs, aluminum accounts for about 40 percent of vehicle weight, mainly to boost acceleration and dynamic performance. Mass-market EVs will continue to converge toward the lower ICE mass-market share of lightweight for three reasons:

- Generational leaps in powertrain technology yield significant weight reductions, which are then directly reinvested into lower-cost structural materials.
- At today's manufacturing cost, batteries, not lightweight materials, are the key to longer ranges.
- EVs lack external incentives for (expensive) weight-reduction measures, which is different from ICEs with their carbon dioxide targets and penalties.

Regarding forthcoming models, the DTC trend will likely continue.

The EV is a radically different vehicle—and it needs a radically different offering logic

Automotive OEMs will have to reconceive their business model to create new income and profit streams for EVs. Today, they rely heavily on customers upgrading the base vehicle with additional engine, transmission, comfort, and safety features, as well as on aftermarket parts and services to boost profitability (and to reach their cost of capital). EVs cost far less to maintain and are far more constrained on options for two reasons (Exhibit 4):

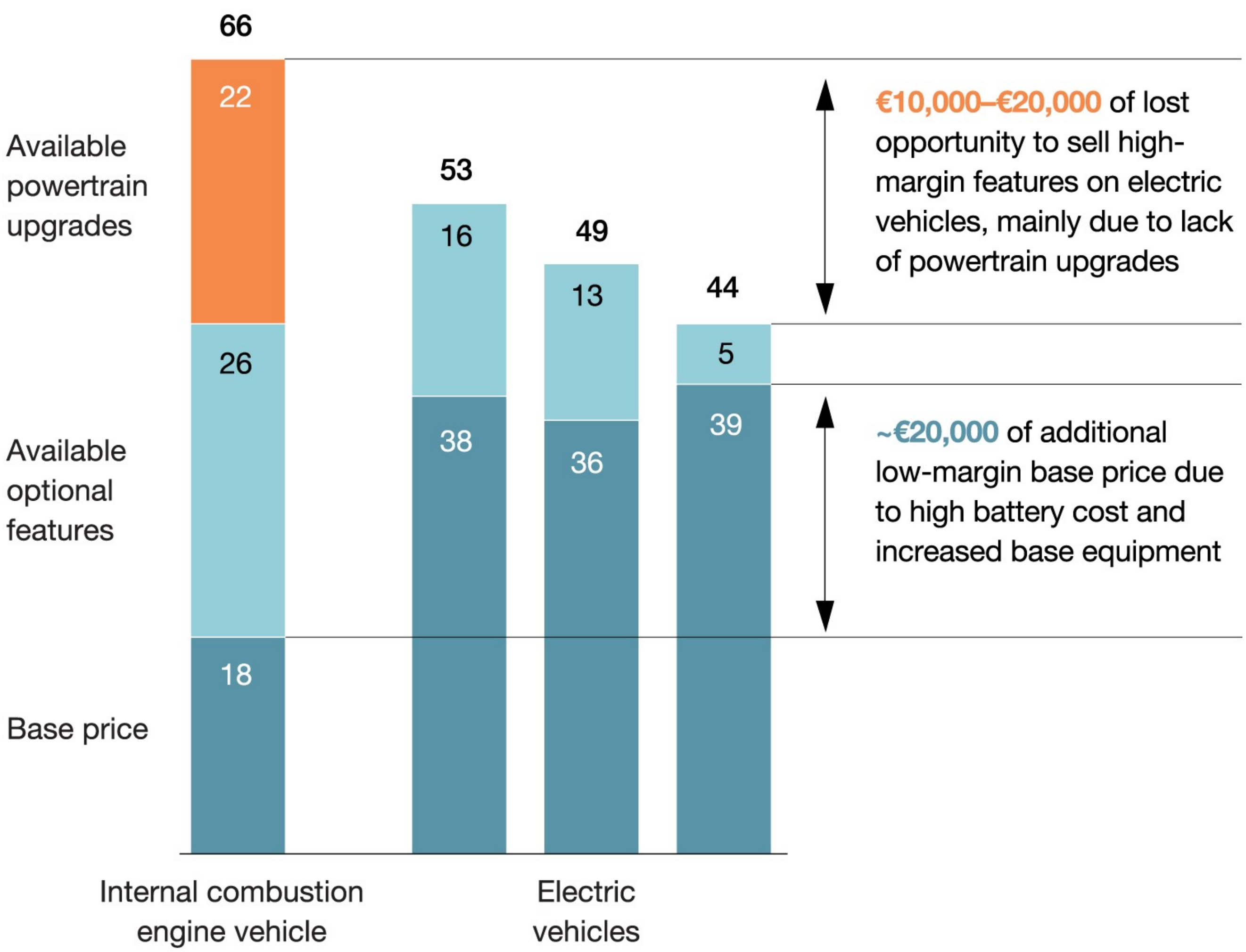
- There is little room for differentiation by performance. Current EVs already offer acceleration comparable to high-specification ICEs in the same segment. Thus, today they offer no more than four combinations of engine and transmission types, compared with the typical 10 to 20 ICE combinations.

- Base EV configurations already contain many options. The high base price of EVs, driven by the cost of the battery, compels OEMs to include more options in the base configuration of an EV than in a comparable ICE, thus losing a high-margin income stream.

Exhibit 4

Carmakers need to overhaul their offering logic for electric vehicles.

Examples of sales prices in German market,[1] € thousands



[1] Excluding external incentives (eg, German Umweltprämie).

McKinsey&Company | Source: A2Mac1; McKinsey Center for Future Mobility

Growing supplier offer on major new EV

components heavily competes with in-house strategies

- EV powertrains are markedly different from their ICE equivalents in necessary competencies, value add, and component complexity. The growth in EV sales therefore threatens the competitive position and market shares of both OEMs and their ICE-powertrain suppliers.
- Using the supplier logos imprinted on torn-down components in combination with publicly available information, we derived an outside-in view on the OEMs' EV-powertrain supply chain. OEMs follow a wide range of strategies when sourcing powertrain components, from almost full vertical integration to nearly full outsourcing. When components are outsourced, the degree of design ownership varies (Exhibit 5).

Exhibit 5

Original equipment manufacturers follow varying powertrain and battery supply-chain strategies for electric vehicles.

Electric-vehicle manufacturers' battery supply-chain strategies

Make Buy

	Battery cell	Battery pack	Battery management system	Power electronics[1]	Motor	Transmission[2]
BYD E6 (2015)						Not available
Tesla S 60 (2013)	Panasonic					Borg-Warner[4]
BMW i3 (2014)	Samsung		Preh			
VW e-Golf (2015)	Panasonic		Panasonic[3]	Bosch		
Chevrolet Spark (2014)	A123		A123			Not available
VW e-up! (2013)	Panasonic		Panasonic[3]	Bosch		
Nissan LEAF (2011)	AESC	AESC	Calsonic Kansei	Calsonic Kansei/Denso		Aichi
Nissan LEAF (2017)	AESC	AESC	Calsonic Kansei	Calsonic Kansei/Denso		Aichi
Chevrolet Bolt/Opel Ampera-e (2017)	LG	LG	LG	LG	LG	LG

[1] DC-DC converter and AC-DC inverter.
[2] Only single-speed transmission.

Given the lower complexity and lower potential for differentiation of most EV-powertrain components, we expect OEMs to outsource a larger share of these components in the future as soon as the design converges to full commodity.

At the same time, we see significant risks for established OEMs and tier-one suppliers. Some tier-one suppliers are already offering a significant share of components outside their original core area. Also, given that EVs are less complex than ICE powertrains, there's greater risk for established OEMs that have strongly differentiated themselves through driving performance. Already, two of today's top five EV manufacturers are new entrants to the EV market: Tesla and BYD.

As demand rises, EV technology and design will continue to evolve, and strategic challenges will follow. Established OEMs and their traditional suppliers will need to rethink their approaches to preserve their revenue and profitability.

About the author(s)

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