STUDY

E-mobility Index 2018

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1. Key takeaways from the E-mobility Index for 2018

> China remains in pole position in the E-mobility Index for 2018. Though France is out in front in terms of technology, China continues to lead the pack in terms of industry and market dynamics (Fig. 2)

> China underscores its lead with strong projected growth in vehicle and battery cell production

> Owing to the strong growth forecasts and prevailing conditions on the market, cell manufacturers will be doing more to secure their raw material supplies and invest in the upstream value chain

> The leading cell manufacturers are thus likely to see their dominant role expand and their negotiating position with OEMs improve

> OEMs therefore have a choice of two strategic options to reverse their growing dependency on cell manufacturers:
  – They can develop long-term close partnerships with players along the supply chain with agreed base volumes complemented by quickly scalable in-house production
  – They can help develop a strong supplier landscape in battery modules with OEMs sourcing consistently from a large number of cell manufacturers on the market

2. Summary comparison of the competitive positions of the world's seven leading automotive nations

There has been a slight change in the competitive positions of the seven leading automotive nations since the last index (Fig. 1, Fig. 2). China retained its overall lead but is now sharing top spot with the United States. Japan edged past Germany into third place with growth in the industry and market indicators.

France is the technology leader

France has defended its lead in terms of technology. French OEMs have expanded their relatively narrow product range with a number of plug-in hybrid electric vehicles (PHEVs) but continue to focus mainly on small, low-cost electric vehicles (BEVs) that offer good value for money. The portfolios of German car manufacturers are reflecting a shift toward PHEV and battery-electric sports utility vehicles (SUVs) with a longer range. This is causing the technological capability of the analyzed vehicles to recede slightly. Germany has therefore lost ground somewhat compared to last year but is still able to defend its second spot in the technology field. Announcements and high number of planned launches of new xEV by German OEMs in the near future lead to an expected increase in the indicator technology in the upcoming assessments.

Korean OEMs have brought more and more new models offering good value for money onto the market in recent years, a fact which is now being reflected in their end customer business and sees Korea climb the rankings (Fig. 4). Korea thus edges past Japan in terms of technology and now sits in third place. Japanese OEMs are adding new models with higher battery capacities to their existing ranges. PHEVs are also expected to make up a bigger share of Japanese production volumes, which brings the technological capability of the electrified vehicles down somewhat. That is primarily because the whole concept of plug-in vehicles gives them a smaller electric range and a lower electrical top speed. Given their lower battery capacity, most of them also are equipped with basic charging technology.

US automakers have caught up with Japan thanks to a slight improvement in the technological capability owing to a focus on fully electrified vehicles in the mid-size segment predominantly. While these vehicles have taken some time to find their way into dealers' showrooms, they have seen a rapid increase in significance in terms of American OEMs' production volumes over the past year.

Government support for research and development in the field of e-mobility are declining. Some countries have seen a reduction in funding. Government R&D programs are reaching the end of their term and are currently not being replaced by new financial undertakings, or where they are, the scope is much narrower. This is particularly apparent in China (Fig. 5). France continues to enjoy the highest amount of funding as a percentage of gross domestic product, which explains its technology leadership. China, on the other hand, has lost out here and fallen down the rankings to one place above Italy.

Industry – China in the lead, Korea catching up

China has defended its lead in industry terms on the back of continued strong growth and a high prospective level of vehicle and cell production. The United States follows in second place, having seen high growth rates of around 100 percent in production volumes for xEVs (battery and plug-in hybrid vehicles), as have German OEMs (Fig. 6). Overall, however, Germany's current lack of cell production keeps the country down in fifth spot in the industry rankings, behind Japan and Korea. Japan makes it up to third place but is overtaken by Korea in terms of its national share in global cell production (Fig. 7).

The considerably expanded range of models now being offered by Korean OEMs has again led to some very high growth rates, with vehicle production volumes rising 400 percent. In absolute figures, Korea is ahead of France but still behind Japan. Italy brings up the rear with no significant increase in production anticipated. China can be expected to maintain its overall lead in the coming years based on the legislative and regulatory changes that have come into force in the past 18 months. These include:

> White-listing of foreign cell manufacturers in China, incl. SKI, SDI and LGC (published by CAAM on April 26, 2018)

> The Vehicle Traction Battery Industrial Development Action Plan set the industrial target at 300 Wh/kg at cell level; cost to be under CNY 1/Wh (EUR 133/kWh) and 3C (dis)charging rates to be reached by 2020 (launched by the Ministry of Industry and Information Technology (MIIT) on February 20, 2017). As consequence, lower-tech battery cell manufacturers are likely to be forced out of the market

> The Standard Conditions for the Automobile Power Storage Battery Industry require new battery cell manufacturers to have a minimum of 8 GWh/a cell capacity in order to enter the market, and pack manufacturers need to offer >80k units/a or >4 GWh/a (issued by MIIT in late 2016)

> Cancelation of JV requirements for special purpose vehicles and xEV cars by 2018, for commercial vehicles by 2020 and for passenger cars by 2022 (released by the Chinese National Development and Reform Commission on April 17, 2018)

Markets growing across the board

In terms of the **market** development, sales figures for battery and plug-in hybrid electric vehicles are on a very positive trajectory in all countries. Sales volumes in China are about 70 percent up on the previous year. The share of partially or fully electrified vehicles in all new Chinese registrations exceeded the two percent mark in 2017 – the first time any country surpassed that level.

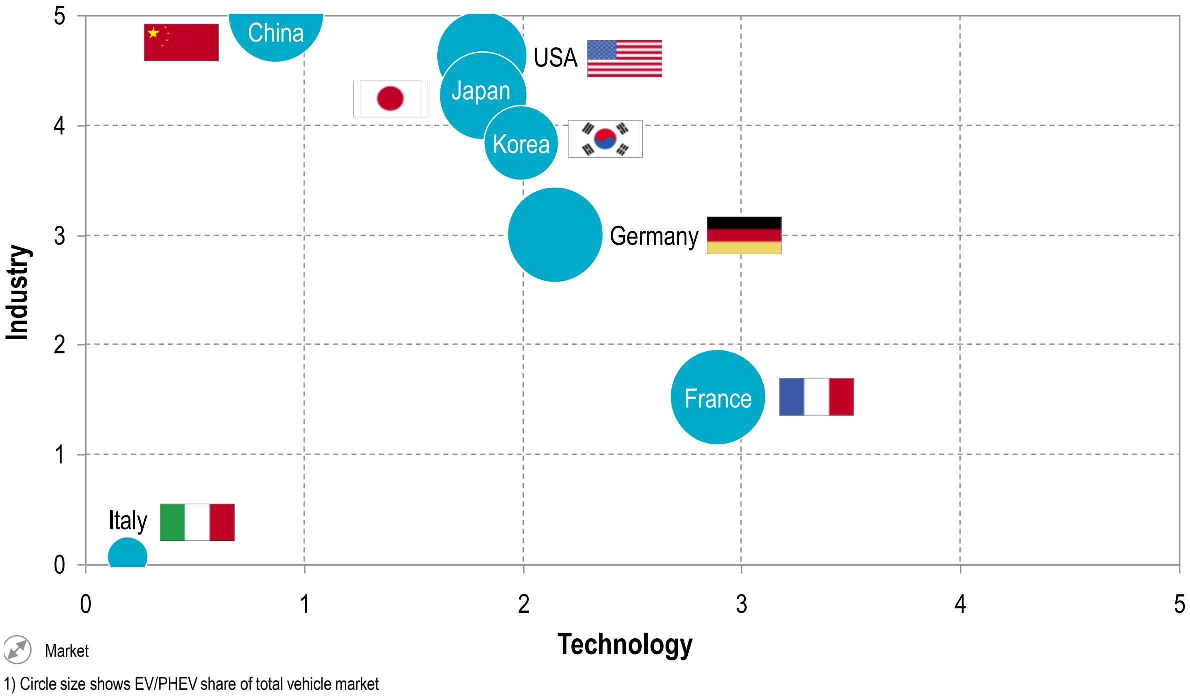
Demand is up more than 90 percent in Germany, where some 1.5 percent of all newly registered vehicles are BEV and PHEV. This puts Germany in third place behind France, which has lower absolute volumes but a slightly higher market share. Sales in France are growing somewhat more moderately, though, up about one-quarter year-on-year, the same as fourth-placed USA.

After a period of stagnation in 2016, the Japanese market is now picking up dramatically and recording high growth. Like Japan, Korea is also experiencing triple-digit growth rates, but with xEVs still accounting for less than one percent of the market, Korea is languishing in sixth place. Italy is still waiting for its market to achieve any significant level of growth, partly due to the lack of electric models offered by home-grown OEMs, the share of xEVs in its new vehicle registrations being 0.25 percent in 2017 (Fig. 8).

Figure 3 illustrates the development of all three indicators over time.

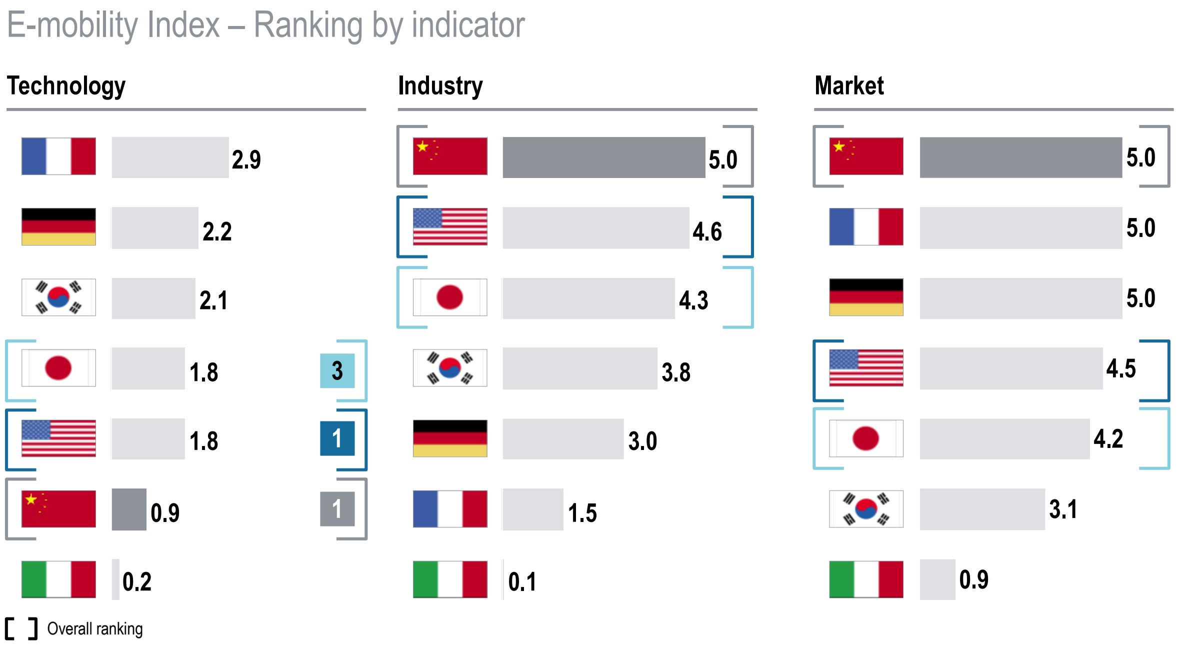
Fig. 1: The US consolidates its joint lead with China – Japan edges past Germany into third

E-mobility Index 2018



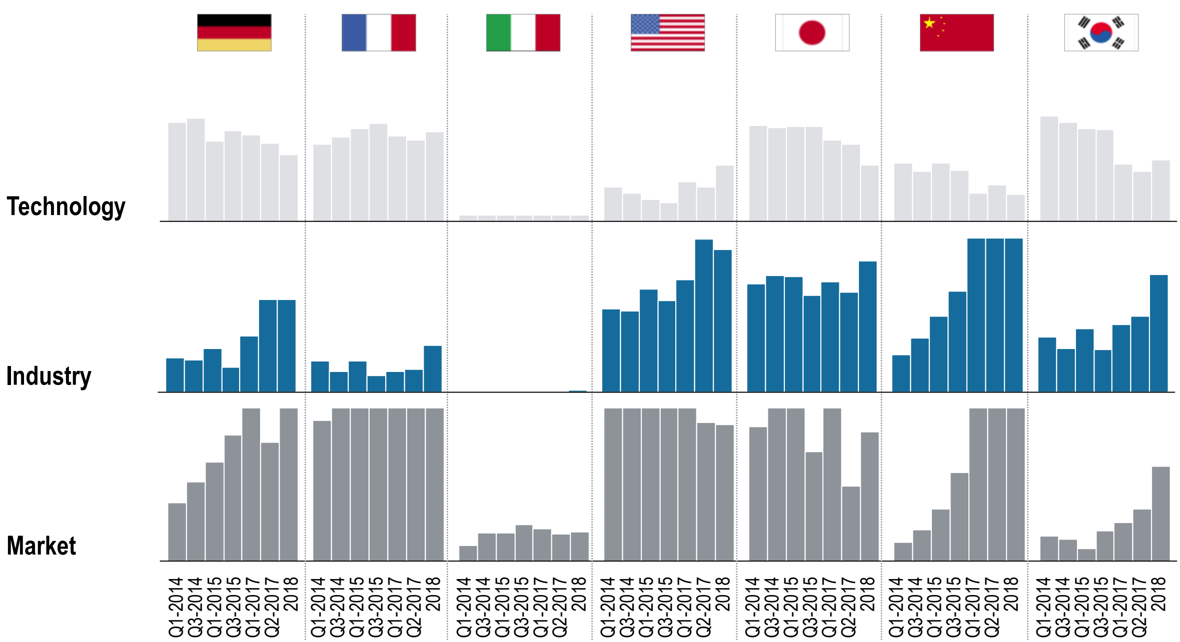
Source: fka; Roland Berger

Fig. 2: China's strong industry puts it slightly ahead of the US - France has a marginal lead on technology



Source: fka; Roland Berger

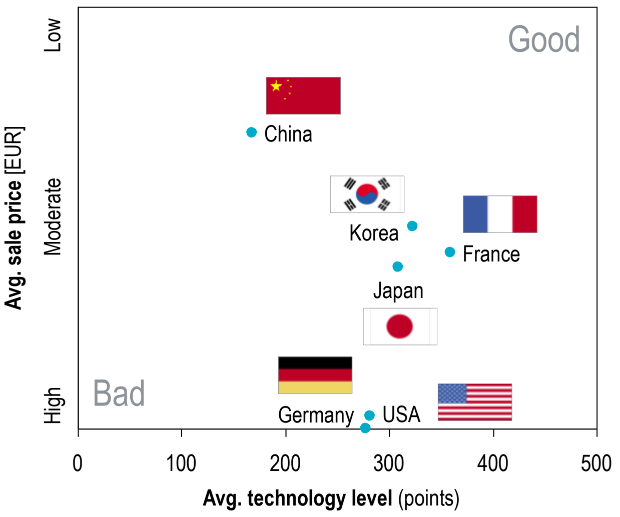
Fig. 3: Changes in competitive positions of leading automotive nations by indicator



Source: fka; Roland Berger

Fig. 4: Value for money increased markedly in Korea, price level up in France – High-priced models remain relevant in Germany and US

Value for money of market-ready BEVs and PHEVs



Note: Italian OEMs have no mass-produced EV/PHEV models

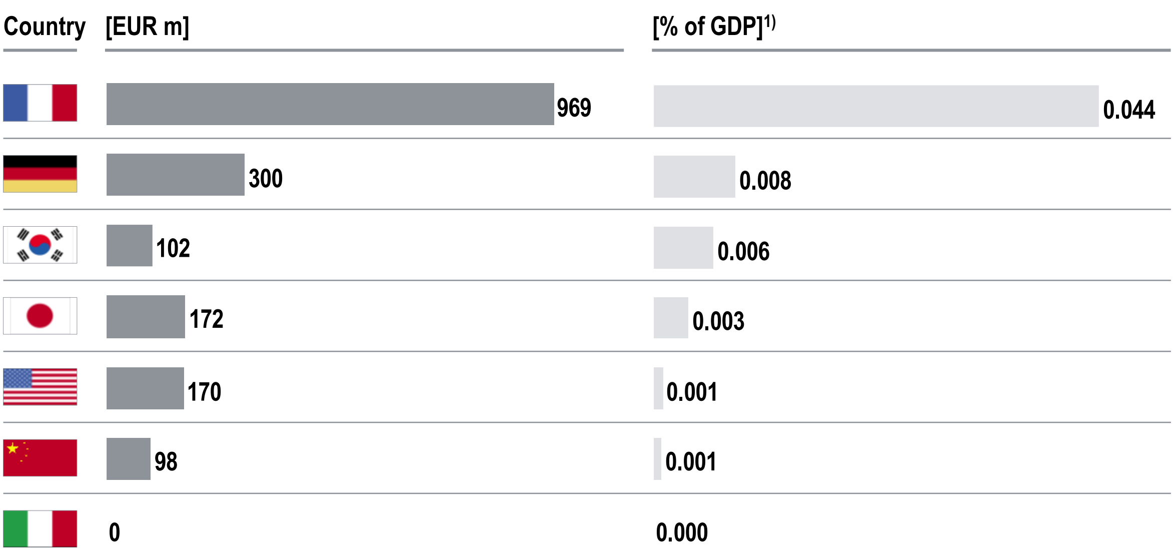
Country

- > Expansion of PHEV and FCEV offering resulted in reduced dominance of compact BEVs and a slight reduction in cost effectiveness
- > High-priced vehicles remain very relevant
- > Compact models being introduced; the Tesla Model 3 is the key model of the future
- > Ongoing trend toward electrification (PHEV) in the executive and mid-range segments
- > Rising number of high-priced models
- > Slight improvement in technology level combined with reduced price level in the car parc
- > Focus on BEVs, growing model mix
- > Improvement in technology level with concurrent improvement in price level
- > Korea overtakes Japan with improved cost effectiveness owing to expansion of model portfolio

Source: fka; Roland Berger

Fig. 5: R&D subsidies are falling in most automotive nations, especially in China – France has the biggest subsidies

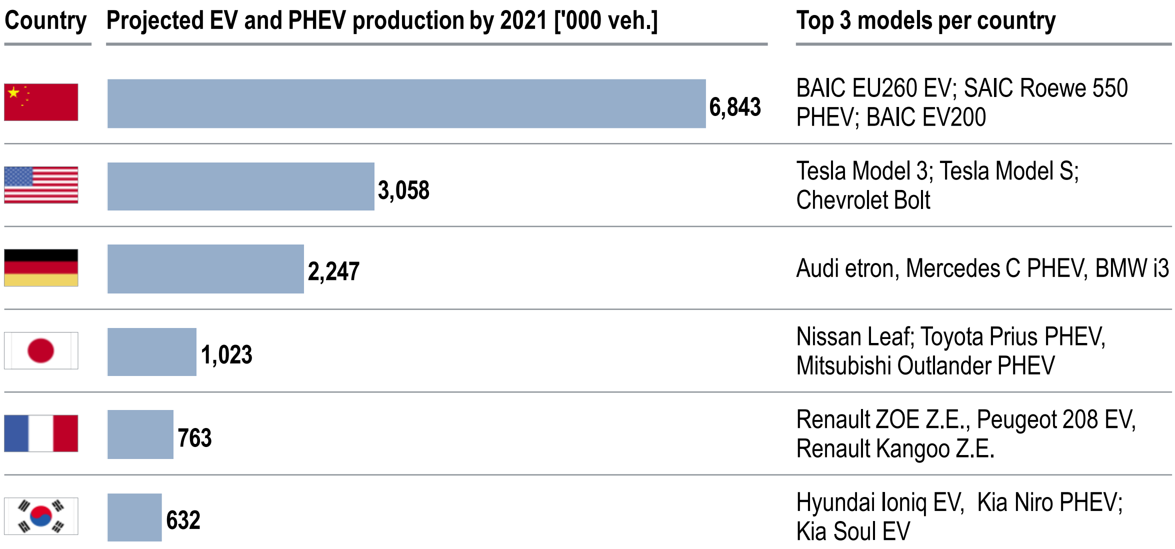
State R&D funding for e-mobility



1) Subsidies expressed as a proportion of current GDP (2017)

Source: fka; Roland Berger

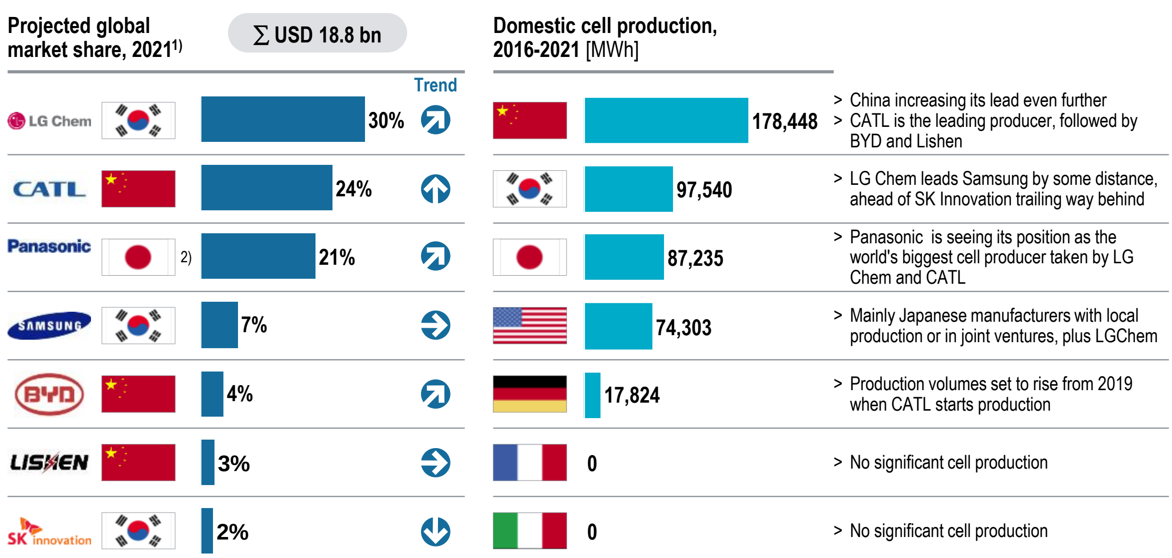
Fig. 6: China retains a clear lead in EV/PHEV production – The US defends its second place, Germany makes up some ground



Note: No significant EV/PHEV production is expected in Italy

Source: fka; Roland Berger

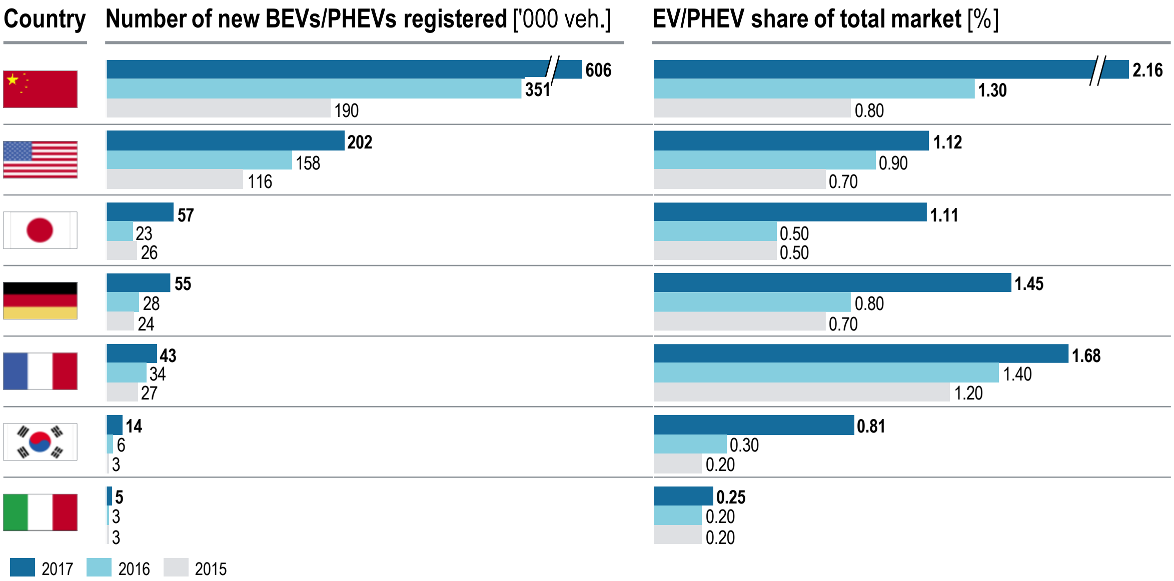
Fig. 7: China establishes itself as the frontrunner in battery production – Korea overtakes Japan on the back of strong growth



1) 2021 market value in USD calculated as follows: USD 140/kWh for PHEV and USD 105/kWh for EV; shift from single to dual sourcing strategies expected in the mid term
2) Including Primearth's market share

Source: fka; Roland Berger

Fig. 8: China continues to experience strong growth in EV sales and is a clear lead market for electrified vehicles – All markets growing



Source: fka; Roland Berger

3. Detailed analysis

3.1 Full vehicle benchmarking to analyze key performance attributes

Benchmarking is rapidly gaining importance given the dynamic pace of advancements in e-mobility. The industry's ever-shorter development cycles and rising numbers of new models being released make it difficult for many OEMs and suppliers to position their products in the market. A combination of functional benchmarking and design benchmarking can answer key questions for both OEMs and their suppliers, with the details differing substantially between the two groups. Whereas the vehicle manufacturers' interests generally lie on the system or technology level, their suppliers focus on the various solutions on a subsystem, subassembly and component level.

Drivetrain and energy storage as key components

Functional benchmarking focuses on detailed analyses of functions in areas such as the powertrain, electrics/electronics or advanced driver assistance systems and chassis. The drivetrain and energy storage are the key components that determine the capability of electrified vehicles as against others. That's why it is important to analyze energy consumption and examine the efficiency of the e-powertrain and identify the detailed characteristics of the battery pack.

Functional benchmarking highlights, for example, major variation in efficiency levels between different power electronics subassemblies, with efficiencies ranging between 90 and 98 percent. This has an effect on the vehicle's overall efficiency. The functional analyses can be carried out ahead of a design benchmarking exercise to analyze the construction of all individual parts and calculate the balance of weight. Design benchmarking involves disassembling the whole vehicle and analyzing all relevant systems and components in detail. The resulting single parts are analyzed regarding their design, weight, dimensions and material usage as well as their position in the vehicle and the joining technologies used.

The problem of battery weight

The results of a benchmark analysis show that the percentage of total vehicle weight taken up by each of the two drivetrain concepts (internal combustion engine (ICE) and electric vehicle (EV)) is almost identical as long as the electric vehicle is a BEV with medium range. The balance of weight shifts in favor of the ICE in the case of battery electric vehicles with long range and a correspondingly heavy battery (cf. Fig. 9).

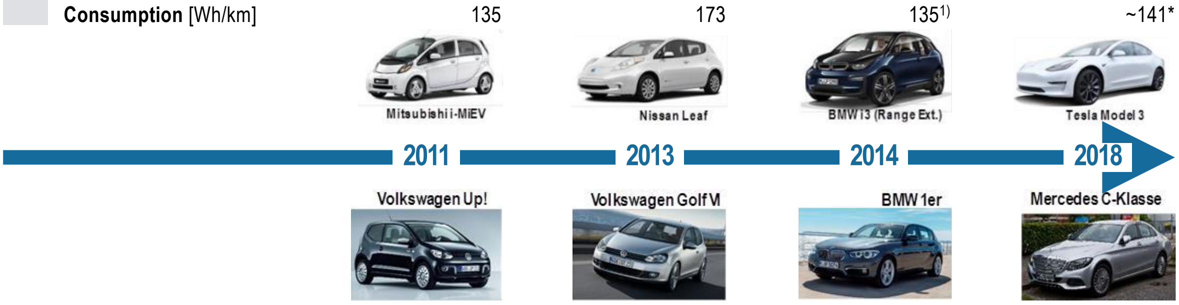
In this case, up to 86 percent of the high-voltage battery's weight is accounted for by the battery cells and the battery management system. A further 11 percent comes from the battery case. But depending on where the case is installed in the vehicle structure, its percentage weight can be even greater – particularly in view of crash safety requirements. The latter can easily shift the weight proportions because battery cases with crash-relevant functions can make up more than 40 percent of the total weight.

Consequently, the design and position of the battery case within the vehicle can be a differentiating factor for xEV manufacturers. Battery charger integration, optimized thermal management as well as use of innovative material combinations and joining technologies are examples of levers that can be applied to reduce the weight of the battery case and thereby improve the gravimetric energy density of the battery system. Furthermore, it can be inferred that cell weight will need to be further reduced in the future, especially given the fact that larger high-voltage batteries with correspondingly high cell capacities will be required in order to achieve longer ranges.

The increase in system weight will inevitably be accompanied by a rise in system costs, and additional research efforts will need to go into bringing these costs down. Against this backdrop, some niche manufacturers are edging into the high-volume automotive markets, seeking to position themselves in direct competition with conventional OEMs. So, besides the vehicles manufactured by incumbents, the products made by these new players make very interesting benchmark objects as well (cf. Fig. 9).

Fig. 9: E-powertrain and battery system offer differentiation potential as key systems – Balance of weight from benchmark analysis

BEV	Mitsubishi i-MiEV	Nissan Leaf	BMW i3 (Range Ext.)	Tesla Model 3
Range [km]	150	175	170	~350*
Mass drivetrain [kg]	313	428	465	n.a.*
Mass battery [kg]	224	304	242	~480*
Consumption [Wh/km]	135	173	135[1)]	~141*



ICE	Volkswagen Up!	Volkswagen Golf VI	BMW 1er	Mercedes C-Klasse
Range [km]	770	775	950	820
Mass drivetrain [kg]	190	370	285	485
Mass fuel tank [kg]	47	59	51	50
Consumption [l/100km]	4.5	7.1	5.3	5.0

Source: fka benchmarking (excerpt) * currently being calculated by fka

Benchmarking therefore offers visibility over where vehicles slot into the market in terms of their technological capability and facilitates direct comparison between electric and conventional powered vehicles. Especially the e-powertrain and the battery system offer considerable potential for improvement as key systems. When it comes to the battery pack, advances at the cell level (suppliers) and the system level (OEMs and suppliers) will be extremely significant in the coming years.

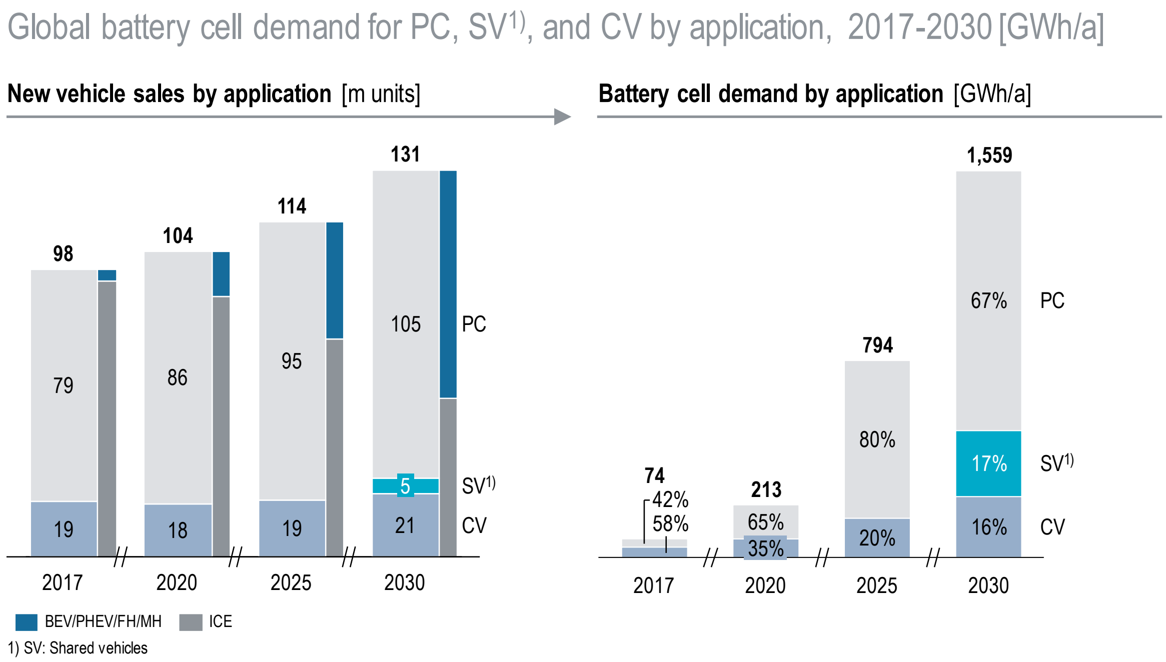
3.2 Strategies on xEV batteries. Quo vadis?

Global xEV sales are expected to grow significantly over the next decade. The major driver of this development is the regulatory frameworks in China and the EU28, which follow a stringent pathway of CO2 emissions reduction. As a result, the demand for battery cells is expected to multiply within a few short years from today's base. Overall, automotive battery cell demand is forecast to grow form 74 GWh (2017) to a total of almost 1,600 GWh (by 2030).

Besides the rise in vehicle sales, OEMs will further increase the battery capacity per vehicle in order to improve the level of customer acceptance across all vehicle segments.

However, the significant demand that will be seen in the period through 2025/2030 pushes the supply industry for battery cells to an unknown magnitude and consequently challenges the entire supply chain, creating significant dependencies between players on all steps of the value chain.

Fig. 10: Electric powertrain with significant share expected – The automotive battery cell demand expected to increase to almost 1,600 GWh in 2030



Source: IHS; Roland Berger

Within the short timeframe until 2021, the major cell suppliers are expected to further enhance their market position. As of today, four major cell suppliers have built up a dominant market position outside of China (cf. Fig. 7) and are expected to consequently maintain their market share without any challengers competing in the automotive arena by 2020/21. Thereafter, potential challengers are likely to reach a competitive technology level and Chinese suppliers will likely internationalize their business.

In China, the market restrictions and regulatory framework have favored local cell manufacturers. Especially the fact that battery cells from major Japanese and Korean cell manufacturers have not been white-listed (which is a key requirement for government subsidies for new car buyers) has pushed the development of selected Chinese cell suppliers significantly. CATL can be considered the major winner owing to its very competitive technology base. Almost all non-Chinese OEMs recently signed contracts with CATL to supply their Chinese xEV production.

Furthermore, CATL plans to start operations in its potential plant in eastern Germany by the end of 2019.

Nevertheless, OEMs are aware of this potential dependency on CATL in China and are expected to take countermeasures. Most likely they will support certain Chinese challengers in their efforts to become technologically competitive and/or restart supply relations with Japanese and Korean suppliers in China after white-listing.

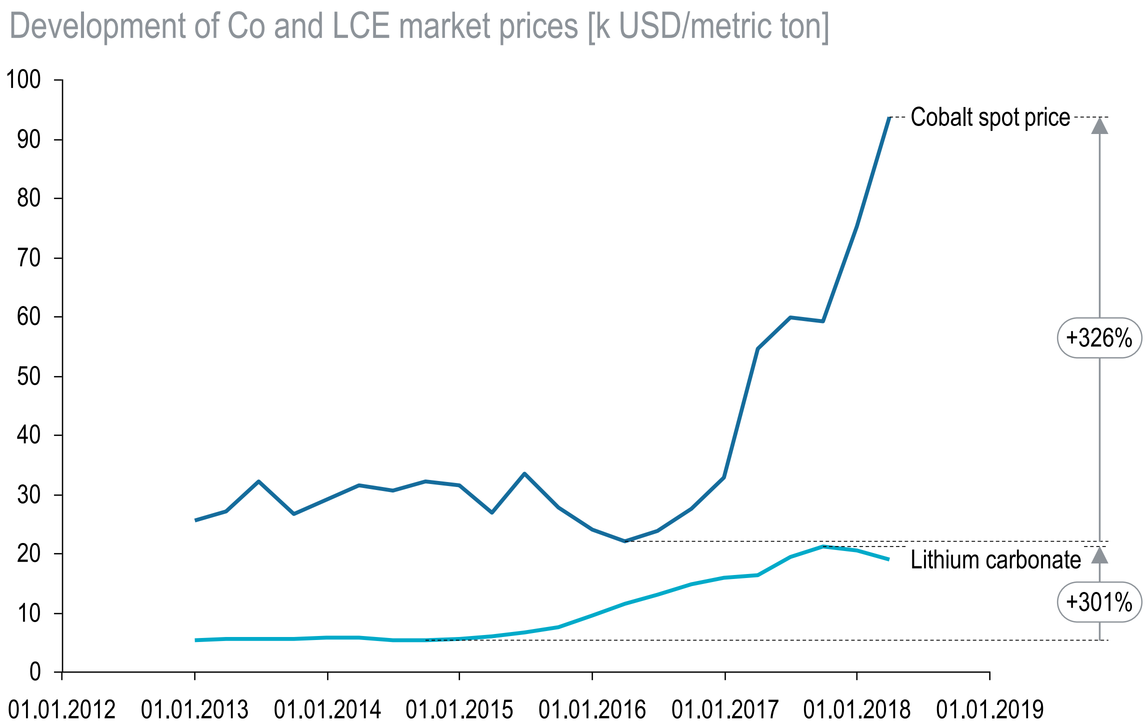
As expected, the impressive growth prospects in the automotive battery cell market are affecting the prices of important raw materials. Of all the major elements in battery active materials – lithium (Li), nickel (Ni), cobalt (Co), manganese (Mn), aluminum (Al) and carbon (C) – Li and Co are considered the most price-sensitive raw materials.

Different from all other elements, the major demand for Li and Co derives directly from battery cell production. The supply of all other elements will always be secured because existing capacities for other applications can be converted to battery use.

Consequently, higher demand for those elements will drive the price and higher prices will make larger raw and refined capacities available for battery precursor materials. As a result, the price increases will be capped at a certain level. However, Li capacities – either in the form of lithium carbonate or lithium hydroxide – need to be newly installed and ramped up in order to secure the physical supply. Aside from the scale of the required initial investments, the lead time for new projects to get online (up to 10 years) is critical and will determine how long market prices remain exceptionally high.

The outlook regarding the physical supply security for Co is even worse. Because Co is commonly a very low-share byproduct of Cu or Ni mining activities, the available Co raw material capacities are determined by the global demand for Cu or Ni. As a consequence, Co was and still is subject to severe speculation and is likely to face periods of physical undersupply. Though these phases of undersupply are expected to be partly covered by public and private Co stocks, investment activities on the part of major OEMs and cell manufacturers in Co mining and refining projects highlight the importance of a secured supply chain.

Fig. 11: The key raw materials Cobalt and Lithium had been subject to speculation causing a price increase of more than 300%

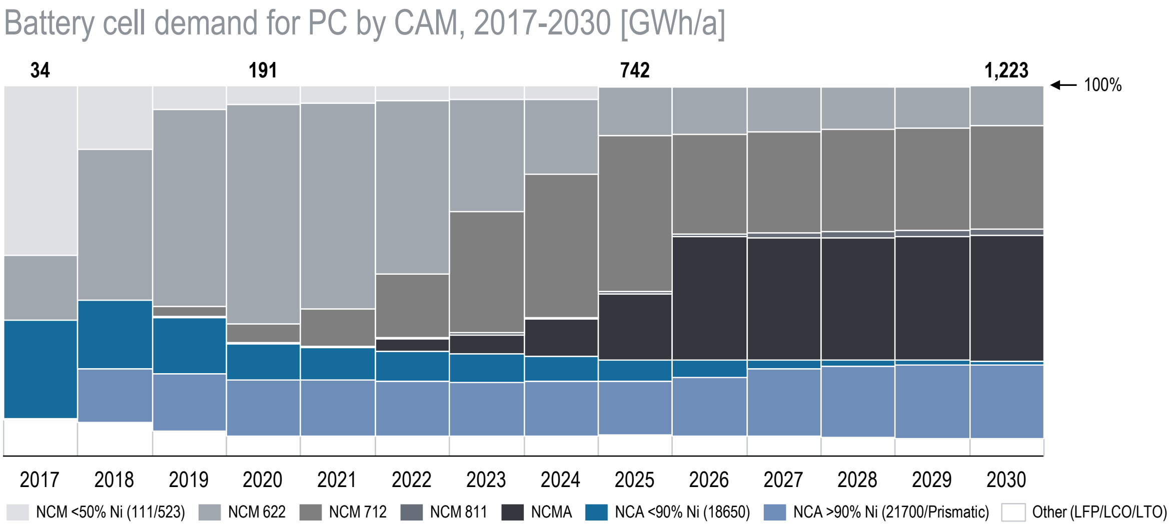


Source: LME, Bloomberg

Mainly driven by the overall technological development toward higher energy densities in battery active materials, the composition of cathode active materials will focus on (high) Ni-rich materials, such as NCM712 or NCA ($Ni_{0.95}Co_{0.02}Al_{0.03}$). By 2023, both ternary CAMs are expected to be enhanced with a fourth element, either manganese or aluminum, into NCMA in order to improve cycle stability (Mn) or power output (Al).

Besides increasing the specific energy density, these materials offer a pathway to substitute or at least significantly reduce the use of Co (compared to today's CAMs such as NCM523/NCM622). Consequently, all major players are developing these kinds of CAMs, but still need to overcome certain hurdles in terms of cycle stability and charging capabilities.

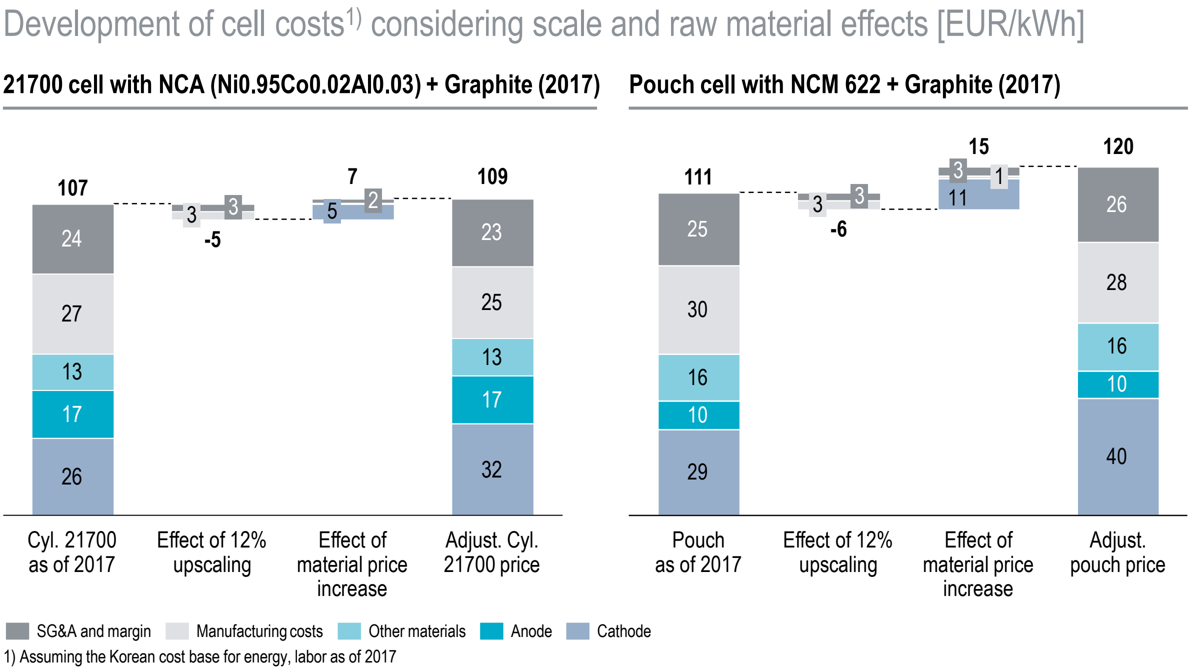
Fig. 12: Driven by the demand for higher energy densities and the need to replace Co, Ni-rich materials will gain significant market shares



Source: LME, Bloomberg

Focusing on a single cell type and cell generation, the potential saving effects from improved manufacturing equipment and scale are comparably lower than the effect of raw material price increases seen in the past two years (cf. Fig. 13).

Fig. 13: Depending on the manufacturing scale, material price effects are partly covered – However, more advanced measures are required



Source: Roland Berger

In a bid to overcome their dependency on highly volatile raw material prices, battery cell manufacturers can take three measures:

> Develop next-gen battery cells with NCMA-based CAM (cathode active material) and advanced AAM (anode active material) like Si or Li-metal foil in order to further increase energy density and (dis)charging characteristics as well as reduce Co share – However, the effectiveness of this measure is limited as all major industry players are developing along similar technology pathways and their exposure to price rises for other raw materials is not covered

> Introduce more advanced manufacturing processes like dry coating and high-speed stacking or advanced cell designs with Li-metal anodes in order to increase leverage on manufacturing and SG&A costs – This measure can effectively compensate for higher raw material costs, but has no prevent characteristics and is not likely to ensure a long-lasting competitive advantage

> Apply a strategy for upstream integration to precursor and raw material processing as well as develop fully integrated price and supply hedging strategies covering all potential measures from short-term spot market hedging to large-scale investments in mining and refining projects

Looking forward, a cost reduction of 20% to 25% is expected to result from the introduction of the next cell generation (from NCM622-based chemistries to chemistries with a high Ni share of >70%). The key enabler of this price drop is the increase in the specific energy of each cell. In addition to the total cost reduction, the share of material costs will increase by approx. 5 percentage point compared to today's share of approx. 50%. Future cell generations after 2020 will even further increase the share of material costs within the BOM.

Consequently, the share of value added will continuously decrease with the introduction of every new cell generation. Hence, SG&A costs need to be leveraged even more consistently on a large production scale in order to improve business profitability and enable greater R&D spending on more advanced cell generations, like solid-state cells.

Fig. 14: Examples of vertical integration and integrated supply chain strategies

Involved parties	Short description	Physical risk coverage[1)]	Financial risk coverage[2)]
> VW group > CATL > Glencore (Mining and refining company)	Vertical cooperation for long-term supply of cobalt, from mining downstream (CHN)	Unknown period, 50% fixed (10 kt p.a.) / 50% variable (10 kt p.a.)	50% fixed price, take-or-pay / 50% annually renegotiated, LME + premium
> BASF > NorNickel	Vertical cooperation for long-term supply of cobalt and nickel, from mining until precursor (EU)	Unknown period, unknown volumes	Likely to be partly fixed / partly variable pricing
> BYD > Shenzhen > Chilean producers	Vertical cooperation for long-term supply of LCE, from refined materials downstream (CHN)	Only MoUs have been signed so far	Unknown
> Tesla > Kidman Resources (Australia)	Vertical cooperation for long-term supply of Lithium I starting when Kidman's project in Western Australia commences production	Three-year contract, incl. two three-year term options	Fixed-price take-or-pay basis
> Posco > Samsung SDI	Vertical cooperation to build and run a cathode production facility in Chile	3,200 tons p.a. of cathode materials - Nickel Cobalt Aluminum and Nickel Cobalt Manganese	Unknown (USD 54.2 m investment)

1) Physical coverage of predefined shipping volumes within a predefined time 2) Pricing mechanism

Source: Interviews with market participants; Public information; HTMA; Roland Berger

As current examples show, major market players consider an integrated value chain strategy to be the most effective measure. Depending on the degree of vertical integration, battery cell manufacturers are able to control the value chain (partly) and balance raw and precursor material prices in a narrower range. However, the stronger the control over the entire material value chain is, the larger the competitive advantages are. But the higher the financial commitment and risk is, at the same time.

That said, cell suppliers operating at larger production scale can more easily compensate for the additional costs. Suppliers with considerable market share can therefore further enhance their competitiveness and gain additional market share – which, in turn, makes them even more competitive.

This being the case, major cell manufacturers are expected to further improve their competitiveness and raise the bar for new market entrants on the current technology base. At the same time, the dependency of automotive OEMs on cell manufacturers is unlikely to decrease.

In order to avoid or reduce dependency on their suppliers, OEMs have two strategic options:

1. They can develop long-term close partnerships with players along the supply chain with agreed base volumes complemented by quickly scalable in-house production
2. They can help develop a strong supplier landscape in battery modules with OEMs sourcing consistently from a large number of cell manufacturers on the market

In addition, OEMs should set up OEM-controlled recycling loops in order to have control of the used battery packs and utilize recycled materials for future cell production. To ensure the sustainability of battery recycling, OEMs will likely need to partner with cell manufacturers in order to reduce transportation, increase energy efficiency and reduce waste.

INTERVIEW WITH MARTIN ANDERLIND – HEAD OF BUSINESS DEVELOPMENT, Northvolt

Roland Berger Senior Consultant Gero Pieper spoke to Martin Anderlind, Head of Business Development at Northvolt, about the likely evolution of the battery cell market and his view of the challenges ahead. Northvolt plans to operate production capacities of 8 GWh p.a. by 2020 and 32 GWh p.a. by 2023. Recent funding rounds to enable this growth have been supported by leading European industry players, such as Vattenfall, ABB and Siemens.

Gero Pieper (GP, Roland Berger): The four major battery cell manufacturers (Panasonic, LGC, SDI and SKI) have built up a dominant market position outside of China, while CATL is presently the market leader in China. Based on their current production scale and the significant ramp-up of new capacities, we expect these five players to further improve their competitive edge over smaller cell manufacturers. Do you think others will be able to catch up with these dominant players in the near future and what are the key success factors that will enable Northvolt to compete with these market leaders?

Martin Anderlind (MA, Northvolt): Well, first of all, I think I agree with the way you look at the market in terms of the big players and also, of course, how you describe our job of breaking into the market, a task the company has begun to address. But I also think that the market will experience some very special conditions in the next phase of its development, over maybe ten years, so there are market opportunities that will allow for new players such as Northvolt to enter. But if we were to come in and play by the same rules, I believe it would be very difficult to establish ourselves in the market. In order to become established, we therefore need to have a couple of key advantages.

First, building large-scale manufacturing capability and scaling up substantially allows us to be the first really large-scale producer in Europe and enables us to enter the market as a challenger.

The second advantage we have is that we're doing things a little bit differently – one of our innovations being the vertical supply chain. Coming in as a new player, we can start with a fresh sheet of paper and go directly to the very beginning of the supply chain, in contrast to the very fragmented supply chain current players are using. This will put us in a more advantageous competitive position.

And third, by locating our activities in Europe and using fossil-free energy, we can produce a much greener battery. As one of the main draws for battery-powered vehicles is sustainability, we can achieve the world´s greenest battery with a full life cycle approach.

GP: Based on the impressive demand forecasts for automotive battery cells in the next ten years, cobalt and lithium raw and precursor materials have been the subject of particular speculation in the last two years. For lithium, new mining and refining capacities need to be established in order to secure the physical supply, while the physical supply of cobalt likely faces supply shortages in the near future due to its high dependency on other raw materials as a mining byproduct. In addition, Chinese market players are heavily investing in mining and refining capacities in order to gain control of the upstream supply chain and hedge prices. Are upstream investments the only way in which battery cell manufacturers can cover their future raw material demand or do you also see other options for more collaborative partnerships between players along the value chain?

MA: It will of course be very interesting to see what happens in the coming years. We don't know any more than anyone else what the price of raw materials will be two years from now, so we're taking that into account in our discussions on pricing, for example.

But we are not particularly worried about a lack of suppliers, as we've taken various steps to make sure that we will have supply, one example being the deal with Nemaska Lithium, who have partnered with Northvolt. We partnered with them to secure our lithium hydroxide supplies for many years to come. And we have similar arrangements for additional crucial markets. In the end, I think supply and demand typically finds ways of working itself out.

And on the subject of cobalt, which is seen as the most critical aspect so far: we're pretty sure that we will be able to source it, and not just source it but do so in an ethically and environmentally sustainable way so as to support the natural reserves, which is important to us.

There will, of course, be a point in time when the supply and demand don't meet, and that's generally why prices go up or down – but we believe that we will be able to secure what we need in order to be productive in battery cell manufacturing. In any case, the amount of cobalt per kilowatt hour is also going down, and it will keep going down, especially if prices stay high, and in the end we think that whatever chemistry the wider market decides on, there will be supply to match that in a cost-effective way.

And if the cost does not come down, then the cars will not become cheap enough for the mass market to take off.

GP: With a view to reducing their dependency on cell manufacturers, we think that OEMs can adopt different strategies in order to build up a more powerful position against today's cell market leaders. Strategies include:

> Investing in their own battery cell production based on lithium-ion or even post-lithium-ion cell technologies – This will involve a major risk to their financials owing to R&D efforts, production facilities as well as raw material prices and supply hedging, but it will also create the highest degree of independence from current cell suppliers

> Actively developing a highly competitive supplier landscape with more competing market players than today, even if financial and technological support is required for currently lower-performing suppliers

MA: I think it's interesting that there is a big discussion involving OEMs, and they definitely have different ways of looking at this market. It also depends whether they believe batteries will become a key differentiating factor over time, or whether the battery is merely a part of the car, a commodity part that all cars have but that lacks any other differentiating value for the customer.

That said, the answer to these strategic questions also depends on the OEM's business model – whether they are selling transportation or selling performance as well as their market position. I believe that most of them, the largest ones, will have at least looked into battery manufacturing, and as of now, it doesn't seem like any of them are chasing investments. They have, of course, looked into partnering with the existing large manufacturers, and some have also asked our company if we could manufacture for them, and the industry certainly has a need for that.

So I think there are a lot of options that are still on the table. And the ones who have put the most effort into this question will likely have come up with a number of alternatives, so they might have made sure that they will have the possibility to work with different suppliers for their platforms. Some also have very good ideas about what type of battery they want to have, what size they want to have, and what chemistries they want to have in that battery as well as what performance they need to get out of that battery. Ultimately, I think all of your strategies are smart ideas on how OEMs can position themselves in the future.

And since you mentioned OEMs supporting other players: We have in fact received tremendous support from some of them, especially the Germans who really want to see this happening, even if they don't end up buying batteries from us. They are just keen to have more supplier options.

GP: Just briefly touching on the debate on battery recycling: Do you think that the OEMs will be able to establish large-scale recycling loops somehow by themselves or will they have to partner with other players, maybe even battery cell manufacturers?

MA: Over time, we believe that recycling will be very important and we don't particularly believe in the second life strategy. And we believe in the sustainability of battery recycling, which is an essential part of our recycling strategy.

But there's another factor to that, and that is the matter of our battery intelligence and data. We have a couple of nice ideas from our data analytics side and have built a very strong team around this.

We will be able to follow our batteries into the field and learn from them, continuously while cars and other products are in the field and then end of life prior to recycling. And as we move forward, we are going to be able to continuously tweak the software in order to over time provide a better product for the end consumer. It's going to be invaluable. And as to recycling – in order for it to be viable, it needs very, very high volumes; recycling is very energy-intensive so it needs cheap electricity. And battery manufacturers should be able to do this better than OEMs.

GP: Considering the issues you mentioned, it looks like the only reasonable place for battery recycling would be close to potential battery cell manufacturing sites, in order to further optimize transportation and energy utilization and maintain the green image of recycling.

MA: Well, the idea is to find smart ways of doing it. It's a little bit early to see exactly how this will play out. We do have a pretty detailed plan. What we're talking to our automotive customers about is how to ensure that we help relieve them from their producer's responsibility. Whether we manage to take the batteries back either by paying for them or getting paid to take them remains to be seen, and then we'll need to have efficient recycling in terms of both cost and sustainability.

GP: Martin, thank you very much for the interview.

4. Methodology

The relative competitive position of individual automotive nations is compared to that of others on the basis of three key indicators:

> **Technology:** The current status of technological development in vehicles made by indigenous OEMs and the support for vehicle development provided by national subsidy programs
> **Industry:** The regional value added in the automotive industry by national vehicle, system and component production
> **Market:** The size of the national market for electric vehicles based on current customer demand

Roland Berger and fka weight the individual indicators (value range 0-5) and combine them to form the E mobility Index (Figure 10). The E mobility Index makes it possible to compare the competitive positions of the world's seven leading automotive nations (Germany, France, Italy, the US, Japan, China and South Korea), assessing their individual automotive markets on the basis of uniform global standards. The index also reveals the extent to which individual nations are able to benefit from the market that e mobility is creating. The criteria applied are assessed as discussed below:

Technology

> The technological performance and value for money of electric vehicles that are currently available on the market or soon to be launched
> National e-mobility R&D programs. Only research grants and subsidies are taken into account (not credit programs for manufacturing, budgets for purchase incentives, etc.)

Industry

> Cumulative national vehicle production (passenger cars, light commercial vehicles) for the period 2016-2021 taking account of BEVs and PHEVs
> Cumulative national battery cell production (kWh) for the period 2016-2021

Market

> Electric vehicles' current share of the overall vehicle market (in 2017)

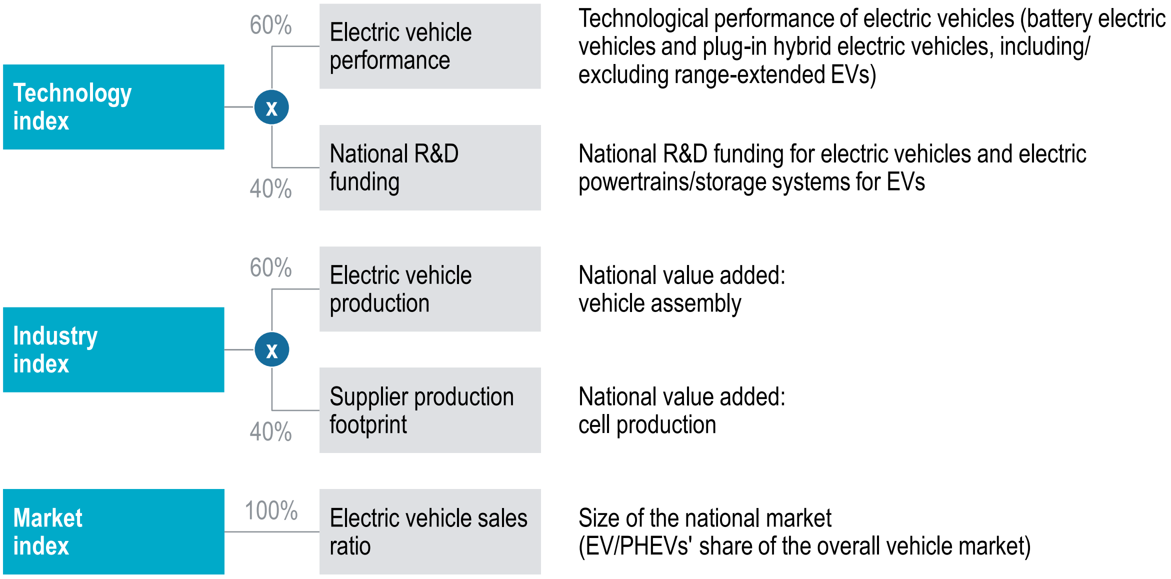
The 2017 index was the first to include projections for 2019, while the 2018 index is the first to include projections for 2021. The additional volume is reflected in higher scores for industry in all markets. However, this does not affect the shifts between markets, and the E mobility Index's comparability with previous indices is thus not compromised.

The measurement threshold for the market indicator was also modified in the Q2 2017 index. The fact that BEVs and PHEVs are increasingly penetrating the market made this step vital to focused assessment in the value range from 0 5. The higher threshold reduces countries' market values compared to previous editions of the index.

The technology indicator was updated in the Q4 2016 E mobility Index. Individual aspects of the methodology used to measure technological performance (safety features, active safety) were adjusted, while on-board charging technology was added as a new criterion. Overall, these adjustments alter the level of the technology indicator compared to previous editions of the E mobility Index. The new charging technology criterion also results in shifts between individual countries.

Fig. 15: The E-mobility Index compares the automotive nations based on three parameters

E-mobility Index – Three parameters: Technology, industry, market



Source: fka; Roland Berger

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