Q-Series®

Global Autos: What is the powertrain of the future?

Equities

Global Automobiles

Patrick Hummel, CFA
Analyst
patrick.hummel@ubs.com
+41-44-239 79 23

David Lesne
Analyst
david.lesne@ubs.com
+44-20-7567 5815

Julian Radlinger
Analyst
julian.radlinger@ubs.com
+41-44-239 13 41

Yankun Hou
Analyst
yankun.hou@ubs.com
+852-3712 4451

Colin Langan, CFA
Analyst
colin.langan@ubs.com
+1-212-713 9949

Kohei Takahashi
Analyst
kohei.takahashi@ubs.com
+81-3-5208 6172

Young Chang
Analyst
young.chang@ubs.com
+82-2-3702 8803

Chervine Golbaz
Analyst
chervine.golbaz@ubs.com
+44-20-7568 1171

Mark Leung
Associate Analyst
mark.leung@ubs.com
+852-2971 8636

Bonil Koo
Analyst
bonil.koo@ubs.com
+852-2971 7158

Sabyasachi Niyogi
Associate Analyst
sabyasachi.niyogi@ubs.com
+44-20-7567 5318

Taisuke Hirose
Associate Analyst
taisuke.hirose@ubs.com
+81-3-5208 6162

Battery electric vehicles are in pole position for the powertrain of the future

In light of COP21, electric cars are set to play an essential role in de-carbonizing the road transportation sector, which accounts for 23% of EU-28 CO2 emissions. Our proprietary analysis shows that battery electric vehicles (BEVs) are likely to achieve cost of ownership (TCO) parity with combustion engine (ICE) cars by 2021 in Europe and 2025 in China, whereas ICE cars remain the cheapest option in the US due to lower fuel prices. Our analysis shows fuel cell vehicles (FCVs), which are earlier stage than BEVs, have the potential to drop in sales price to a level similar to BEVs, but have higher operating costs. While our math excludes incentives, we expect rising political support to improve EV economics.

BEVs are the best ecosystem fit and have lower infrastructure costs than FCVs

BEVs are the better fit in a future low-carbon ecosystem, due to the storage aspect (batteries will be a key enabling technology also for the electricity sector), and can be combined with electricity self-generation. Given today's electricity mix, FCVs have lower 'well-to-wheel' emissions than BEVs in most countries. However, infrastructure costs for FCVs are twice the expected costs for BEV infrastructure, and the multiple is 4-5x in a zero-carbon world. Also, "the chicken and egg" problem is more relevant for FCVs, as vehicles will only be sold after governments have invested in hydrogen infrastructure.

Entering the steep part of the S curve: Expect 10m EV annual sales in 2025

While near-term EV sales will be regulation and incentive-driven, we expect EVs to grow their market share rapidly in Europe and China in the coming decade as economics for consumers improve. We estimate 9% of global car sales (9.7m cars) will be EVs in 2025 (based on $75 oil). Our estimated EV market share in 2021 is 2.5% or 2.5m vehicles sold, vs. 0.5m today. In the US, where the CO2 regime is less strict and EV economics are weaker on lower fuel prices, we see only a slight increase in EV penetration to 3%. BEV-related battery demand could grow by more than 5x by 2021.

Implications for the industry and best positioned companies

OEMs currently sell EVs at low margins, while low sales figures hardly help to achieve CO2 targets. We believe EV margins should normalize gradually after 2020 and rising EV penetration should bring CO2 compliance costs to (almost) zero. We see Renault/Nissan, BMW, GM and Toyota as EV innovation leaders, while generating solid FCF in the "legacy" business to fund the transformation. Continental and Delphi look to be the best-positioned suppliers for rising EV penetration.

Contents

Patrick Hummel, CFA
Analyst
patrick.hummel@ubs.com
+41-44-239 79 23

David Lesne
Analyst
david.lesne@ubs.com
+44-20-7567 5815

Julian Radlinger
Analyst
julian.radlinger@ubs.com
+41-44-239 13 41

Yankun Hou
Analyst
yankun.hou@ubs.com
+852-3712 4451

Colin Langan, CFA
Analyst
colin.langan@ubs.com
+1-212-713 9949

Kohei Takahashi
Analyst
kohei.takahashi@ubs.com
+81-3-5208 6172

Young Chang
Analyst
young.chang@ubs.com
+82-2-3702 8803

Chervine Golbaz
Analyst
chervine.golbaz@ubs.com
+44-20-7568 1171

Mark Leung
Associate Analyst
mark.leung@ubs.com
+852-2971 8636

Bonil Koo
Analyst
bonil.koo@ubs.com
+852-2971 7158

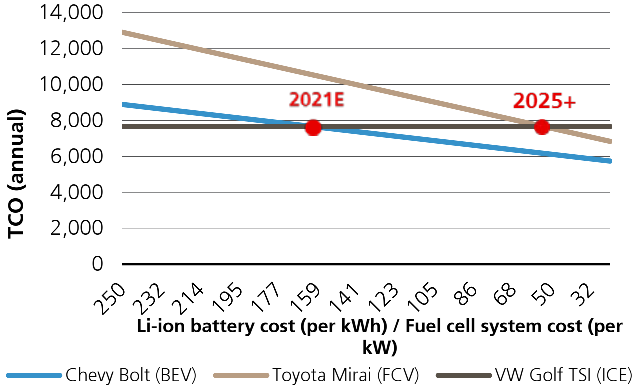
Sabyasachi Niyogi
Associate Analyst
sabyasachi.niyogi@ubs.com
+44-20-7567 5318

Taisuke Hirose
Associate Analyst
taisuke.hirose@ubs.com
+81-3-5208 6162

Executive summary

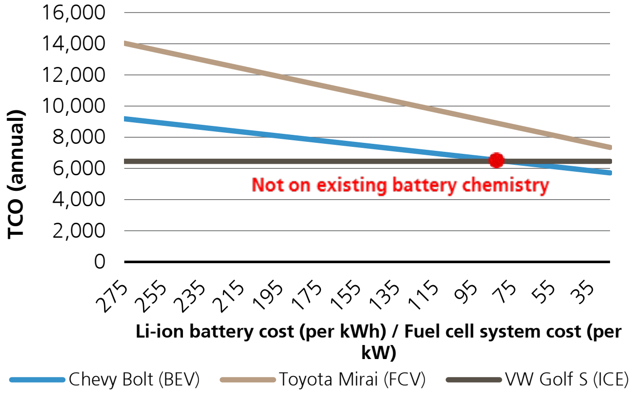
Battery electric vehicles to become competitive with internal combustion engine cars in Europe by 2021 and in China by 2025. Based on our proprietary analysis, battery electric vehicles (BEVs) will reach cost of ownership parity with internal combustion engine (ICE) cars in Europe by 2021 and in China by 2025. Lower battery costs, which we expect to decline by 36% to €160/kWh (c$180/kWh) by 2021, are the key driver. In the US, BEVs will not beat ICE cars for the foreseeable future and growth will depend on incentives. Our research indicates fuel-cell vehicles (FCVs) will not be competitive for the next 10 years, even though the technology is too early-stage for a final assessment.

Figure 1: BEVs to reach consumer cost parity in EU by 2021



Source: UBS estimates

Figure 2: Economics in the US are still better for ICE cars

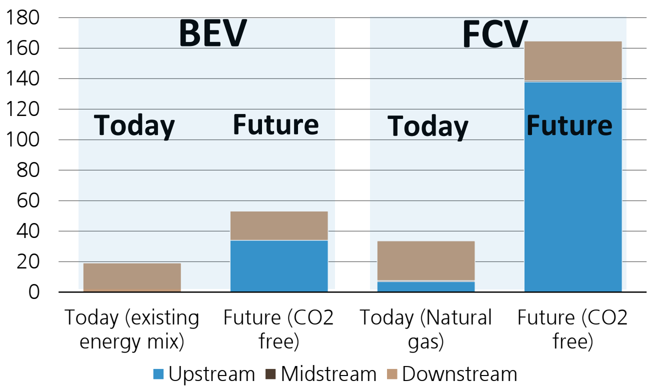


Source: UBS estimates

BEVs fit best in a low-carbon future ecosystem. We expect BEVs to receive solid political support, in light of the COP21 commitments and pollution problems in large cities. Decisive factors are: (1) BEVs they provide valuable storage capacity to the power grid; (2) they can be powered with self-generated electricity; and (3) infrastructure costs for FCVs are 2-5x higher than for BEVs. Higher FCV penetration would depend on not yet planned government spending on hydrogen infrastructure.

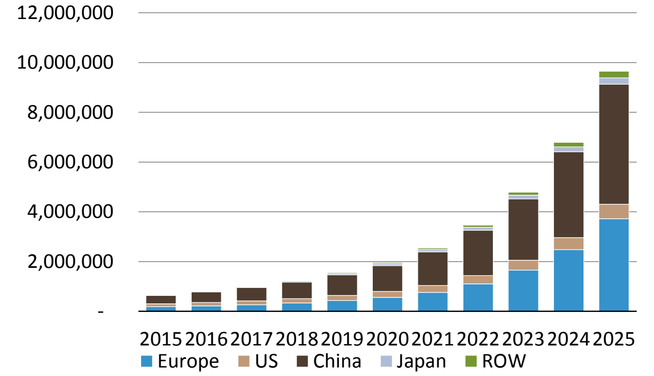
Steep part of the sales S curve coming in the next decade. We expect 2.5m global EV sales in 2021 (including plug-in hybrids), versus 550k in 2015. We expect 9.7m EV sales (9.2% of the market) on a 2025 view. China and Europe are likely to lead the growth. Most EVs will be battery electric, we believe.

Figure 3: Infrastructure cost for 15m EVs (€bn) – charging much cheaper than hydrogen infrastructure



Source: UBS estimates

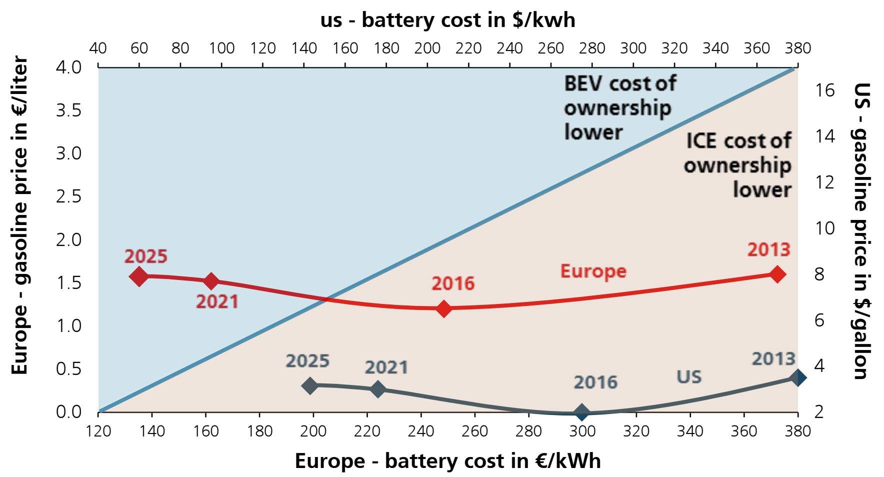
Figure 4: EV sales penetration to accelerate after 2020 (million units by region)



Source: UBS estimates (includes plug-in hybrids)

Proprietary interactive model. Our interactive model [click link] shows the sensitivities of EV economics, depending on battery cost, fuel cell cost and oil/petrol prices.

Figure 5: BEV economics and the axes of uncertainty (battery and gasoline px)



Source: UBS estimates

Electrification will bring disruption – we identify potential winners and losers. We do not disagree with consensus that the transition will bring disruption and earnings pressure for OEMs in the next few years (EVs are sold at low contribution margins, high upfront R&D required), but rapidly rising EV penetration in the next decade would lower CO2 compliance costs to (almost) zero. We see **Renault/Nissan**, **BMW**, **GM** and **Toyota** as winners on the OEM side, and **Continental** and **Delphi** on the supplier side. Players along the **battery value chain** (from commodity mining to battery production) should also be among the structural beneficiaries from rising EV penetration. On the other hand, the **oil sector** will be negatively affected (even though the global car parc keeps growing). EVs are likely less maintenance intensive and have fewer wearing parts than ICE cars. This poses a threat to the service revenues of **car dealerships**.

Figure 6: Stock exposure to EV theme

Stock	UBS rating	Positively or negatively affected by the theme?	Is the theme priced in?
OEMs			
BMW	Neutral	Positive	No
Daimler	Buy	Neutral	No
FCA	Neutral	Negative	No
Ford	Buy	Neutral	No
GM	Buy	Positive	No
Honda	Neutral	Positive	No
Hyundai	Buy	Negative	No
Jianghuai	Buy	Positive	No
Kia	Buy	Negative	No
Mitsubishi	Not covered	-	-
Nissan	Buy	Positive	No
PSA	Neutral	Negative	No
Renault	Buy	Positive	No
Tesla	Sell	Positive	Yes
Toyota	Neutral	Positive	No
Volkswagen	Buy	Neutral	No
Yutong	Buy	Positive	No
Suppliers			
Autoliv	Sell	Neutral	No
Continental	Neutral	Slightly positive	No
Delphi	Neutral	Positive	No
Faurecia	Sell	Negative	No
Lear Corp	Buy	Positive	No
Valeo	Buy	Slightly positive	No
Other sectors			
Johnson Matthey	Neutral	Positive	No
LG Chem	Neutral	Positive	No
Samsung SDI	Neutral	Positive	No
Umicore	Buy	Positive	No

Source: UBSe

BEVs score well in full cost analysis from consumer perspective in EU/China

We expect BEVs to cross the consumer cost parity inflection point by 2021 in Europe and by 2025 in China, driven by lower battery costs, excluding incentives. In the US, ICE cars remain the lowest-cost option for the foreseeable future, given the low oil price. While we consider it possible that the price of FCVs will be similar to BEVs' on a 2025 view, operating (fuel) costs are structurally higher. The picture looks more favourable for EVs when incentives are included, which we believe are here to stay, given COP21 commitments.

Lower battery costs are the key driver

Summary of proprietary cost analysis

Proprietary work on battery cost and total cost of ownership

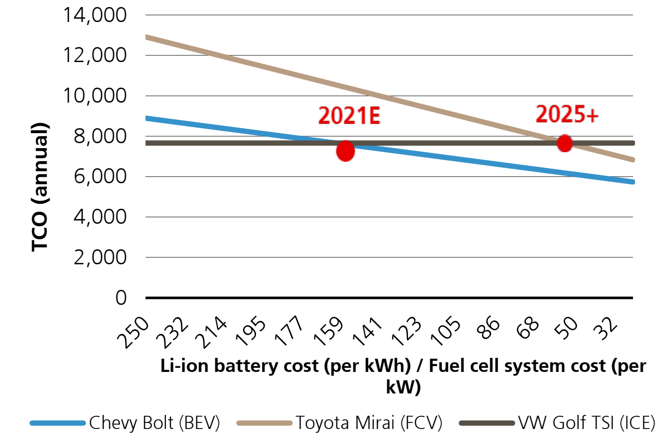
Our proprietary model, which is also available as an interactive version on Neo, provides detailed analysis of the total cost of ownership (TCO) by technology. Battery and fuel (cell) costs are the key drivers of EV economics. We have interviewed several companies and industry experts, and reviewed various scientific research.

Our analysis focuses on the total cost of ownership. We use actual vehicle prices and exclude any sort of purchase incentives or car tax relief for EVs. We do not normalize differences in contribution margins between the vehicles, as we assume that EVs will be sold in a competitive environment at lower margins for as long TCO are not superior to consumers. As we expect EV incentives to increase in the coming years, the effective cost parity is likely to be achieved earlier in several markets. Our analysis for 2021/25 is based on UBS's $75/bbl oil forecast. The detailed assumptions are shown in the *Appendix* section of this report.

Key results by region:

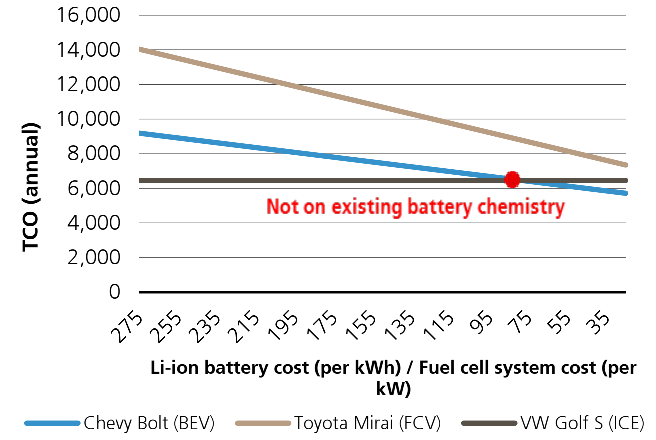
- **Europe:** At a battery cost of €160/kWh (our base case for 2021, 36% below today's level), BEVs will have the same TCO as ICE cars. Fuel cell system costs would have to drop more than 70% to €75/kW to be at cost parity with ICE technology, which we think is unrealistic for the next 10 years.
- **US:** At the current low fuel prices, BEVs will not be fully competitive (excluding incentives) for the foreseeable future, as battery costs would have to drop to less than $75/kWh – a scenario that we think is unlikely to materialise based on existing li-ion chemistries. The situation is even less certain for FCVs, which are starting from a higher cost base.
- **China:** Ignoring various support measures, including exemption from licence plate restrictions and tax incentives, battery costs would have to drop roughly by half, to RMB910/kWh, to reach cost parity with ICE technology. We expect this be achieved around 2025. The FCV situation is uncertain.
- **Japan:** As in the US, reaching cost parity will be more difficult here: battery costs would need to drop 55% for mass-market BEVs to reach cost parity with ICE cars on our analysis; the situation for FCVs is more uncertain still.

Figure 7: TCO by technology – Europe (€)



Source: UBS estimates

Figure 8: TCO by technology – US ($)



Source: UBS estimates

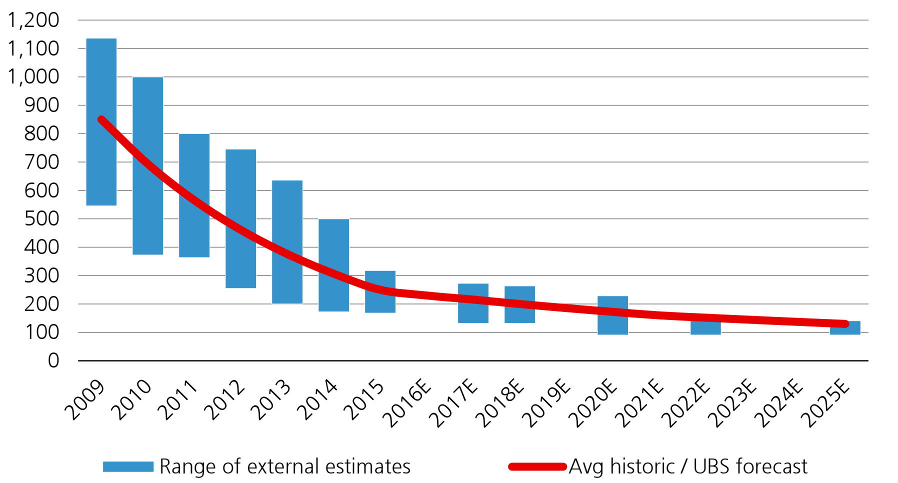
We believe plug-in hybrids are likely to become a suboptimal choice in many markets, once the shortcomings of BEVs have been addressed

We have not included plug-in hybrids (PHEVs) in the above TCO analysis, because we see them as a bridge technology for the next 10 years. Once the shortcomings of BEVs have been addressed (range, charging time and infrastructure), we believe PHEVs will become a suboptimal choice in many markets, due to the extra weight necessitated by two powertrains (200-300kg), the limited electric driving range, and the limited benefit to real-world fuel economy. Nevertheless, PHEVs are likely to have their niche in markets where charging infrastructure remains a bottleneck also longer-term (for example, in rural areas) and for heavy users generating long daily driving distances.

BEVs: Battery costs are the key driver

Unsurprisingly, the reduction in battery costs is a key driver of BEV competitiveness. We expect the battery cost per kWh to drop by 36% to €160/kWh (c$180/kWh) by 2021 on existing chemistry. The cost should decline by another 19% to €130/kWh (c$145/kWh) in 2025 with further optimization of the existing technology (higher energy density, lower weight, less use of commodity materials). Our assessment is based on various company interviews, and our analysis of more than 20 industry and academic research papers.

Figure 9: Battery cost to decline 36% by 2021 on existing chemistry (€/kWh)

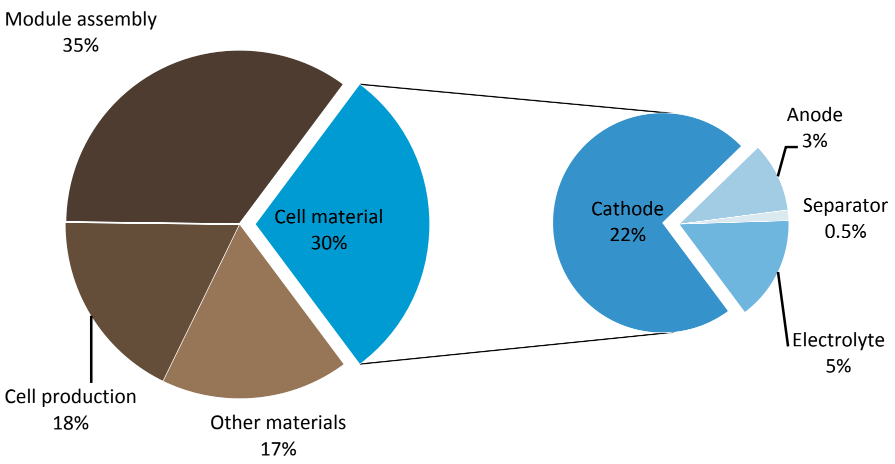


Source: Review of more than 20 academic and industry sources, UBS estimates

Deep dive into battery costs

To better understand the cost reduction potential for batteries, we break the cost down into materials (commodities), cell production and module assembly. We focus on NCA (nickel cobalt aluminium) and NMC (nickel manganese cobalt) technologies. NCA is only used by Tesla (which is the largest player in the market), while all other OEMs and battery suppliers focus on NMC. All chemistry differences between NCA and NCM are in the cathode part of the material (see below; and find a detailed overview of the technologies and their attributes in the *Appendix*).

Figure 10: Breakdown of mainstream technology battery cost

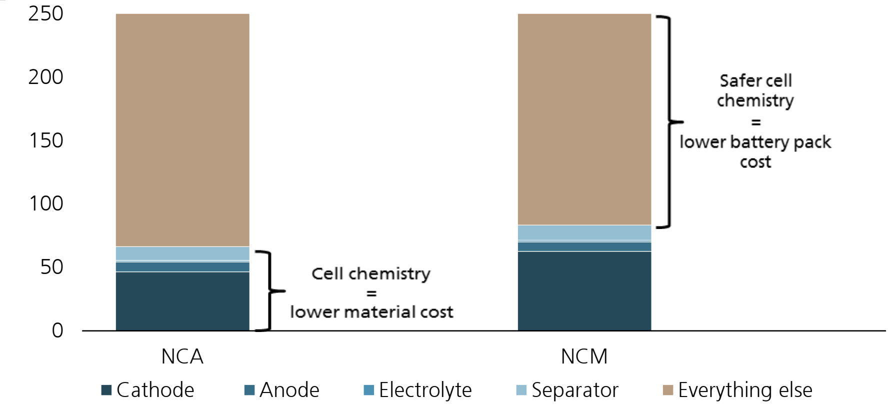


Source: MIT, JMAT, Umicore, UBS estimates

Materials costs to decrease slightly on optimization of cells, including higher energy density

Today, the battery pack cost is around €250/kWh (c$280/kWh), of which battery materials (commodities) account for c30% or €75/kWh, depending on the chemistry. The cell cost (including materials) is around 50% of the total pack cost (the Chevrolet Bolt cell cost is $145/kWh). The following figure shows the differences between the chemistries. NCA technology (used by Tesla) has lower materials cost and better energy density, but requires higher safety costs in the pack than NMC technology (i.e. it is more expensive to keep an NCA battery from overheating).

Figure 11: NCA versus NMC cost breakdown (today, approx €/kWh)



Source: UBS estimates

In our modelling, we assume increasing energy density (15% by 2021). As a consequence, the materials cost per kWh and subsequent processing cost per kWh decline. Our assumption includes slightly higher commodity prices, as a function of higher demand for those materials. (See analysis further down in the document).

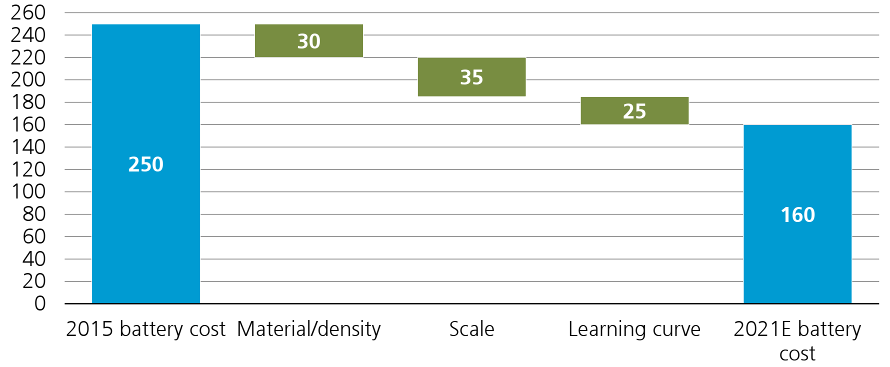
36% cost reduction potential in cell/module assembly cost by 2021

In total, we estimate 36% cost reduction potential in the cell and module assembly cost by 2021 (on the same chemistry) to €160/kWh (c$180/kWh), driven by:

1. Higher energy density (and consequently lower commodity cost);
2. Economies of scale in manufacturing (cell and pack);
3. Learning curve effects, such as optimization/automation in production processes.

The figure below summarises the cost drivers and our expectations for 2021.

Figure 12: Battery cost to decline >35% on existing chemistry by 2021 (€/kWh)



Source: UBS estimates

Additional cost reduction to €130/kWh in 2025 is close to the maximum possible cost reduction potential on existing chemistry

On a 2025 view, we expect an additional reduction to €130/kWh on further improvements in materials use and energy density. We believe this is close to the maximum possible cost reduction potential on existing chemistry. Innovation through new chemistry is unlikely to enter the automotive market in the next 10 years, as alternative materials are still at the laboratory stage; and, on top of that, commercialisation of a new technology takes another 5-10 years in automotive, we believe.

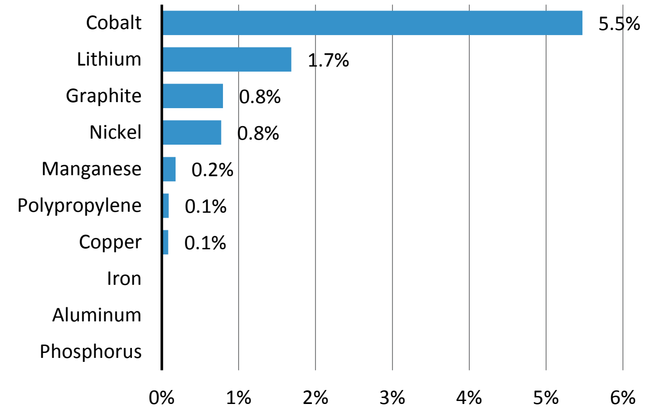
Can rising battery materials demand trigger a spike in commodity costs?

We believe that NCA and NMC batteries will dominate the market in the coming years, and we expect higher growth rates for NMC between the two technologies. That said, could booming battery demand cause price spikes in raw materials? In order to answer this question, we have assumed that 10% of all vehicles sold globally in 2025 (10m cars) will be BEVs; and as a 'stress test', we assume there are no plug-in hybrids, which have smaller batteries. We then determine the incremental demand for raw materials and how these figures compare with the size of the world market today. We assume 25% of BEVs will use NCA technology and 75% NMC.

Our stress test suggests none of the commodities should pose a hard bottleneck. Our scenario indicates the cobalt market will be most impacted by high BEV penetration, as annual demand for BEVs would represent 5.5% of proven reserves and 1.6% of estimated resources. While potential BEV demand could be 3.5x times the current market size, we would not expect any imminent shortages, provided that mining capacity is expanded accordingly. An increase in cobalt production by such a magnitude likely requires significant investment, but should be realistic with a 10-year view. For details, please see the table in the *Appendix* to this report.

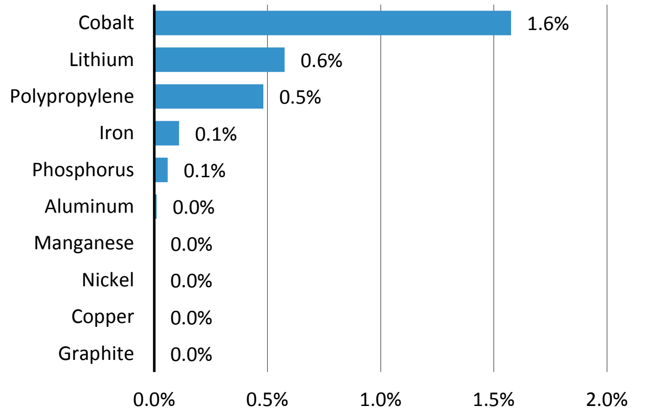
The cobalt market will be most impacted by high BEV penetration

Figure 13: Raw materials demand as a % of current reserves for 10m EVs produced (UBSe for 2025)



Source: USGS, Ceresana, Wood Mackenzie. UBS estimates

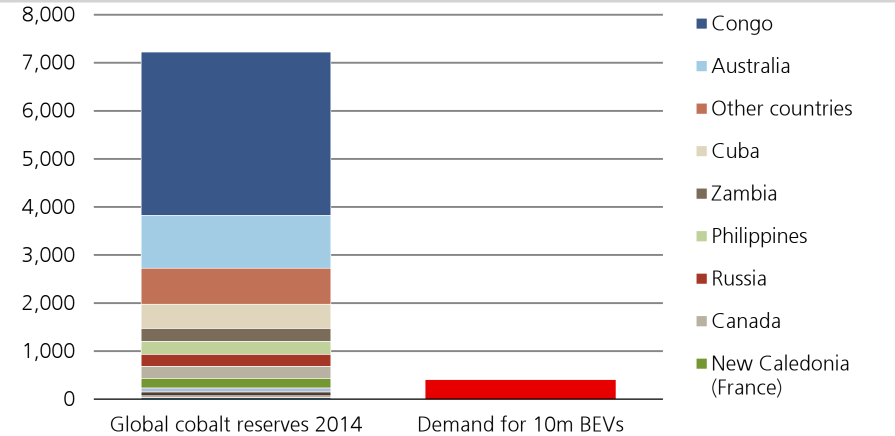
Figure 14: Raw materials demand as a % of estimated resources for 10m EVs produced (UBSe for 2025)



Source: USGS, Ceresana, Wood Mackenzie. UBS estimates

Political uncertainty in African cobalt-mining countries (where the world's largest reserves of cobalt are located) is commonly cited by the market as a key risk factor in the raw material supply chain for li-ion batteries. To quantify that risk, we illustrate the country breakdown of global cobalt supplies below, and size it up against the estimated cobalt demand for 10m BEVs. We find that in 2014, global cobalt reserves *without Congo* would have been enough to supply 10x the required amount needed for 10m BEVs.

Figure 15: Cobalt proven reserves vs. demand for 10m BEVs ('000 Mt)



Source: USGS, UBS estimates

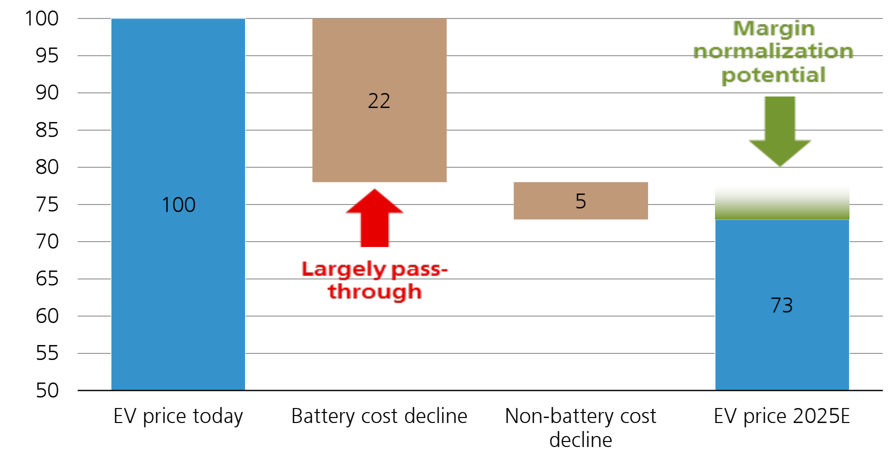
Another cause for concern could be lithium. While resources are plentiful, the market is not (yet) very liquid. Concerns about a supply squeeze at a single Australian mine drove a tripling of the price of Chinese lithium since October

2015. While lithium prices cannot be ignored, we note that for NMC and NCA technologies, lithium only represents c2.5% of the total bill of materials in the battery on our estimates. For this reason, the lithium price increase was fully outweighed by price declines in other raw materials such as aluminium, copper and nickel, (see *Appendix* for details).

Further cost reduction potential in non-battery part could help improve OEM contribution margins

Cost reduction is not only driven by batteries. We believe the first-generation EVs have many components with a high margin of safety, and OEMs are likely to reduce or eliminate these cost items as they gradually understand EVs better. Such cost reduction is the source of improving OEMs' profitability under the assumption that OEMs buy batteries from suppliers, i.e. lower battery prices are just a pass-through. EVs are currently sold at low contribution margins or even at a loss.

Figure 16: EV contribution margin should grow on the reduction in non-battery costs (2016 = 100)



Source: UBS estimates for mass-market BEV

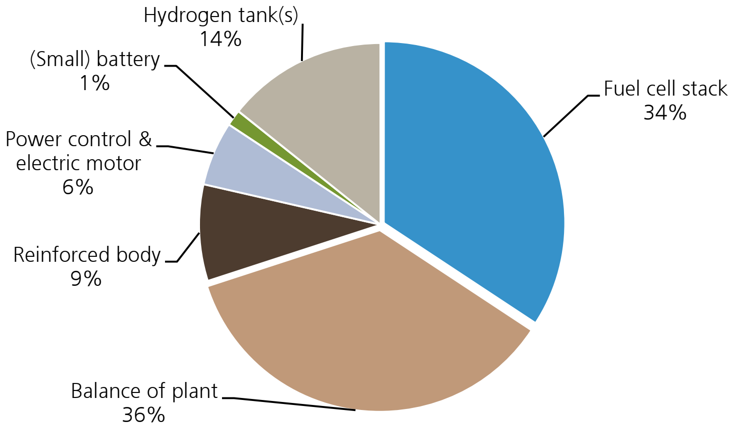
Fuel cell costs: Heading for a steep decline, but from a very high base and with high uncertainty

FCV manufacturing has very high cost reduction potential, but battery technology has much better momentum in scale

FCVs are the substantially more expensive option than BEVs today, but the technology is clearly earlier-stage than batteries. The all-new Toyota Mirai, which comes as a C segment sedan, has a sticker price of $57,500 in the US. We believe the price hardly covers the manufacturing cost. Overall, we are confident that FCV manufacturing has very high cost reduction potential. However, battery technology is not standing still and has much better momentum in scale in the coming years.

The key cost driver of FCVs is the fuel cell system, and within the system, the fuel cell stack. We estimate total fuel cell system costs to be around $300 per kW (2015) in a small-scale manufacturing environment, which translates into a total cost of just less than $35,000 in the case of the Mirai. This includes the fuel cell as the largest item (around $20,000 or $170/kW), which consists of the fuel cell stack, and the balance of the plant (i.e. the necessary auxiliary equipment, such as pump and gaskets). Further components include reinforced body architecture, the power control unit and battery, as well as hydrogen tanks (the Mirai uses two). The cost breakdown below is based on today's manufacturing scale.

Figure 17: Cost breakdown of a fuel cell system today (will vary with scale)



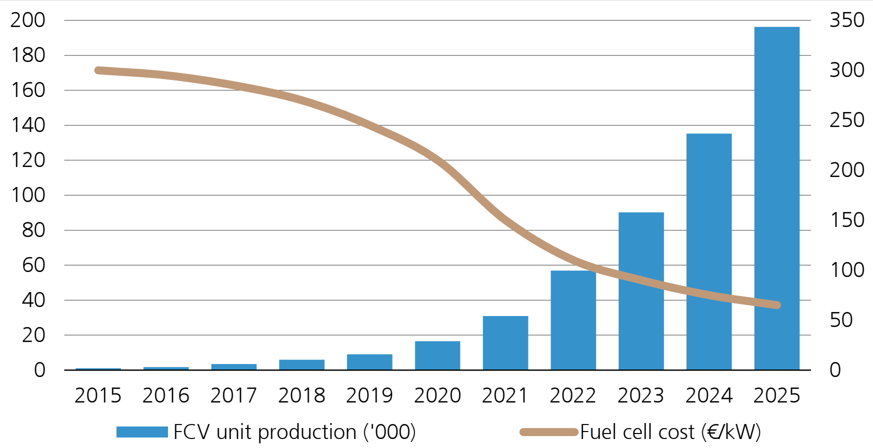
Source: Dept. of Energy, IEA, UBS

The fuel cell system cost can be reduced substantially in a large-scale manufacturing environment

Various research suggests the fuel cell (FC) system cost can be reduced substantially in a large-scale manufacturing environment. The Department of Energy (DOE) estimates $55/kW for the stack and the balance of the plant, based on today's fuel cell architecture. Assuming the same rate of decline for the other components, this could reduce the sticker price of the Toyota Mirai by -43% to c$33,000 (all else remaining equal). We highlight that large-scale manufacturing refers to more than 100,000 units/year: this may be a challenge to achieve for a single manufacturer in the foreseeable future. However, we consider such a number to be realistic based on a 2025 view. Another potential driver of lower cost is a reduction in the use of platinum. On our estimates, the Mirai's fuel cell contains more than $1,000 of platinum value.

In our base-case forecasts for FCVs and FC system costs below, we consider the following potential impediments to growth over the next 5-10 years: (1) the lack of hydrogen fuel stations in most major markets; and (2) the lack of model selection for the consumer (three models available as of March 2016). With more stations and models available, we expect growth to accelerate from around 2021. This should enable scale in manufacturing, especially if OEMs share production and/or R&D costs through alliances, and consequently a more meaningful reduction in fuel cell costs per kW. We consider the cost development depicted below as a realistic base case.

Figure 18: FCV unit sales (lhs) vs. fuel cell system cost/kW (rhs)



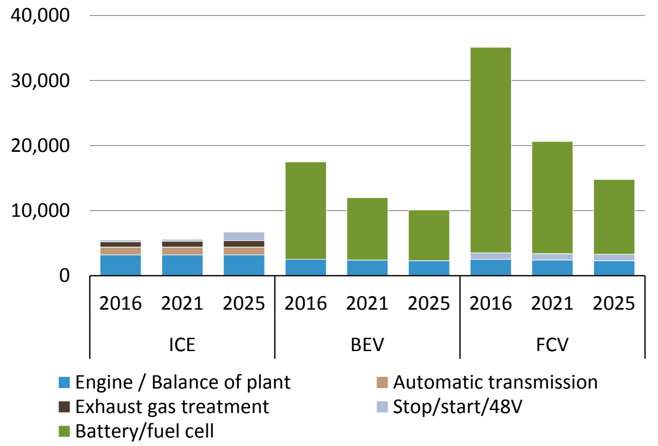
Source: UBS estimates (includes balance of plant, tanks)

Comparing total cost of ownership

Difference in powertrain cost (at unchanged margins) between BEV and ICE car to narrow from €11k today to c€6k in 2021 and c€3k in 2025

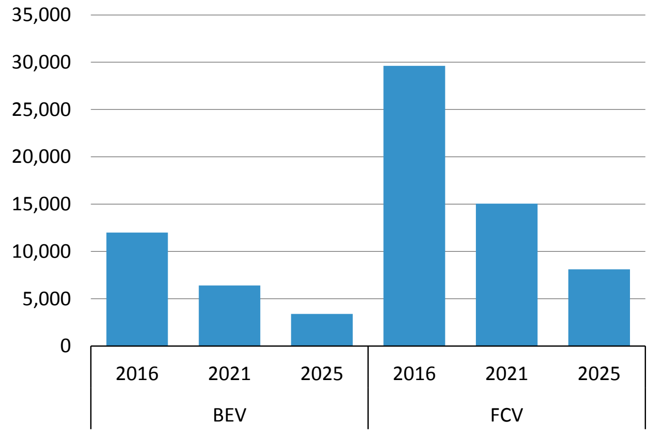
The difference in cost between an electric and ICE powertrain is set to narrow as a function of battery and fuel cell costs. At the same time, we assume the ICE powertrain is likely to become more expensive, due to tighter emission requirements (CO2 and other pollutants). For the BEV (maths below are for Europe), the difference between battery-electric and ICE powertrains should narrow from around €11k today (based on the sticker price difference between the Chevy Bolt and the VW Golf) to about €6k in 2021 and €3.4k in 2025.

Figure 19: Powertrain cost comparison (€, Europe)



Source: UBS estimates

Figure 20: Difference to ICE powertrain cost (€, Europe)

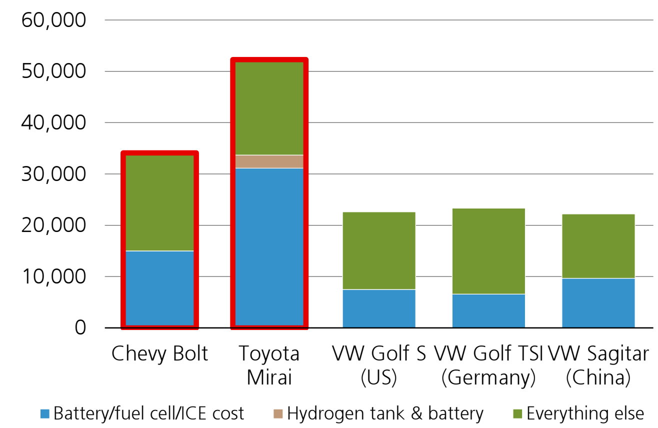


Source: UBS estimates

How much will sticker prices decline for EVs?

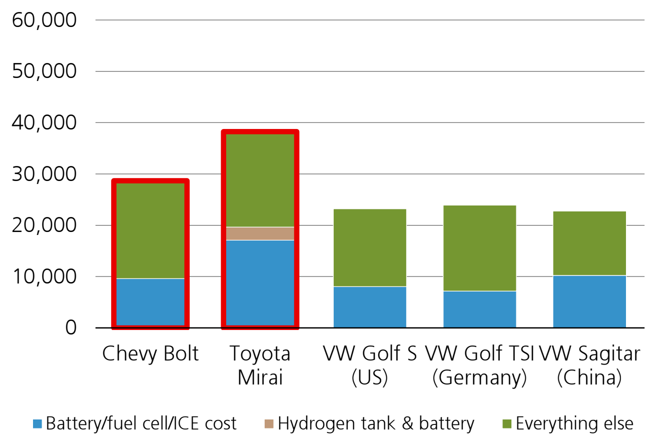
As a basis for our model, we use the sticker prices (excluding incentives) of the Chevrolet Bolt (BEV), the Toyota Mirai (FCV) and a comparable B segment ICE model by region. We then back out the estimated cost of the powertrains. Based on our cost forecasts for batteries and fuel cells, we model what the sticker price of those cars would be in 2021 (all else being equal, no inflation). We don't model any changes in pricing policy of the OEMs, which are hard to predict.

Figure 21: Vehicle price comparison 2016 (€)...



Source: Company data, UBS (excludes incentives)

Figure 22: ...and estimated for 2021 (€)



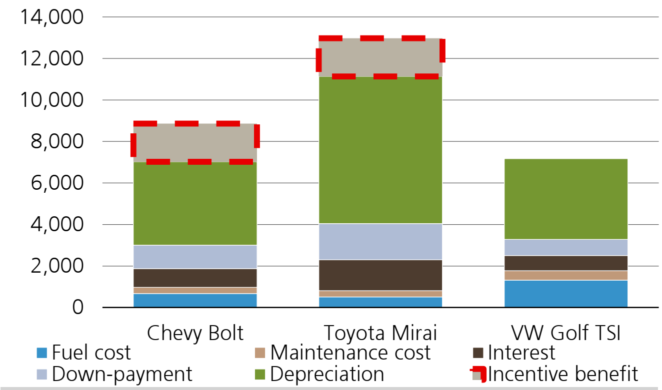
Source: Company data, UBSe (excludes incentives)

TCO comparison by region – Europe and China most promising for EVs

We look at a typical three-year lease contract, with 15,000km of annual driving and 50% residual value. Our base-case assumption is a battery life of 10 years (or 150,000km). Already today, ICE cars have the highest operating cost. First, the monthly fuel bill is higher than the cost of electricity. Batteries aside, ICE cars have more moving/wearing parts (engine oil, ignition, brake discs) and consequently, higher maintenance costs over the lifecycle. For the figures below, we look at the 2016 TCO at today's fuel and electricity prices, and at the expected 2021 TCO including oil at $75/bbl. The charts also illustrate the impact of incentives currently available (in the case of Germany, we include the anticipated €5k/car purchase incentive). We are not touching the taxation of fuels and electricity. Given the political focus on the de-carbonization of the transportation sector, we see no reason to expect taxation changes that would have an adverse impact on EVs.

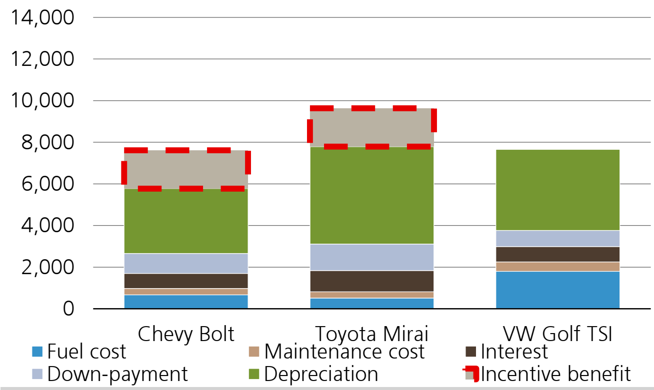
In **Europe (Germany)**, we the TCO for the BEV will be on par with ICE cars by 2021 without incentives while the FCV is likely to remain more expensive.

Figure 23: TCO by car type in Europe – 2016E (€)…



Source: UBS estimates

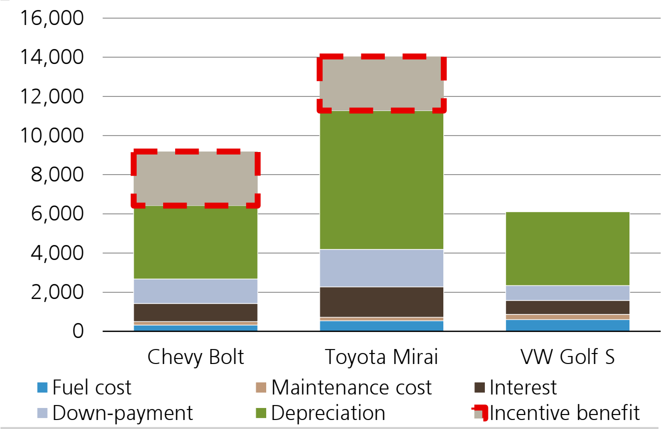
Figure 24: …and 2021E (€)



Source: UBS estimates

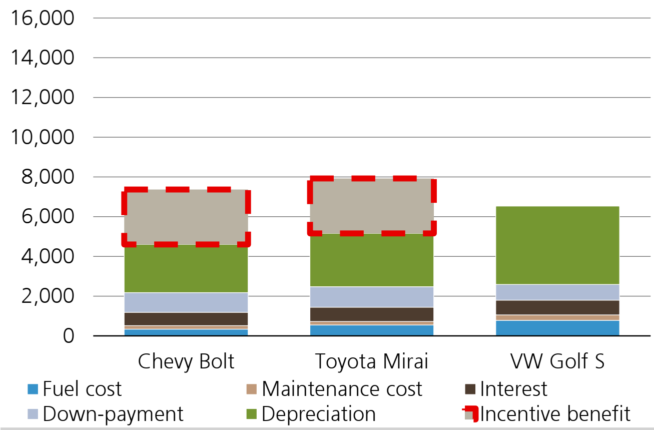
In the **US**, ICE cars remain the lowest-cost technology even on a 2025 view, primarily due to lower petrol prices. Without incentives, an oil price of c$200 would be needed to make the BEV competitive.

Figure 25: TCO by car type in the US – 2016E ($)…



Source: UBS estimates

Figure 26: …and 2025E ($)

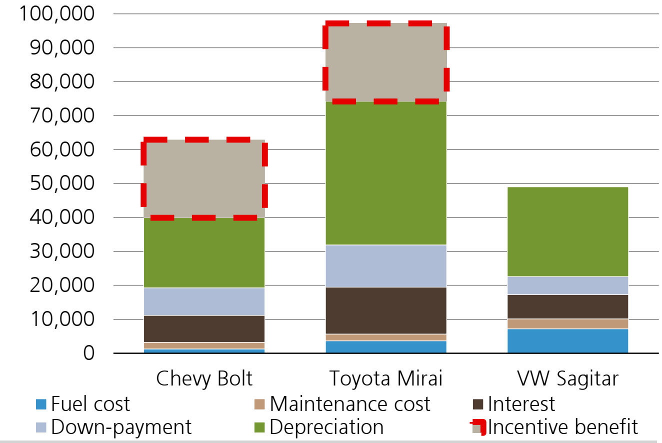


Source: UBS estimates

In **China**, BEV economics are positively impacted by low electricity prices while petrol prices are almost at the European level. As a consequence, our analysis suggests the BEV TCO would be almost at parity with the ICE model by 2021

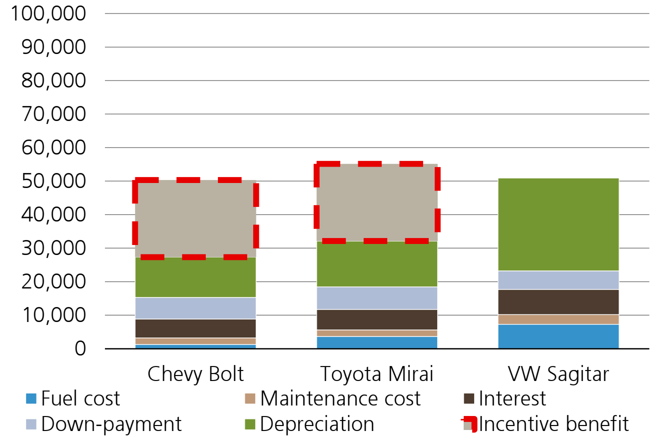
without incentives. Once current incentives enter the picture, the Chevrolet Bolt is already cost competitive today. Also here, we expect FCVs to remain more expensive.

Figure 27: TCO by car type in China – 2016 (RMB)…



Source: UBS estimates

Figure 28: …and 2025E (RMB)



Source: UBS estimates

Figure 29: UBS 2016/2021E/2025E core scenario assumptions

Region		**US**	**Germany**	**China**	**Japan**
Currency		$	€	RMB	¥
Distance		Miles	km	km	km
Gasoline metric		Gallons	Liters	Liters	Liters
Constant values					
USD exchange rate		-	0.9	6.5	115
Residual value	%	50%	50%	50%	50%
Interest rate	%	3.5%	3.5%	3.5%	3.5%
Time of ownership	years	3	3	3	3
Annual driving dist.	miles/km	9,000	15,000	15,000	15,000
Maint. cost EV/FCV	Cent / mile/km	2	2	13	230
Maint. cost ICE	Cent / mile/km	3	3	20	345
2016 scenario values					
Li-ion battery cost	cost / kWh	275	250	1,788	31,625
Fuel cell system cost	cost / kW	300	275	1,950	34,500
Cost of gasoline	cost per gallon	2.00	1.10	6.00	110
Cost of electricity	cost per kWh	0.15	0.30	0.55	15.0
Cost of hydrogen	cost per kg	4.00	3.64	26.00	460
2021E scenario values					
Li-ion battery cost	cost / kWh	176	160	1,144	20,240
Fuel cell system cost	cost / kW	165	150	1,073	18,975
Cost of gasoline	cost per gallon	3.00	1.50	7.00	140
Cost of electricity	cost per kWh	0.15	0.30	0.55	15.0
Cost of hydrogen	cost per kg	4.00	3.64	26.00	460
2025E scenario values					
Li-ion battery cost	cost / kWh	143	130	930	16,445
Fuel cell system cost	cost / kW	72	65	465	8,223
Cost of gasoline	cost per gallon	3.12	1.56	7.28	146
Cost of electricity	cost per kWh	0.16	0.31	0.57	15.6
Cost of hydrogen	cost per kg	4.00	3.64	26.00	460

Source: UBSe

On top of the above assumptions, we model a 2% increase in ICE fuel efficiency p.a. as of today, and a 0.5% increase in ICE cost p.a. to reflect more expensive emissions components.

What about the life-cycle TCO if the battery life is limited to 10 years?

For our life-cycle TCO analysis, we assume that the EV is worth zero after 10 years, given the limitations of battery/fuel cell life. We think this is a conservative approach for BEVs because after 10 years, an EV battery can still be used for stationary appliances. For the ICE car, we still assume a residual value of 14% of the purchase price after 10 years. With a long-term view, this may be overstating the value of the ICE car. For example, if we look at 2021 life-cycle TCO, we forecast an ICE residual value for 2031. By then, limitations or penalties may be in place for owning/driving an old ICE car, which would undermine the residual value.

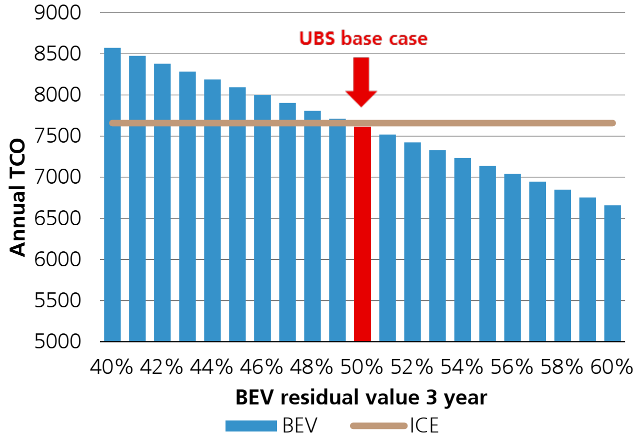
Figure 30: Life-cycle TCO comparison (10-years)

	US ($)		Europe (€)	
	BEV	ICE	BEV	ICE
2016				
Lifetime depreciation	37,500	19,752	34,091	20,376
Lifetime fuel/maintenance/interest cost	16,862	15,827	20,467	25,052
Lifetime TCO	**54,362**	**35,579**	**54,558**	**45,428**
2021E				
Lifetime depreciation	31,560	20,250	28,691	20,891
Lifetime fuel/maintenance/interest cost	14,991	19,007	18,766	30,038
Lifetime TCO	**46,551**	**39,257**	**47,457**	**50,928**
2025E				
Lifetime depreciation	29,580	20,658	26,891	21,312
Lifetime fuel/maintenance/interest cost	14,499	19,520	18,472	30,921
Lifetime TCO	**44,079**	**40,178**	**45,363**	**52,232**

Source: UBS estimates. Assumes ICE residual value of 13% after 10 years, BEV at zero.

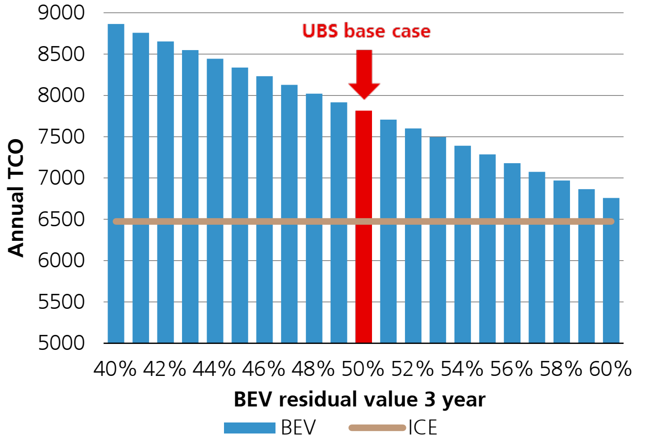
Our conclusion is similar to the three-year lease TCO above. BEVs will have a lower TCO than ICE cars in the coming decade in Europe and China, while economics in the US still look weaker than those for the ICE car.

Figure 31: TCO comparison vs. EV residual value EU (2021; €)



Source: UBS estimates

Figure 32: TCO comparison vs. EV residual value US (2021; $)



Source: UBS estimates

Alternative scenario in which BEV economics would not work

Alternatively, we look at a scenario that encompasses higher BEV pricing (under the assumption that OEMs would not continue to sell BEVs at lower contribution margins than ICE cars) and faster ICE fuel efficiency improvements (4% p.a. instead of our 2% p.a. main case), as shown in the table below. This scenario also factors in a higher residual value for the ICE car after 10 years, equivalent to the battery replacement cost of the BEV. And finally, we assume current low fuel prices also for the long-term. In this scenario, the ICE car remains the lowest-TCO option, not only in the US but also in Europe.

Figure 33: Alternative scenario: Higher BEV prices, higher ICE residual values, better ICE fuel economy

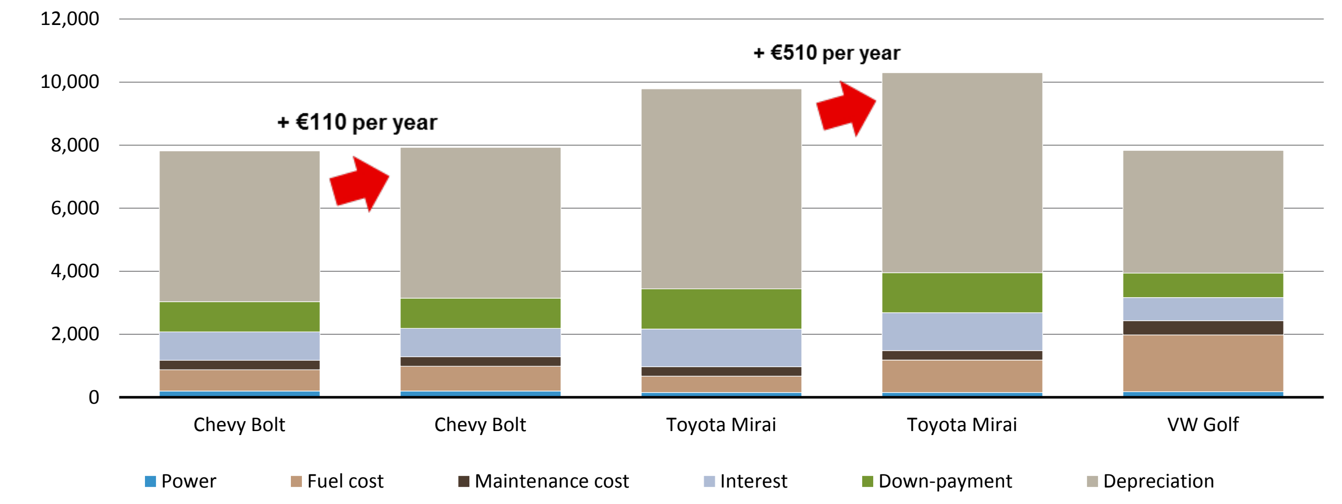
	2025			
	US		Europe	
	ICE	BEV	ICE	BEV
Financing				
Economic Cost*	$30,000	$37,300	€ 27,273	€ 33,909
Down-payment	*$3,000*	*$3,730*	*€ 2,727*	*€ 3,391*
Interest rate	3.0%	3.0%	3.0%	3.0%
Annual Interest	*$810*	*$1,007*	*€ 736*	*€ 916*
Fuel & Maintenance				
Miles Travelled	9,000	9,000	9,000	9,000
Fuel Economy	37.0		46.6	
CAGR vs. 2015	4%		4%	
Fuel Price (per gallon/equivalent)	1.80	0.05	5.00	0.05
Fuel Cost	*$438*	*$420*	*€ 965*	*€ 420*
Maintenance per mile	0.03	0.02	0.03	0.02
Annual Maintenance	*$270*	*$180*	*€ 270*	*€ 180*
Residual Value				
Residual Value	23%	0%	23%	0%
Life	10	10	10	10
10 Yr Vehicle Value	$6,900	$0	€ 6,273	€ 0
Replacement Battery Cost**	$0	$6,800	€ 0	€ 6,182
10y Value ex replacement cost	**$6,900**	**$6,800**	**€ 6,273**	**€ 6,182**
Total Cost	**$41,278**	**$57,102**	**€ 43,442**	**€ 52,456**
EV vs. ICE		**-$15,824**		**-€ 9,014**

Source: UBS estimates
* Est based on $155/kWh & 60kW; less -$2,000 lower other costs vs. ICE
** Est based on $100/kWh for just cells & 60kW; 30% repair premium, less $1,000 salvage value for old battery

How might TCO change in a CO_2-free scenario?

We have also analysed the TCO in a truly carbon-free value chain (from well-to-wheel). This implies that hydrogen is produced via electrolysis at €8/kg, and electricity is generated solely using renewables at €0.35/kWh. Consequently, prices for hydrogen and electricity will be higher than today. In **Europe**, BEVs would still be the cheapest technology, whereas in **China**, ICEs would be slightly more expensive than BEVs.

Figure 34: Annual TCO by technology in Europe – how things change in a long-term fuel cost scenario (€)

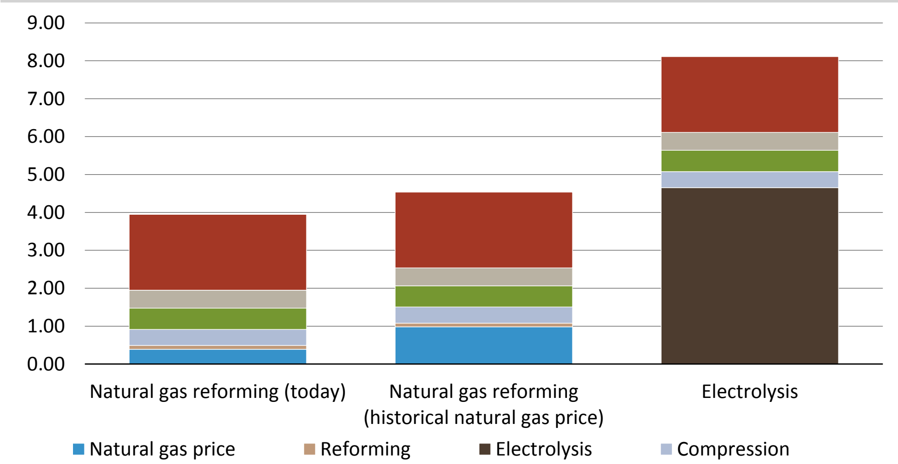


Source: UBS estimates

We calculate a CO_2-free hydrogen price of €8/kg

Based on the currently dominant (CO_2-emitting) natural gas reforming process, about 20% of hydrogen costs are driven by natural gas prices, which are currently at multi-year lows. For our base-case scenario, we assume hydrogen prices at the gas station of €4/kg. A doubling of natural gas prices would increase the hydrogen price by 10%. If hydrogen is produced via electrolysis powered by renewable energy sources, its cost would almost triple, on our calculations. We calculate a CO_2-free hydrogen price of €8/kg. This price would be commodity-independent as wind and solar power generation is largely a fixed-cost business model.

Figure 35: Cost of hydrogen (€/kg) – carbon-free generation would double cost



Source: UBS estimates

Given the lower efficiency of the fuel cell (only c30% of power generated by the wind turbine or solar panel will be brought to the wheel of the car, versus c85%

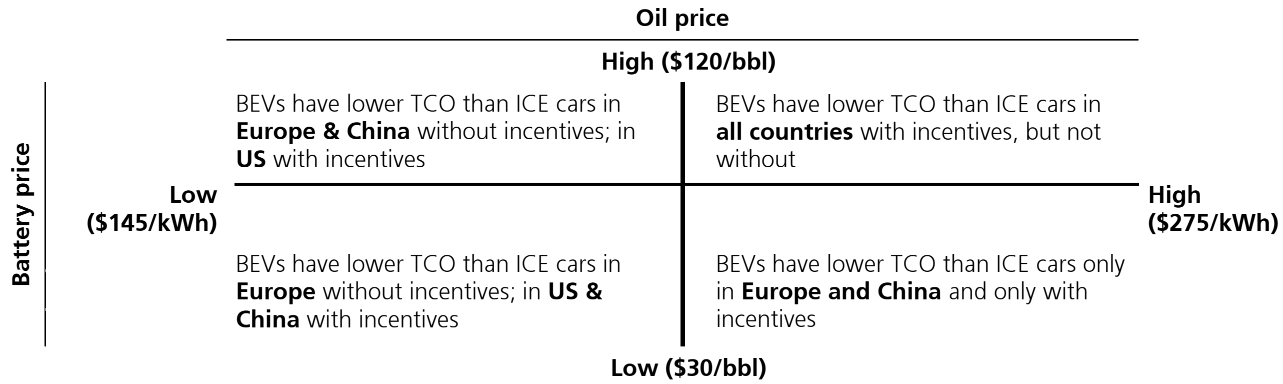
for a BEV), the electricity cost alone would be three times as high for an FCV as for a BEV. We have not included the cost of a charging station or the cost of retrofitting a gas station for hydrogen.

Sensitivity of forecasts to battery/oil prices

Our forecasts are sensitive to battery cost/oil price assumptions

As shown in detail above, the economics of EVs vs. ICE cars are highly dependent on fuel prices and battery costs. Consequently, our market forecast is subject to uncertainty. The figure below shows the relative TCO superiority of BEVs and ICE cars when screened against varying oil prices and battery costs. Should oil prices stay very low for longer and should battery costs not decline meaningfully, our projected EV sales growth would not materialise. Conversely, in a low-battery-cost/high-oil-price scenario, we would expect a further acceleration of growth.

Figure 36: BEV economies and the "axes of uncertainty"



Source: UBS estimates

Figure 37: BEV-to-ICE TCO gap sensitivity in 2021E

Battery cost/kWh	Oil price (price/bbl): $30	$75	$120
Europe			
€ 250	23%	16%	10%
€ 160	6%	0%	-5%
€ 130	0%	-5%	-11%
US			
$ 275	49%	42%	36%
$ 175	26%	21%	16%
$ 145	19%	14%	10%
China			
RMB 1788	28%	25%	22%
RMB 1144	8%	6%	4%
RMB 930	2%	0%	-2%

Source: UBS estimates. Note: UBS base case scenarios are shown in the center-most cells

Range, charging time and expected life should be less of a concern for BEVs, medium term

Figure 38: How do the technologies score, besides TCO (2016)?

	Battery	Fuel cell	ICE
Range	150-450 km	500-700 km	400-900 km
Charging/refuelling time	20 min (80%)	5 min	2 min
Expected life	200-400k km	200-300k km	250-450k km
Performance	up to 500kW	up to 200kW	up to 735kW
Weight	200-600 kg	175-200 kg	200-500 kg

Source: UBS

Charging time and range

We believe BEVs' range and charging time will become much less of a concern for many car buyers in the major markets

A key advantage of FCVs is that hydrogen fuelling is as easy and almost as quick (3-5 minutes) as refilling an ICE car. Fast-charging of BEVs takes about 30 minutes for a lower range, which brings us to the other advantage. Today, the Toyota Mirai FCV already has a 500km range, whereas the Tesla S model in its highest-range configuration achieves 430km of EPA-rated range. The new "mainstream" BEVs such as the new Chevy Bolt will have about a 320km range.

We believe that the disadvantages in terms of range and charging time for BEVs are set to become much less relevant in the next five years.

- As battery costs decline, larger batteries will be introduced in the mass-market segment. Holding the price of a Chevrolet Bolt stable vs. today, its battery capacity (and range) could be increased by >30kWh, or >50% on a 2021 view. We expect OEMs to offer consumers different range options, enabling buyers to pick the version that best fits their needs in terms of usage patterns.
- BEV charging will become faster. For example, Porsche plans to introduce a BEV in 2018 (based on the "Mission E" concept car) with a 15-minute "turbocharging" time. Several OEMs have plans to present induction-charging solutions for home-charging (kerb-side parking is also technically possible), which would make the nightly plugging-in of the car obsolete.

On a post-2020 view, we believe the range and charging times of BEVs are likely to become much less of a concern for many car buyers in the main markets. On the contrary, consumers may even find it convenient to avoid the weekly visit to the gas station.

Today's batteries last longer than current (early-stage) FC technology

A battery could last up to 2,000 cycles, which would likely exceed the assumed 10-year life

A key determinant of the lifecycle cost of BEVs and FCVs is the expected life of batteries and fuel cells. Lithium-ion based batteries achieve up to 2,000 charging cycles until capacity drops below 80% of initial capacity. They could still be used after that time (including for stationary applications), but in our modelling we assume that their automotive life ends after 10 years. With 15,000km annual driving, there should not be more than 1,000 full cycles in a 10-year period.

Today's fuel cells are good for up to 5,000 hours of operation. Assuming an average speed of 40 km/h over the life of a car, the expected fuel cell life would only be 200,000km. We expect longevity to improve substantially as the technology matures.

Battery value after end of auto lifecycle could still be positive

EV batteries could be used for stationary applications

Battery recycling is essential and comes at a meaningful cost. Based on our reading of published literature in the area, we believe the recycling of an EV battery costs about €1,000 in a large-scale environment. This "negative" value of a battery needs to be taken into account when calculating its true life-cycle cost. However, it is also true that while batteries may no longer deliver sufficient automotive performance after 8-10 years in a car, they still can be used in stationary applications. A solar energy system on a residential rooftop doesn't require a battery larger than 10kWh, which is only a fraction of the capacity of EV batteries. Taking this "life after death" opportunity into account, we believe that EV batteries do not carry a negative net value after being replaced in the car. As highlighted before, we assume zero value.

BEVs fit best into the future, low-carbon ecosystem

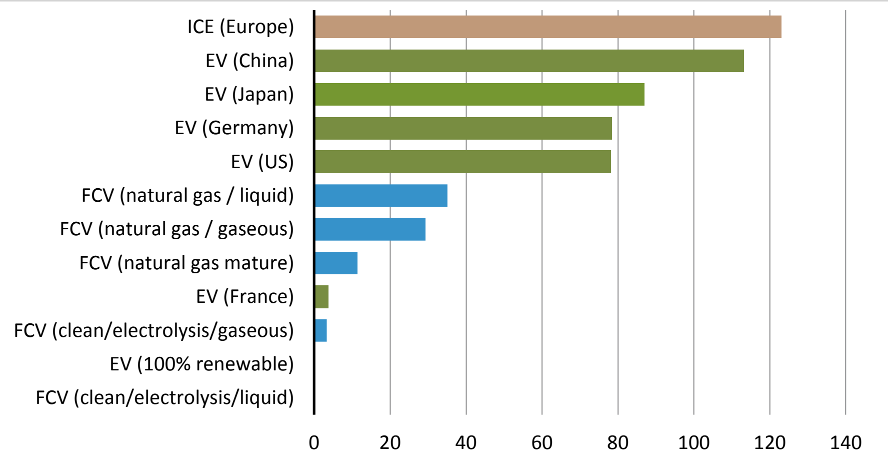
As a consequence of COP21 climate targets, we think governments and regulators will need to accelerate the de-carbonization of the transport sector. We conclude that in the current energy system, FCVs are superior to BEVs in terms of well-to-wheel emissions, given the carbon-heavy electricity mix in many countries; and long-term, in a renewables-driven electricity system, BEVs are the cheapest zero-emissions technology. Viability of BEVs looks even better when taking the storage aspect into account. Our calculations indicate that: (1) the storage capability of a BEV carries substantial value; (2) infrastructure costs for BEVs are only c50% of FCVs'; and (3) the required investment per tonne of carbon saved in an emissions-free scenario is €80-90 (with a declining trend, long term), versus c€50/t avoidance cost in power generation.

CO_2 comparison: Electricity mix matters

The actual "well to wheel" CO_2 emissions of BEVs depend on a given market's electricity mix

The question about "well-to-wheel" CO_2 emissions is relatively easy to answer for ICEs and FCVs, but in the case of BEVs the answer very much depends on the electricity mix in the country where the car is used. The following chart compares the CO_2 emissions of the different technologies for a medium-sized sedan. For BEVs, we run calculations for Germany, France, the US, China and Japan.

Figure 39: CO_2 emissions by technology (g/km)



Source: UBS estimates. Note: Includes CO2 emissions to operate the vehicle. Excludes CO2 footprint of manufacturing and recycling.

ICE cars produce more emissions than electric cars. Even BEVs running in countries with a high proportion of coal generation in the electricity mix, such as China, have lower well-to-wheel emissions than ICE cars. Assuming the share of renewables in the mix will generally increase, not at least as a result of the COP21 climate agreement, the advantage of BEVs should grow further. EVs in France, a country that largely relies on nuclear and hydro power, are today almost zero-emission cars already from a well-to-wheel point of view.

FCVs have CO_2 emissions around 30g/km, which is superior to BEVs in many countries, but FCVs are entirely emission-free only in the case of CO_2-free hydrogen generation via (expensive) electrolysis.

BEVs fit best into the future ecosystem

A key advantage of BEVs is that they fit well into a renewables-powered, decentralised electricity ecosystem of the future.

Figure 40: Key features of BEVs and FCVs from an ecosystem point of view

	BEV	FCV
Storage/power grid balancing	Yes	No
Powering the home	Yes	Yes
Use self-generated solar power	Yes	No
Infrastructure cost	Significant	Higher than BEV

Source: UBS

Storage and self-generation could reduce EV electricity bill by more than half

Monetization of storage and self-generation of electricity could cut annual electricity cost of an EV by up to c60% in some markets

Vehicle batteries will represent millions of storage units that can, when connected to the power grid (the average car has 95% idle time), help to balance volatility in a renewables-powered electricity world. Batteries can be charged and also discharged to stabilise the grid, if the owner wishes to offer this "service" to power utilities. As access to EV batteries would be valuable to grid operators, the BEV owner would be remunerated. This does not work with FCVs. In a renewables-focused power generation system, the value of power storage to the grid operator is around €200 per BEV per year, on our estimates, which accounts for 30-60% of the annual electricity bill for the consumption of the BEV. On a 2025 view, the global value of EV storage available to utilities could be €6bn p.a.

Figure 41: The value of storage could be up to 1/3 of electricity cost of a BEV

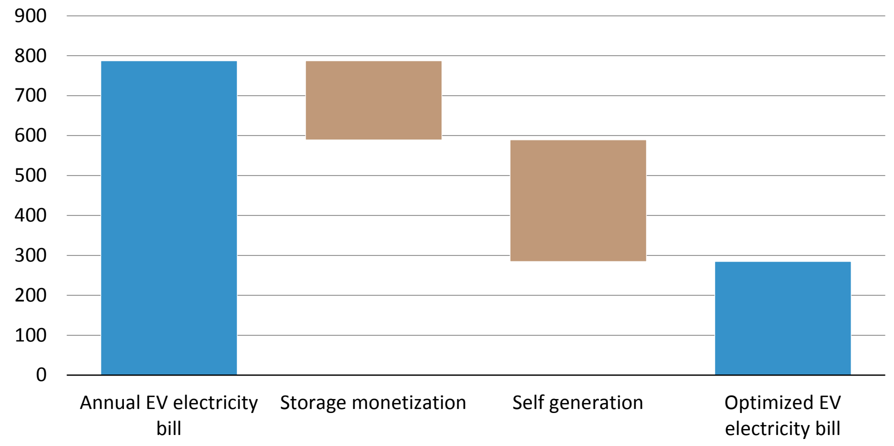
Battery capacity per car (kWh)	60
Capacity available to the grid (%)	33%
Available storage capacity (kWh)	20
Value of storage (€/kWh)	0.05
Number of cycles per year	200
Value per BEV/year (€)	**198**

Source: UBS estimates

The BEV can also be charged by solar panels on the roof of a home. This works even 'virtually' when the car is parked elsewhere, via smart grid solutions. In markets with high power prices, such as California, Japan or Germany, self-generation could substantially lower the electricity bill for EVs. Powering the car through self-generated green electricity could also become an important non-monetary aspect for an increasing number of car owners.

Our analysis suggests that the combination of monetization of storage and self-generation of electricity could reduce the annual electricity cost for the EV by up to c60% in markets with high grid power prices. The graph below uses Germany as example.

Figure 42: EV electricity bill could be lowered by >60% (Germany, € p.a.)



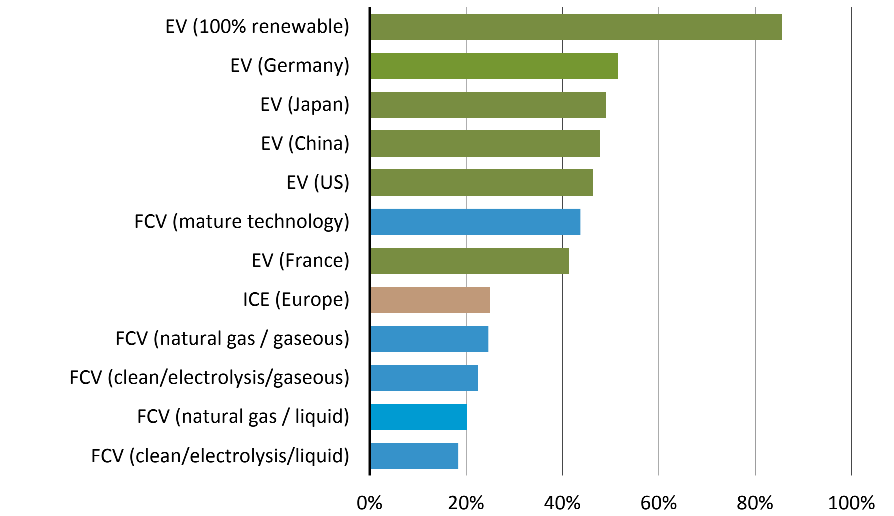
Source: UBS estimates

BEVs require much less power generated per kilometre driven

We estimate that investments in BEV infrastructure will be lower than for FCVs when including the associated investments in power generation and electrolysis capacity, as shown in the analysis below. BEVs' threefold superiority to FCVs in terms of "well-to-wheel" efficiency gives them a substantial advantage when it comes to the need for CO_2-free power generation capacity. In other words, a BEV can drive three times as far as an FCV on the same amount of renewable electricity generated.

We estimate a BEV can go three times further than an FCV on the same amount of renewable electricity generated

Figure 43: 'Well-to-wheel' energy efficiency by technology



Source: UBSe

Comparing the total bill for infrastructure – BEV wins

The following charts summarize our estimates for the infrastructure costs of BEVs and FCVs. We compare the cost in today's "upstream" world, i.e., using existing power generation and natural gas reforming capacity, as well as in a future zero-carbon scenario. Therefore, we also include investments in power generation and hydrogen electrolysis capacity. To compare the required investments, we base our calculation on a scenario of 15m vehicles on the road (BEVs and FCVs each) globally.

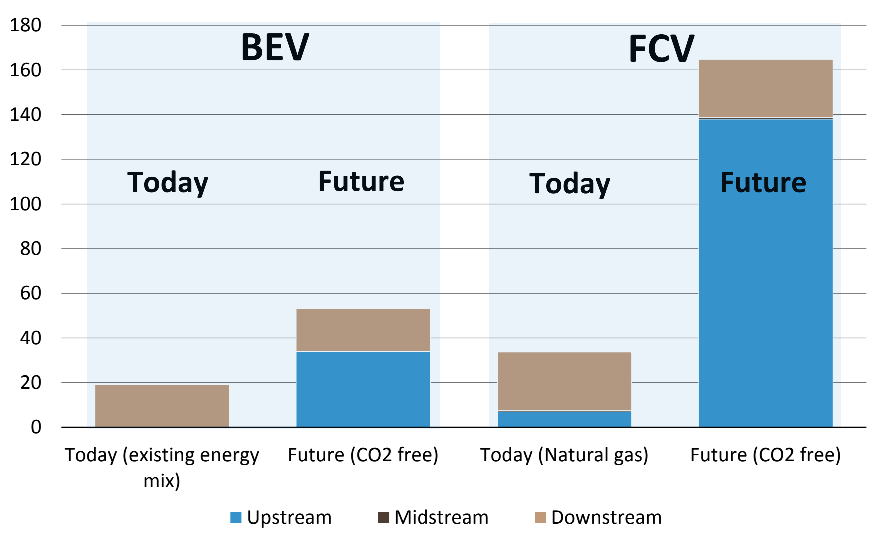
- Due to the efficiency disadvantage of fuel cells (we assume 60% energy efficiency for mature fuel cell technology, which is well above the current c40% and well below the 85-90% for BEVs), the "**upstream**" investments are substantially higher. In other words, more power generators are needed for the same amount of miles driven in an FCV world.

- "**Midstream**" infrastructure, i.e., transport, should also be cheaper for BEVs as the existing power grid can be used, whereas hydrogen requires investment in trucks or pipelines etc. What is not included in our estimates is a potential upgrade of some transformers in local distribution grids, which may be necessary in markets with limited grid reserves.

- **"Downstream"**, i.e., the point of consumption, is the largest cost position for both technologies. BEVs require more charging points, but a significant proportion of the charging can be done at low-power outlets (at home, kerbside, in parking garages) that come at low cost. A limited number of "superchargers" (we assume 52,000 for 15m vehicles) will be required, which can be built at significantly lower cost than hydrogen fuelling stations. Overall, we assume downstream cost should be lower for BEVs.

The detailed calculations behind the below graph can be found in the appendix.

Figure 44: BEV infrastructure is cheaper than for FCVs, in particular in a CO_2-free ecosystem (in €bn for 15m vehicles of each type globally)



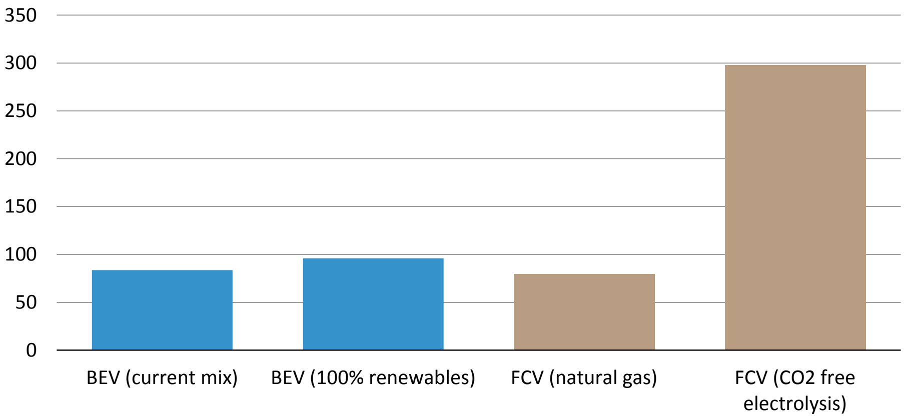
Source: UBS

BEV infrastructure investments cost about €80/t of CO_2 saved

The following chart illustrates the infrastructure costs per year in relation to CO_2 emissions saved. We assume an expected life of 20 years for the infrastructure. Infrastructure cost for BEVs would amount to c€1,300 per car per year with the current electricity mix, or c€3,500/car including investments in renewable power generation infrastructure. We think only a modest element of the investment (low-power kerbside charging infrastructure) will have to be carried out by national or local government. The investment would be equivalent to c€80-90 per tonne of CO_2 saved (compared to ICE cars). For comparison, the cost of CO_2 avoidance in

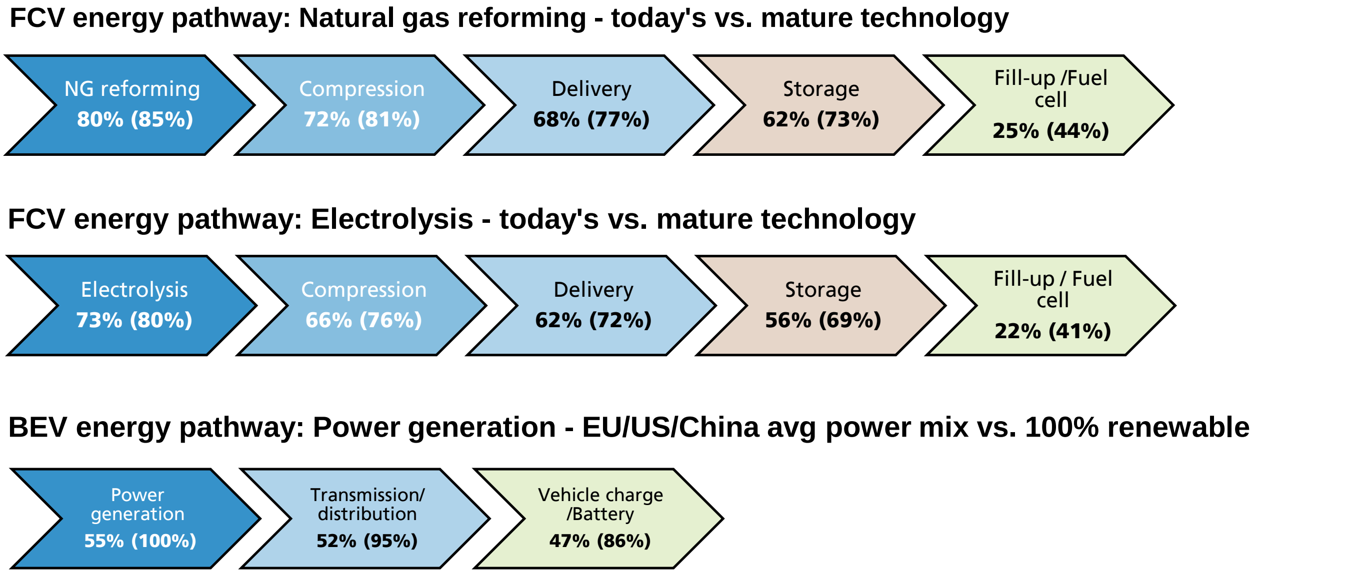
the power generation sector is around €50/t. In our 100%-renewables scenario, the CO_2 avoidance cost includes the EV *and* the power generation element.

Figure 45: BEV infrastructure cost shown as CO_2 avoidance cost (€/t)



Source: UBS estimates

Figure 46: Well-to-wheel efficiency comparison of FCV and BEV, based on today's technology (and mature technology)



Source: UBS estimates

Other considerations and benefits

In our view, BEVs represent the best fit in a car-sharing economy

- The UBS Autos team has done extensive work on how the car-sharing economy will likely disrupt the auto sector. Click here and here to access the reports. We believe that BEVs are the best fit in a car-sharing world. In contrast to ICEs and FCVs, BEVs can be charged while not in use, at the point at which the vehicle is dropped off, i.e., neither users nor fleet operators need to drive to the next gas station for a refill.

- We expect local governments to focus on locally emissions-free driving when signing contracts with car-sharing operators. Hydrogen infrastructure may be more difficult to install than charging stations in major city centres, not least for safety reasons.

- In spite of our detailed analysis, It remains difficult to anticipate the behaviour of consumers regarding the topics of "range anxiety" and to assess the access to charging infrastructure (which also depends on city-level politics). These will remain the key non-quantitative factors to watch.

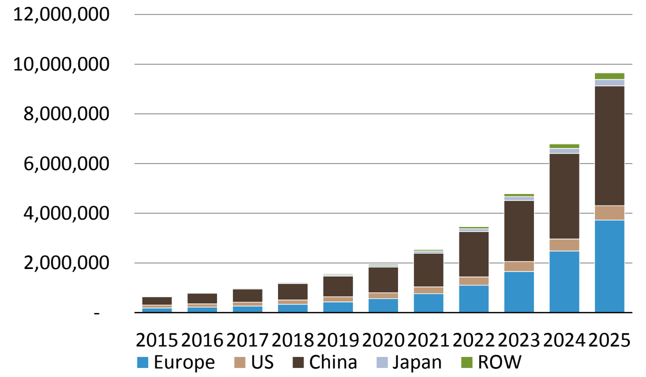
Putting it all together: What does our analysis suggest for EV sales penetration?

We expect EV sales to grow to 2.5m units by 2021, from 0.5m today. While growth in the remainder of this decade will likely be largely driven by regulation and incentives, we expect EV penetration to enter the steep part of the s-curve in the coming decade as TCO declines further. On a 2025 view, we expect 9.7m EVs to be sold, equivalent to 9.2% of global passenger vehicle sales by then. EV penetration rates in new car sales should be around 14% in China and 18% in Europe, on a 2025 view. The acceleration in the coming decade is anti-consensual, we believe. Plug-in hybrids (PHEVs) will be relevant as a bridge technology, but we see their share in the mix declining, long term. We believe the US, however, looks likely to be a laggard with only 3% sales penetration in 2025 on low fuel prices and a less strict CO2 regime, which provides limited incentives for OEMs to push EV sales aggressively.

Global EV sales penetration at 9.2% in 2025

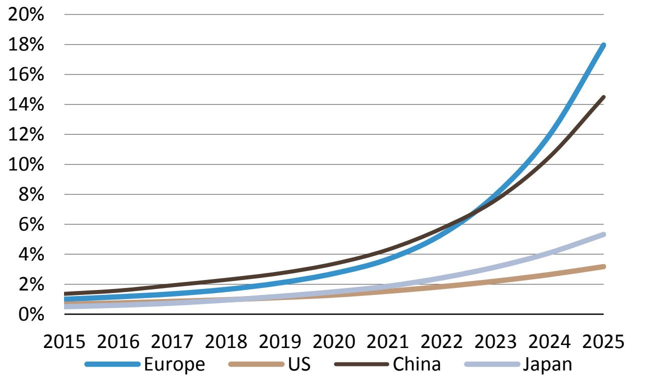
As EVs become more affordable with more mainstream models due to be launched (Chevrolet Bolt, Tesla Model 3), we expect continuous growth in the next few years, albeit from a very low base. Regulation and incentives should be a key growth driver, near term. We expect 2.5m EVs to be sold globally (including plug-in hybrids) in 2021, vs. 0.5m in 2015. The proportion of EVs will likely remain relatively small, though, at an estimated 2.5% in 2021. With the TCO of BEVs falling below that of ICE cars in Europe in China by around 2021/22, we expect an acceleration in global EV sales to 9.7m units, equivalent to 9.2% of global passenger car sales, by 2025.

Figure 47: Trend in annual EV sales (units)



Source: UBS estimates

Figure 48: EV penetration to accelerate over next 10 years



Source: UBS estimates

Looking at EV sales by region, we believe Europe and China are likely to see the highest near-term growth, mainly on the back of purchase incentives and CO_2 regulation. In China, licence plate and rush-hour restrictions in large cities for ICE cars are a key driver of EV demand. We also see the possibility that European cities authorities will begin to require locally emissions-free driving within city limits. The US will likely accelerate only with a time lag, given the current low fuel price situation. Purchase incentives will remain essential for the remainder of this decade, in particular in the US.

We expect Europe and China to see the fastest near-term growth in EV sales, mainly on purchase incentives and CO_2 regulation

Figure 49: EV sales by region (units)

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Europe	185,266	222,319	266,783	333,479	433,522	563,579	760,832	1,103,206	1,654,809	2,482,214	3,723,321
US	116,099	133,514	153,541	176,572	203,058	233,517	280,220	336,264	403,517	484,220	581,064
China	206,400	425,589	531,986	664,982	831,228	1,039,035	1,350,746	1,823,506	2,461,734	3,446,427	4,824,998
Japan	25,328	30,394	36,472	45,590	56,988	71,235	89,044	115,757	150,484	195,629	254,318
ROW	15,000	18,000	21,600	25,920	33,696	43,805	56,946	79,725	119,587	179,381	269,071
Global	**548,093**	**829,815**	**1,010,382**	**1,246,544**	**1,558,492**	**1,951,171**	**2,537,787**	**3,458,458**	**4,790,131**	**6,787,871**	**9,652,772**
Market share		*0.9%*	*1.1%*	*1.3%*	*1.6%*	*1.9%*	*2.5%*	*3.4%*	*4.6%*	*6.5%*	*9.2%*

Source: UBS estimates (including PHEVs)

We expect BEVs to represent the lion's share of EV sales. PHEVs will play a key role during the transition phase, but we expect their share to shrink over the long term as the shortcomings of pure BEVs (range, charging time and infrastructure) become less relevant. FCVs should enjoy a favourable development in markets where government spending on hydrogen infrastructure is significant.

Our market forecasts do reflect incentives which will matter in particular over the next few years, when TCO of EVs are not yet competitive.

Figure 50: EV incentives by country (as of end-2015)

	Tax exemption	Other incentives
Austria	Fuel consumption tax and monthly vehicle tax	
Belgium	Registration tax; 120% deductibility from corp. income of expenses related to use of company cars	
Czech Rep.	Road tax (business cars only)	
Germany	Annual circulation tax for 10 years after first registration	Direct purchase incentive of €3,000-5,000 currently being discussed
Denmark	Registration tax	
Finland	EVs pay minimum rate of CO2 based registration tax	
France	Company car tax	Direct purchase incentive of €6,300; €10,000 for trading in 13y-or-older diesel car
Greece	Registration tax, luxury tax, luxury living tax, annual circulation tax	
Hungary	Registration tax, annual circulation tax	
Ireland	Registration tax relief up to €5,000	Direct purchase incentive of €5,000
Italy	Annual circulation tax for 5 years, then 75% reduction of tax for further 5 years	
Latvia	Registration tax	
Netherlands	Registration tax, annual circulation tax	
Norway	VAT and purchase, road tax, road tolls, tunnel-use charges, and ferry charges (roll-back as of 2018)	Free parking, free charging, and use of bus lanes
Portugal	Registration tax, annual circulation tax	
Romania	Registration tax	
Sweden	Registration tax for 5 years, company car tax reduced by 40%	Direct purchase incentive of up to SEK40k (€4,300)
Slovakia	Annual circulation tax	
UK	Annual circulation tax	Direct purchase incentive of £5,000
US	Up to $7,500 tax credit for EVs (based on capacity), phasing out after 200k vehicles; various state tax credits	
Canada		Ontario: $5,000-8,500; BC: up to $5,000 direct purchase incentive
China	Exemption for purchase tax (10%) for approved NEVs	Purchase subsidies up to RMB110k for EVs with >250km range; exemption from rush-hour restrictions; concessions on number plates/number plate restrictions for ICE cars
Korea	Car tax exemption	Won4m ($3,300) incentive; up to Won12m ($10,000) including local subsidies.
Japan	Eco-car and green vehicle tax-breaks	2/3 of the price gap between EV and comparable ICE; various state incentives up to JPY300,000

Source: ACEA, US DoE, Ontario Ministry of Transportation, EVI, The Wall Street Journal, Tesla

Implications of EVs on the value chain

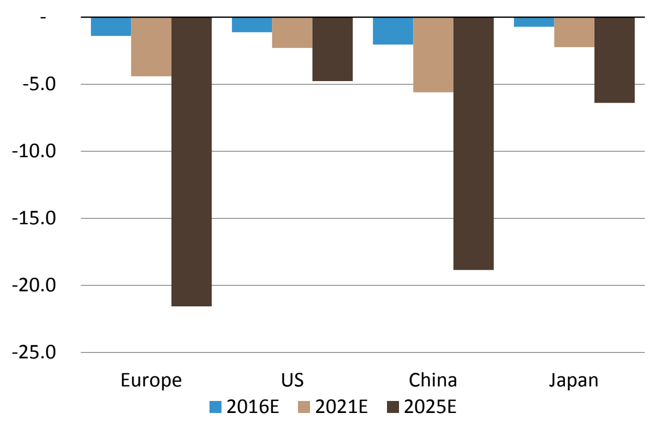
Global OEMs: Higher EV sales a mixed bag

EVs' ROCEs unlikely to match current ICE levels before 2025

We think OEMs are likely to suffer, initially, from higher EV sales, due to lower contribution margins of EVs and large fixed costs, including R&D. Therefore, even with an improving margin contribution over time, we think it will take at least until 2025 for EVs' ROCEs to reach levels similar to those of ICE cars today. Also, it looks increasingly likely that Chinese OEMs and suppliers will disrupt the global competitive landscape. China will likely represent the biggest market, supported by government incentives, and battery know-how already exists because of consumer batteries. We expect to see more Chinese EV exports in the longer term, and would also not rule out the export of EV powertrains to international mass-market OEMs. In this case, powertrains would become more commoditized and therefore pose a (further) risk to industry profits in the mass market.

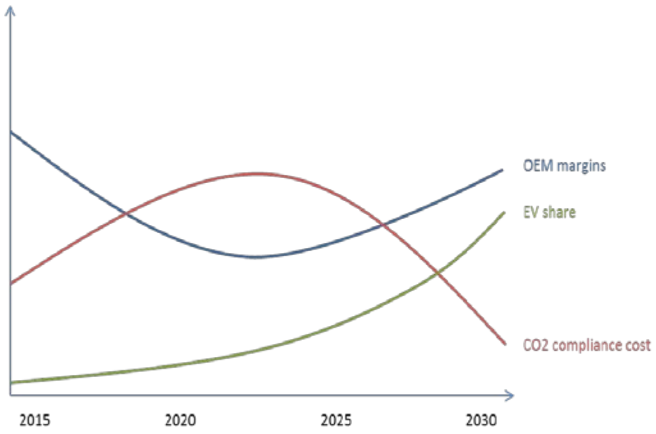
Our EV sales projections for 2021 suggest only a minor positive impact for OEMs from CO_2 targets. We estimate a c4g/km fleet emission reduction in Europe and the US thanks to EVs (excluding PHEVs). Also, we believe that EVs sold will have substantially lower contribution margins than the ICE portfolio, even more should OEMs need additional EV sales to meet 2021 CO_2 targets. On a 2025 view, however, consumers are likely to choose EVs thanks to favourable TCO. By then, we expect the EV margin situation to improve for OEMs as the cars will no longer need to be incentivised by OEMs. Also, a rapidly rising EV penetration should reduce the cost of complying with 2030 CO_2 targets (which have yet to be defined) to almost zero, and therefore represent a major source of relief for OEM investment budgets.

Figure 51: EV contribution to fleet CO_2 emissions (g/km)



Source: UBS estimates

Figure 52: How EVs will reduce CO_2 compliance cost, long term (conceptual illustration)



Source: UBS estimates

We think the future success of EVs will likely be driven by a combination of the following factors:

- The extent to which EVs are the **core of an OEM's long-term investment strategy**, including presence in (plug-in) hybrids, which should generate synergies and additional scale;
- Solid **cash generation** from "legacy" businesses to fund the transformation; and

- Scale via **partnerships** with other OEMs to share the investment burden.

The table below screens UBS's global OEM coverage against these criteria. We use EBIT margins over the past five years as a proxy for cash generation over the cycle.

Figure 53: OEM EV heatmap – who are the potential winners and losers?

Name	UBS rating	# of BEV/FCVs on sale (2016E)	EV invest-ment focus	EBIT margin last 5 years	Partnerships with other OEMs	What's priced in?
BMW	Neutral	1	High	11.2%	FCV partnership with Toyota	Zero
Daimler	Buy	2	Medium	7.8%	FC powertrain with Ford/Nissan, compact BEV powertrain with Renault	Zero
FCA	Neutral	1	Low	2.7%	-	Zero
PSA	Neutral	3	Low	0.2%	BEV partnership with Mitsubishi (current) and Dongfeng (future)	Zero
Renault	Buy	4	High	1.3%	BEV powertrain with Nissan/Daimler	Zero
VW	Buy	2	Medium	5.8%	FCV partnership with SAIC (Chinese JV partner)	Zero
Ford	Buy	1	Low	3.4%	FC powertrain with Daimler/Nissan	Zero
GM	Buy	2	Medium	3.0%	FCV partnership with Honda	Zero
Tesla	Sell	2	High	Negative	-	1m deliveries in 2025 plus full storage utilization
Nissan	Buy	2	High	5.4%	FC powertrain with Daimler/Ford; BEV powertrain with Renault/Daimler	Zero
Honda	Neutral	1	Medium	5.0%	FCV partnership with GM. Stronger focus on FCVs	Zero
Toyota	Neutral	1 (FCV)	Medium	7.4%	FCV partnership with BMW; comprehensive partnership with Mazda. Stronger focus on FCVs.	Zero
Hyundai	Buy	2 (1 BEV, 1 FCV)	Medium	7.6%	BEV powertrain with Kia	Zero
Kia	Buy	1	Medium	5.4%	BEV powertrain with Hyundai	Zero
Mitsubishi	Not covered	1	Medium	4.3%	BEV partnership with Nissan; PSA	-
Yutong Bus	Buy	8	High	9.4%	-	Reduction of 6-8 meter NEV bus subsidy and no future sales contribution from 8-12 meter & above 12 meter bus sales.
Jianghuai	Buy	4	High	1.2%	-	No robust EV sales volume growth and earnings contribution from EV sales.

Source: Company data, UBS. Only BEVs and FCVs, excluding hybrids.

Tesla, GM, BMW, Renault/Nissan and Toyota lead the way in the EV space, based on our analysis

Overall, we believe **Tesla**, **GM**, **BMW**, **Renault/Nissan** and **Toyota** are the most advanced OEMs in the EV space, and we see **Daimler**, **Volkswagen** and **Honda** among the fast followers. Except for Tesla, the OEMs have only a marginal share of BEVs and FCVs in their mix. While European, US and Chinese OEMs have a stronger focus on BEVs, Japanese and Korean OEMs have both BEVs and FCVs in their portfolios. Furthermore, we expect Apple to arrive with a BEV in around 2018. Tesla, which is the only dedicated BEV producer, largely depends on external funding of its growth plans, which makes its investment plans less certain in the event of a down-cycle, we believe.

A detailed table with current and future EV models sorted by OEM can be found in the *Appendix*. We discuss each briefly below.

Europe

- **BMW** is fully focused on BEVs under the "i" brand. While the i3 has had limited success so far due to its low journey range and its positioning in a price-sensitive segment, we believe the planned larger i5 (likely an SUV, to be launched in 2019-20) could prove to be more successful from a financial standpoint.

- **Daimler** has a battery-electric version of the Smart and B Class, and will launch a fuel cell version of the GLC SUV in 2017. The company has indicated a large BEV launch by 2020, at the latest. Unlike BMW, Daimler sells electric cars under its existing brand structure and may act in a more opportunistic way than BMW.

- **Volkswagen** has announced it will launch BEVs under the Audi (SUV) and Porsche (sports sedan) brands in 2018, with a c500km range. In the wake of the diesel issue, VW has also announced it will develop a modular electric platform for implementation across mass-market brands, similar to the MQB.

- **Renault** currently has 4 models on offer: the Twizy (car sharing, communication tool), Fluence (no longer sold in Europe, built in Korea, could be introduced in China), Kangoo (deliveries and fleet) and Zoe (mainstream). Renault has not announced any major launches since it already has good market coverage. We believe Renault could be one of the main beneficiaries of an improved TCO and higher-than-expected volumes.

- **PSA** remains a marginal player in EV and currently offers the I-on and Citroen C0. It is planning to launch another EV by 2020. We expect the company to provide more details on future plans during its capital markets day on 5 April.

- **FCA** is not pursuing a proactive EV strategy at present. Instead, we see the company as a follower, likely pursuing an R&D-light strategy driven, in our view, by balance sheet constraints.

Japan/Korea

- **Toyota** self-produces core components used in HEVs and BEVs, including batteries, motors, PCUs, etc. It already produces over 1m HEVs/year and has a cost advantage in BEVs as well. The main source of improvement in average fuel efficiency lies in its HEVs, where volume growth is expected. For a long-term response to environmental regulations, Toyota takes a portfolio approach of pursuing all products. Proactive in developing technology for BEVs, Toyota categorises them as short/medium-range commuter cars. It also provides small EVs to car-sharing businesses for testing purposes.

- **Nissan:** Together with Renault, Nissan places BEVs at the core of its next-generation zero-emission cars. The range of the "Leaf" has grown to 280km and Nissan/Renault's combined BEV sales were the largest globally in 2015. While the company has not made any official announcements regarding future BEV models, we expect an expansion in the number of models to maintain leading position in the space.

- **Honda:** Like Toyota, Honda has a full line-up of HEV, PHEV, EV, and FCV cars. It views BEVs as short-medium range commuter cars. The company aims for PHEV/BEV/FCVs to comprise 2/3 of total sales by 2030.

- **Hyundai/Kia Motors**: HEVs, PHEVs, EVs and FCVs are a long-term group focus. Hyundai and Kia Motors combined plan to increase the number of these models to 22 by 2020 from 7 in 2015. By 2015, Hyundai and Kia had launched green versions of the following existing models: HEV (Sonata, Grandeur, K5, K7), PHEV (Sonata), EV (Soul), and FCV (Tucson). In January 2016, Hyundai launched the Ioniq HEV from its own platform, and plans to launch EV and PHEV versions of the model in 2016. Kia plans to launch the Niro HEV in 2016. Hyundai has increased its focus on EV, but also focuses on FCV.

US

- **Ford** currently has one BEV in production, the Focus Electric. It plans to refresh the Focus Electric, increasing its range from 76 miles to about 100 miles. The new 2017 model is to begin production late 2016. Ford also has a line-up of HEV and PHEV vehicles including the Focus C-Max, Mondeo, and Lincoln MKZ.

- **GM** was one of the first OEMs to invest in PHEV, launching the Volt in 2010. The Volt was just refreshed late last year, dropping the weight of the vehicle and improving the all-electric range from 38 miles to 53 miles. Additionally, GM produces the Cadillac ELR PHEV and two BEVs, the Spark and upcoming Bolt. GM expects the Bolt BEV to appeal to the mass-market with a 200-mile range and price of only $30k after incentives.

- **Tesla** is currently the only OEM purely focused on BEVs, producing the Model S luxury sedan and the Model X luxury SUV. The mass-market Model 3 is planned to go into production in late 2017.

China

- **Yutong Bus** is the largest bus producer in China, with a c23% total bus market share as of 2015. The company started selling new-energy buses in 2012, selling c.20k in 2015, and accounting for 20% of the Chinese NEV bus market. Its NEV product mix includes pure electric buses (8 products), plug-in hybrid electric buses (8) and LNG buses (13).

- **Jianghuai** started NEV passenger car production in 2014 and currently has two EV models, the IEV4 and IEV5. Its EV sales represented about a third of the total NEV market in Beijing in 2015. Over the next 12 months it plans to launch two new NEV models, the IEV6 and IEV6S. We believe Jianghuai will continue to benefit from Beijing's expansion of the licence plate quota for NEVs.

Suppliers – who's hot and who's not?

In order to assess the risks and opportunities for the suppliers, we look at today's revenue and EBIT contributions from their ICE powertrain-related businesses (engine and transmission parts, exhaust gas treatment, etc), and their activities in the field of EVs. We see **Continental** and **Delphi** as key winners from higher EV penetration.

Figure 54: Suppliers – EV exposure by company

	Powertrain (2014/15)			
	as % of sales	as % of EBIT(DA)	Product offering in BEVs/FCVs	EV content
Autoliv	NA	NA	NA	NM
Continental	18%	9%	– Sensors and actuators	1.9-3x ICE
			– High-voltage axle drives	ICE content
			– Power electronics	
			– Battery management systems	
			– Inverters and DC/DC converters	
			– Electric water pumps	
			– Conti has invested €1bn in EVs	
Faurecia	36%	43%	NA	NM
Valeo	25%	26%	– Battery thermal management for PHEV/EV	NA
			– Power electronics	
			– On-board battery chargers	
			– DC/DC converters	
			– Range extender generators	
Denso	35%	NA	– Engine power control units	Has higher content in HEV than in BEV
			– ECU (engine control units)	
			– Electric compressors	
			– DC-DC converters	
			– System main relays	
			– Battery current sensors	
			– Battery monitoring units	
Lear	23%	36%	– Wire harnesses	Wiring 2x ICE content
			– Terminals and connectors	
			– Advanced efficiency systems	
Delphi	53%	55%	– Inverter and converters	Average ICE content of US$300-400
			– Battery controller	HEV is 4-5x
			– High-voltage battery packs	EV is up to 7-8x
			– Battery cooling – air/liquid	
			– Power electronics	

Source: Company data, UBS

- **Autoliv** should not experience a meaningful impact on sales from a shift towards EV since, assuming cars are not fully automated by then, cars will still require seatbelts and airbags (80%-plus of group sales). Autoliv might benefit from the higher electronic content required in an EV.
- **Continental's** true exposure to EV is running at about €150m (less than 1% of auto division sales) and the activity is loss-making. The legacy cost of a shift

towards 100% penetration could reach €3-3.5bn, or about 15% of auto division sales). However, Conti claims the content offered for FCV-related business is three times higher than for the equivalent gasoline-related business. Assuming a similar market share to the one Conti currently has in Powertrain, Conti expects a slight positive impact from this shift.

- **Faurecia** is the leader in emissions control. The key products within Emissions Control Technologies (ECT) are catalytic converters, diesel particulate filters, mufflers and exhaust heat recovery manifolds. Those products will not be required in an EV. ECT represents 40% of Faurecia' sales and 40-45% of Faurecia's EBIT (adjusted for exteriors disposals). In 2015, ECT generated sales of €7.5bn (of which 44% monoliths) and an EBIT of €360m (margin of 4.8%).

- **Valeo's** true exposure to EV today is very limited (less than 1% of group sales). For the Powertrain division, we see the following potential impacts related to a 100% penetration of EVs: (1) some products will disappear, such as transmissions and clutches; (2) some products will benefit, such as electric motors, inverters, converters, battery chargers. Powertrain Systems represents c25% of group sales and EBITDA. Within Thermal Systems (28% of sales; 24% of EBITDA), the higher content will come from battery thermal management. There could also be a negative impact on aftermarket (13% of sales; 25% of EBIT [UBSe]) since there are fewer parts in an EV than in an internal combustion engine.

- **Lear** should see a boost from a shift towards EV. Electronics and electrical architecture currently drives about 23% of revenue. EVs should drive twice the wiring content. We think seating is unlikely to be impacted by EVs; rather a shift towards more connectivity in the seat ("intelligent seat", biometrics, seating positions, etc) should leverage additional electrical content.

- **Delphi** looks well positioned to gain from EV penetration. Its E&A (electrical & electronic architecture) business (53% of sales) should benefit from increased wiring and connector content on BEVs and HEVs. E&S (electronics & safety, 18% of sales) is an area where Delphi is aggressively pursuing market share and should benefit from increased sales of inverters, converters, hybrid control units and battery packs. Loss in traditional powertrain (29% of sales) content should be offset by gains of its supervisory controller device.

- **Denso** makes key components, such as motors, invertors, converters and ECUs for HEV/PHEV/BEVs, and supplies software to control entire vehicle systems. It is a main supplier for Toyota HEVs, which makes more than 1m units annually, and has a competitive edge over global competitors in terms of cost and mass production system. It makes automotive semiconductors internally, and accumulates knowledge of technologies and cost structure. It also has alliances with major semiconductor manufacturers such as Intel, and maintains cost competitiveness. It has a number one position in A/C systems, which is a key component for BEVs. It has been expanding its A/C market share in developed countries with sophisticated energy and temperature control technologies.

Other industries impacted by rising EV sales

We believe the trend of electrification will be disruptive not just for the OEMs and the auto suppliers industry:

Potential structural winners

- Battery and component/materials suppliers and battery recycling services;
- (Renewable) electricity suppliers and power grid operators on higher electricity demand.

Potential structural losers

- Entire oil value chain;
- Auto dealerships due to shrinking maintenance business (EVs are likely to require less service)

Batteries: Manufacturers growing capacity in line with projected EV growth

We think global battery capacity can support BEV growth, assuming manufacturers' capacity expansions proceed as planned

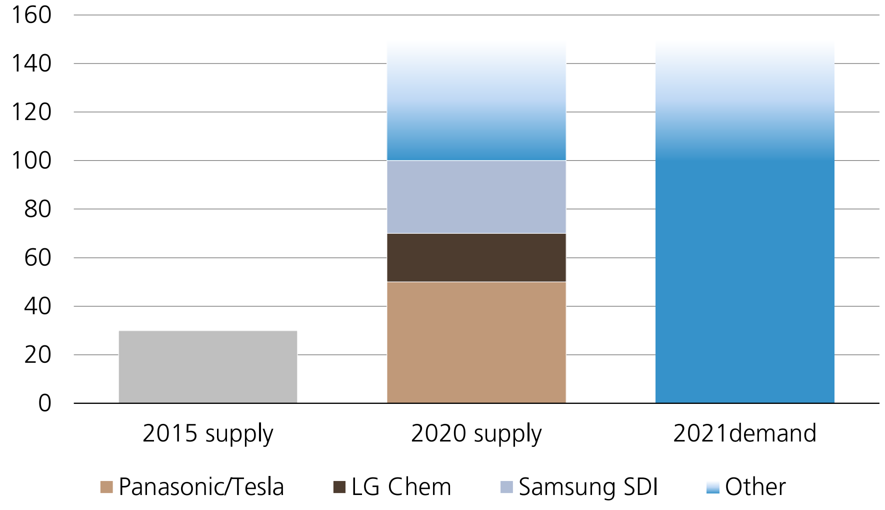
Our recent checks suggest average battery capacity is now 30kWh for passenger vehicles and 200kWh for commercial vehicles. We assume battery capacity per pack increases by about 10% per annum until 2020 for both passenger vehicles and commercial vehicles. As a result, we estimate total battery demand for BEVs will be around 125-150GWh by 2020, including passenger vehicles and commercial vehicles. From a supplier standpoint, this implies global capacity should have grown by 4-5x by then, given we think the current global capacity is around 30GWh.

Is this achievable? Yes, we think so, considering the capacity expansion plans of major EV battery players and the feasibility of their plans. Global battery makers are aggressive on expanding their capacity. For example:

- **Panasonic** currently has an 18% global market share, and is to add the new Gigafactory with Tesla, which should have 50GWh capacity by 2020, according to the company.
- We expect **LG Chemical** to increase its capacity by c5x to c20GWh by 2020.
- We estimate **Samsung SDI** will increase its capacity for mid/large size batteries by about 6x from 2015 to 2020, to around 30GWh.

We think global battery capacity can support the growth of BEVs, assuming capacity expansions proceed on schedule. Are their plans feasible? Yes, we think so. Battery makers have hitherto spent about $100m for a production line to manufacture c.1-1.5GWh of batteries per year. For a normal size fab with 3-5 production lines, shells and infrastructures have required additional $200m, depending on actual sizes. Consequently, we think the global battery industry would need around $13-18bn to build the required capacity mentioned above, and we believe this is possible, though we see some potential for capex to be lower than this, driven by increasing capacity per production line thanks to technology improvements.

Figure 55: Battery capacity growth (GWh) to support expected demand



Source: Company information, UBS estimates

Does this mean the entry barrier of the EV battery industry is low? Not really. Unlike the components used in other applications, for instance smartphones, EV components are directly related to human safety, and thus the experience and track record of suppliers and parts is key. We believe the standards of existing products/models would likely act as a barrier to entry. All in all, we think the beneficiaries are likely to be existing players rather than newcomers. Of the existing players, we think the current top-ranked names have a greater opportunity, as their capacity and client bases should give them an advantage when it comes to R&D, increasing capacity and acquiring new clients.

Appendix

EV model line-up

Figure 56: BEV line-up (ex China)

OEM	Model name	Launch year	Range km	Range miles	Price (basic) €	Battery capacity kWh	Charging time mins	Engine HP	Market
					Available today				
Daimler	Smart Electric Drive	2009	145	90	23,700	18	60-420	75	Global
Mitsub.	Mitsubishi i MiEV	2010	100	62	21,600	16	60-480	67	Global
Peugeot	Peugeot iOn	2010	150	93	17,850	15	60-360	67	Europe
Peugeot	Peugeot C- Zero	2010	150	93	17,850	15	60-360	67	Europe
Renault	Renault Twizy	2011	100	62	7,000	6	210	17	Europe
Renault	Renault Kangoo Z.E.	2011	170	106	20,300	22	360-540	60	Europe
Renault	Fluence Z.E.	2011	160	99	26,000	22	30-480	94	Global
Nissan	Nissan Leaf S	2011	135	84	26,400	24	60-300	107	Global
Nissan	Nissan Leaf SV	2011	172	107	30,900	30	60-300	107	Global
Tesla	Tesla Model S - 70D	2012	385	240	84,000	70	60	315	Global
Tesla	Tesla Model S - 90D	2012	460	288	98,500	90	60	373	Global
Ford	Ford Focus Electric	2012	122	76	26,540	23	215	130	US
Bolloré	Bolloré Bluecar	2012	200	124	19,000	30	360	68	France
Renault	Renault Zoe	2013	170	106	21,500	22	60-360	88	Europe
BMW	BMW i3	2013	135	84	35,000	19	60-300	170	US/Europe
VW	VW e-Up!	2013	120	75	27,000	19	60-480	82	Global
FCA	Fiat 500e	2013	140	87	29,100	24	240	111	US
GM	Chevy Spark EV	2013	130	81	23,600	19	60-420	140	US
Honda	Honda Fit EV	2013	130	81	32,700	20	180-720	75	Global
VW	VW e-Golf	2014	130	81	35,000	24	60-480	115	Global
Daimler	Mercedes B-Class ED	2014	200	124	39,200	28	144	179	US/Europe
Kia	Kia Soul EV	2014	160	99	28,000	27	60	111	Global
Nissan	Nissan e-NV200	2014	170	106	24,000	24	60-480	109	EU/Japan
Tesla	Tesla Model X	2015	350	217	80,000	70	60	328	Global
					Announced/planned				
Hyundai	Honda Ioniq EV	Q3 16	250	155		28		120	Global
BMW	BMW i3 (upgrade)	2016	193	120		30			Global
Peugeot	Citroen e-Mehari	2016	100			30	480-780	48	France
GM	Chevy Bolt	2016/17	322	200	34,000	60		200	US
GM	Opel Ampera-E	2016/17	322	200		60		200	EU
Tesla	Tesla Model 3	2016/17	322	200	31,800	28			Global
VW	e-Golf (upgrade)	2016/17	174	108		31			Global
Daimler	Smart EV	2016/17							Global
VW	Porsche Mission E	2018	500	310			30	582	Global
VW	Audi e-tron quattro	2018	500	310					Global
Daimler	Mercedes B-Class ED (upg.)	2018							Global
Apple	Apple Car	2018							?
BMW	BMW i5 or i6	2019/20	500						Global
Daimler	Mercedes EV	2019/20	>400						Global
Renault	Low-cost EV for China	?							China
VW	Skoda EV	2019/20							?

Source: Manufacturer data, UBS

Figure 57: FCV line-up

OEM	Model name	Launch year	km	Range miles	Price (basic) €	Battery capacity kWh	Charging time mins	Engine HP	Market
					Available today				
Toyota	Toyota Mirai	2014	500	310	57,500	-	-	150	Global
Hyundai	Hyundai ix35/Tucson FC	2015	600	370	65,450	-	-	136	Global
					Announced/planned				
Honda	Honda Clarity FC	Q2 16	700	345	63,000				Japan
Daimler	Mercedes GLC SUV	2017							
Nissan	FCV	By 2017							
BMW	FC luxury sedan	2020							
Toyota	Lexus LF-FC	?							
VW	Audi h-tron quattro	?	600	373				150	

Source: Manufacturer data, media reports, UBS

External cost estimates

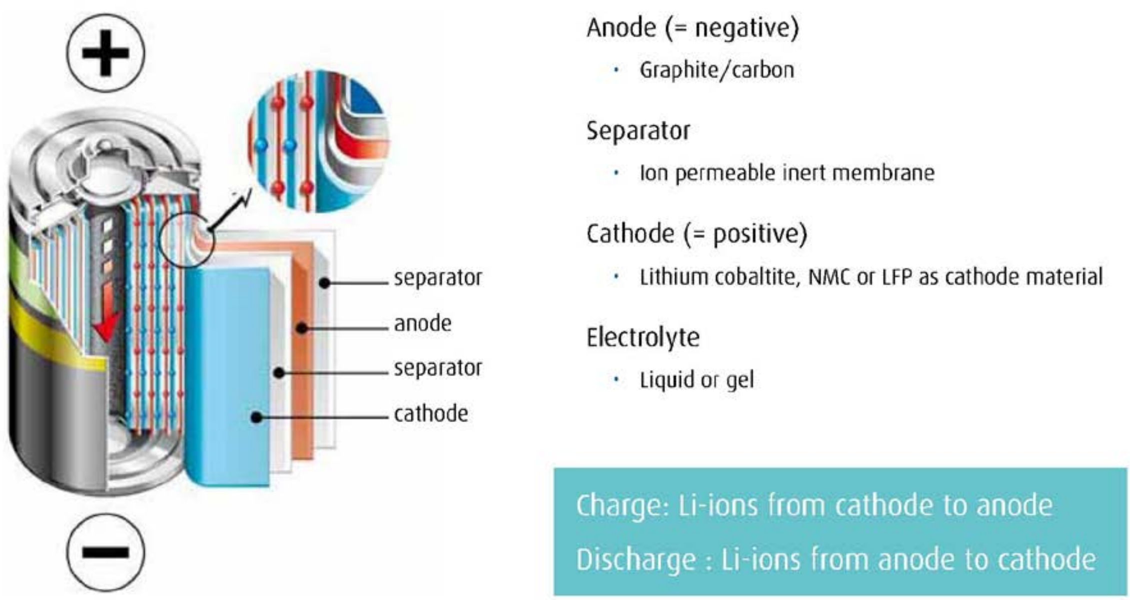
Figure 58: External battery cost estimates ($/kWh) reviewed for this report

Total pack cost $/kWh	Time of est.	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Tesla	2014					200-300							150-200					100
Tesla	2015												100					
GM	2015									145-245			120		100			
Auto Lectrification	2014						311-361						208-252					133-155
US Dept. of Energy	2014					325	300								125			
MIT (Sakti et al.)	2014						190-330											
MIT (Industry expert interviews)	2015							200-300			170							
Stockholm Environment Institute	2015	600-1250	410-1100	400-880	280-820	280-700	250-500											
Umicore	2014	1100					360						200					
USABC (Industry)	2013												250					
Johnson Matthey	2012				500-900													
Johnson Matthey	2015							300										
Bloomberg New Energy Finance	2015		950	800	650	550	500	350					200					
Argonne National Lab	2013					220-360												
LG Chemical	2010		625															
Avicenne Energy	2015						500	400					250					
Australian Renewable Energy Agency	2014						550			300			200					
Advanced Automotive Batteries	2014					310	280	260	250	240	230	215	190		170			150
VTT Tech. Research Centre of Finland	2014							185-215										

Source: Sources named in the table; UBS

Deep dive into battery technology

Figure 59: Basic components of a lithium-ion battery cell

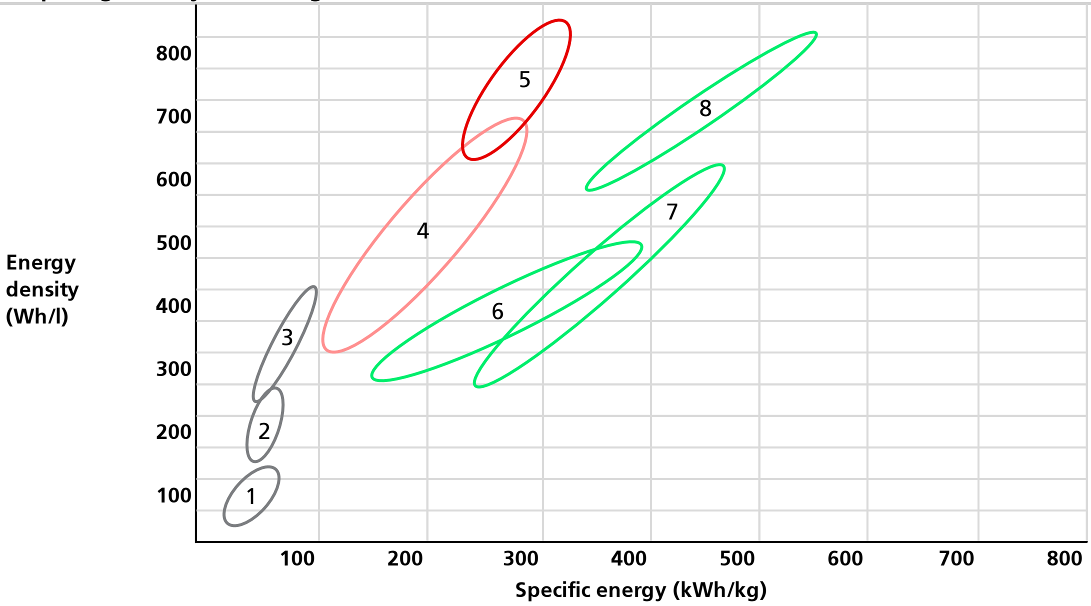


Source: Umicore

Types of battery

The first generations of lithium-ion batteries came to market in 1991. The next generations are currently under development, but will most likely not be commercialised within the next 10 years. The following figures summarize the most important differences among existing and future battery technologies.

Figure 60: Comparing battery technologies (1)



Source: Johnson Matthey

Figure 61: Comparing battery technologies (2)

	Battery technology	Introduction	Use in cars
1	Lead Acid	~1930	Starting Lighting Ignition (SLI) - conventional car battery
2	Nickel Cadmium (mostly banned)	1956	-
3	Nickel Metal Hydride	1989	HEV - Mild and Full Hybrids (but also starting to use li-ion)
4	Conventional Li-ion	1991	PHEV
5	Next Gen Li-ion	~2005	EV
6	Li-Metal	Under development	
7	Li-Sulfur	Under development	
8	Zinc Air	Under development	

Source: EU regional development fund, JMAT, NSR E-Mobility

Figure 62: Performance heatmap of different li-ion battery types (cathode materials)

		Performance					
		Energy	**Power**	**Safety**	**Life**	**Cost**	**Applications (status 2015)**
LCO	Lithium cobaltite						
LMO	Lithium manganese oxide						Nissan Leaf, Chevrolet Volt, Renault Zoe
LFP	Lithium iron phosphate						Chevrolet Spark EV
NCA	Nickel cobalt aluminium						Tesla Model S
NMC	Nickel manganese cobalt						VW eUp, VW eGolf, BMW i3, Smart ED, Fiat 500

Source: Umicore, VTT

Figure 63: Key attributes of different battery technologies

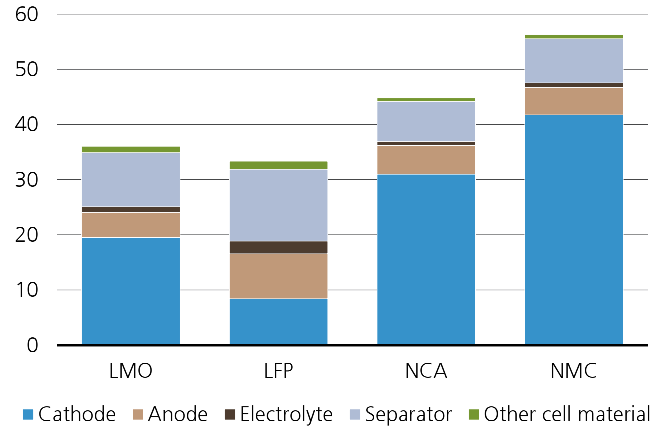
					Lithium-ion				
Attribute	Unit of measurement	Lead Acid	NiCad	NiMH	LCO	LMO	LFP	NCA	NMC
Cell Voltage	Volts	2	1.2	1.2	3.6	3.8	3.2	3.6	3.7
Specific Energy	Wh/kg	30-40	35-80	55-110	150-240	100-150	90-120	200-260	150-220
Energy Density	Wh/l	50-90	50-70	160-420	400-460	240-360	190-300	490-670	260-400
Power Density	W/kg	100-200	100-150	100-500	500-5000	500-5000	500-5000	500-5000	500-5000
Speed of discharge	Rate	6-10C	20C	15C	1C	3-10C	5-10C	2-3C / 1C	3-6C / 1-2C
Speed of charge	Rate				0.7-1C	0.7-1C	1C	0.7-1C	0.7-1C
Useful Capacity	Depth of Discharge %	50	50	50-80	>80	>80	>80	>80	>80
Charge Efficiency	%	60-80	60-80	70-90	>95	>95	>95	>95	>95
Self-Discharge	%Month	3-4	15-20	15-30	2-3	2-3	2-3	2-3	2-3
Temperature Range	°C	-40 to 60	-20 to 70	-20 to 65	-20 to 60	-20 to 60	-20 to 60	-20 to 60	-20 to 60
Cycle Life	# full cycles before capacity reaches <80%	200-400	300-1000	500-1000	500-1000	1000	1000-2000	500	1000-2000
Memory Effect		No	Yes	Yes	No	No	No	No	No
Micro-Cycle Tolerance		Poor	Poor	Yes	Yes	Yes	Yes	Yes	Yes
Robustness (Over/under Voltage)		Yes	Yes	Yes	Needs BMS	Needs BMS	Needs BMS	Needs BMS	Needs BMS

Source: Johnson Matthey, Battery University

Battery cost

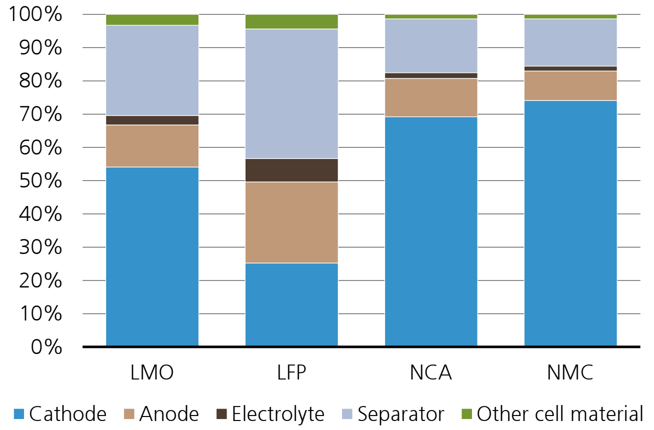
Below we analyze the raw material components of the cathode and their costs (at current raw material prices).

Figure 64: Battery materials cost ($/kWh)



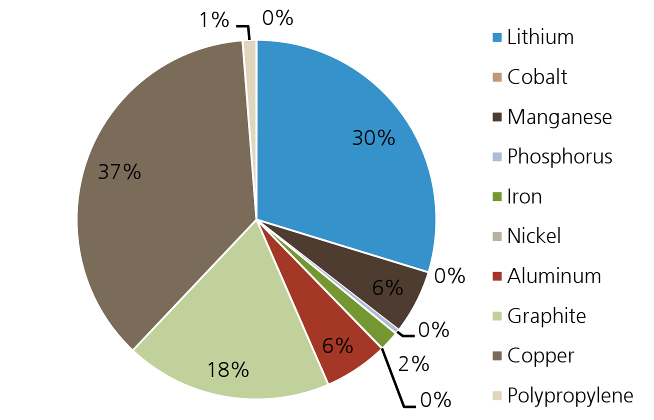
Source: UBS

Figure 65: Battery materials cost (% of total bill of mat's)



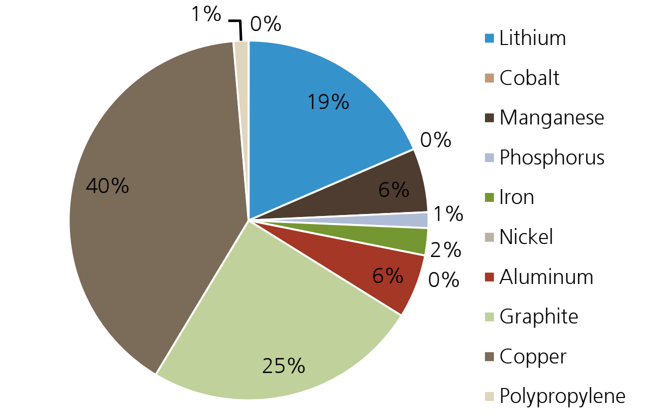
Source: UBS

Figure 66: Total active material bill of materials (LMO)



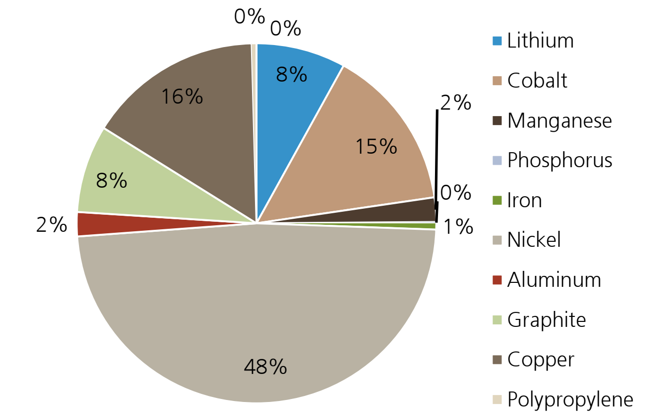
Source: UBS

Figure 67: Total active material bill of materials (LFP)



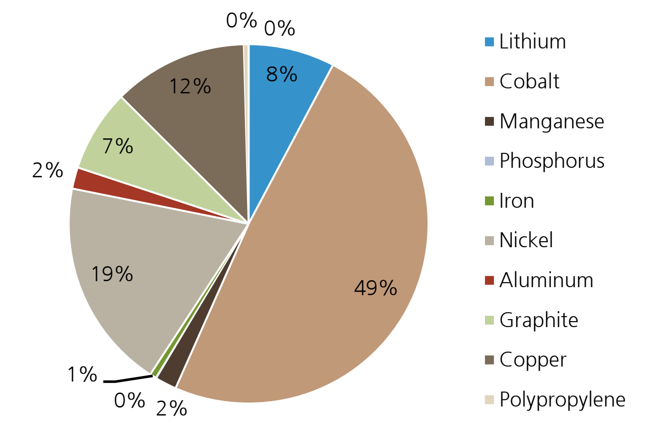
Source: UBS

Figure 68: Total active material bill of materials (NCA)



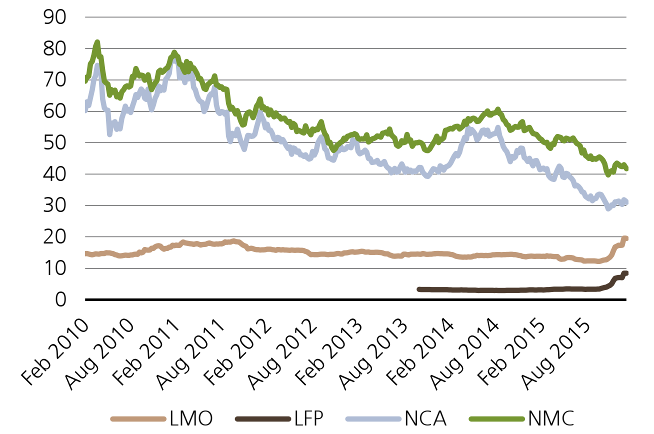
Source: UBS

Figure 69: Total active material bill of materials (NMC)



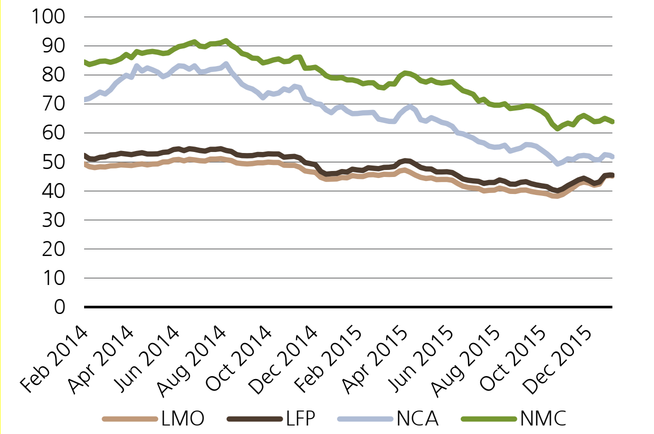
Source: UBS

Figure 70: Li-ion cathode cost by technology ($/kWh)



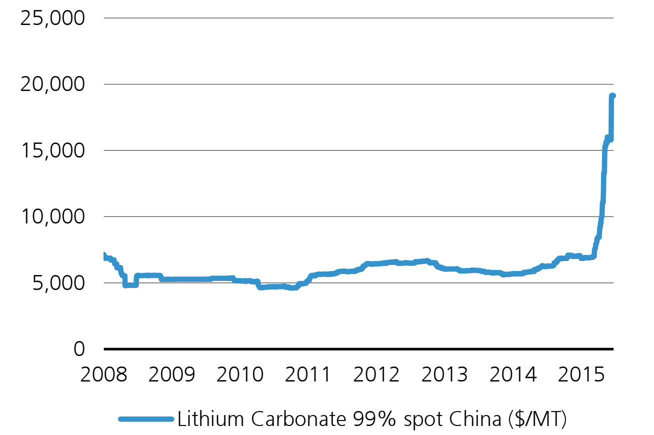
Source: Datastream, Bloomberg, UBS

Figure 71: Li-ion total active cell material cost by technology ($/kWh)



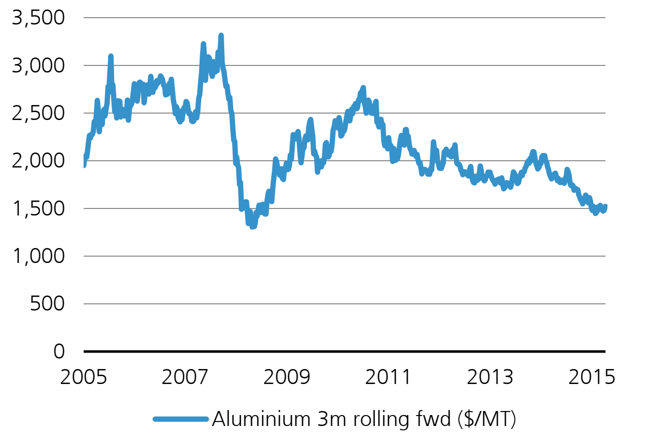
Source: Datastream, Bloomberg, UBS

Figure 72: Lithium Carbonate 99% spot China ($/MT)



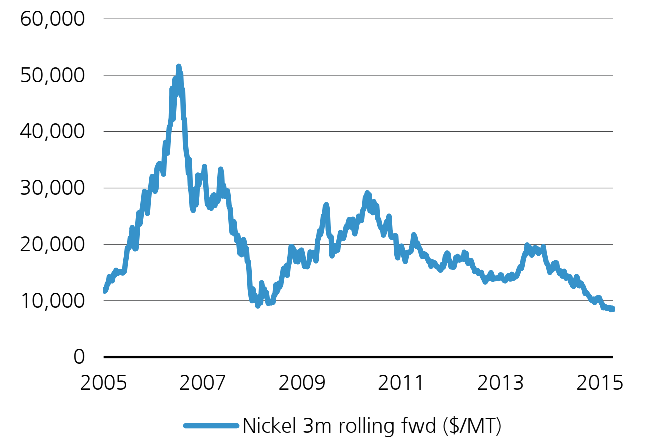
Source: Datastream

Figure 73: Aluminium 3m rolling fwd ($/MT)



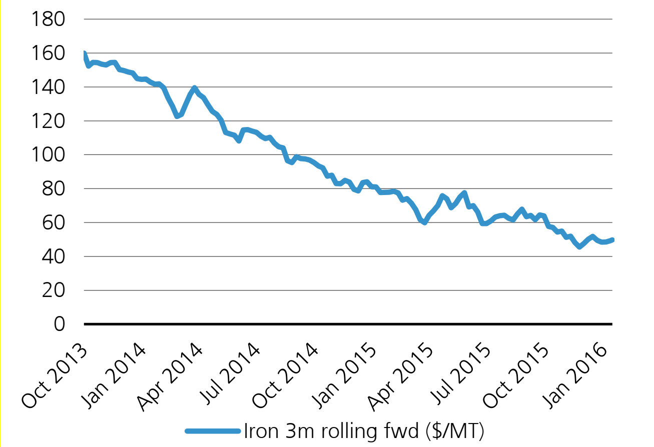
Source: Bloomberg

Figure 74: Nickel 3m rolling fwd ($/MT)



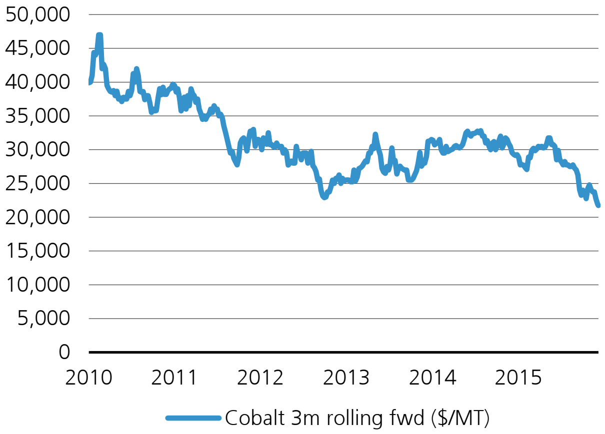
Source: Bloomberg

Figure 75: Iron 3m rolling fwd ($/MT)



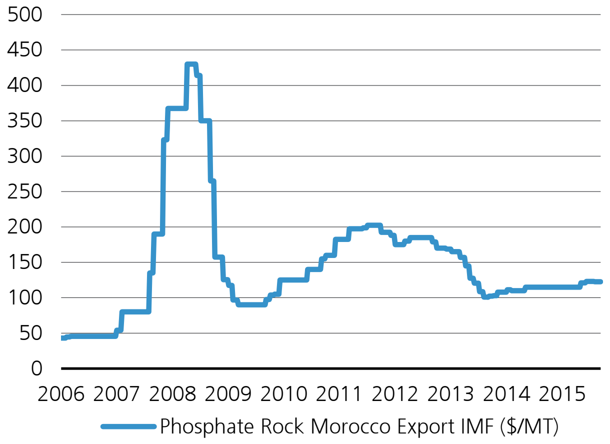
Source: Bloomberg

Figure 76: Cobalt 3m rolling fwd ($/MT)



Source: Bloomberg

Figure 77: Phosphate Rock Morocco Export IMF ($/MT)

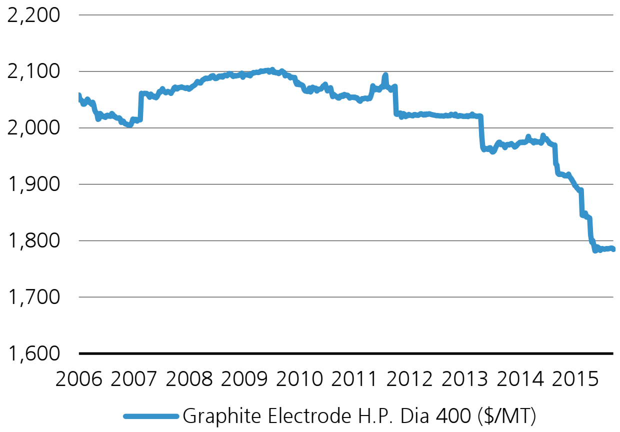


Source: Bloomberg

Figure 78: Manganese Spot ($/MT)

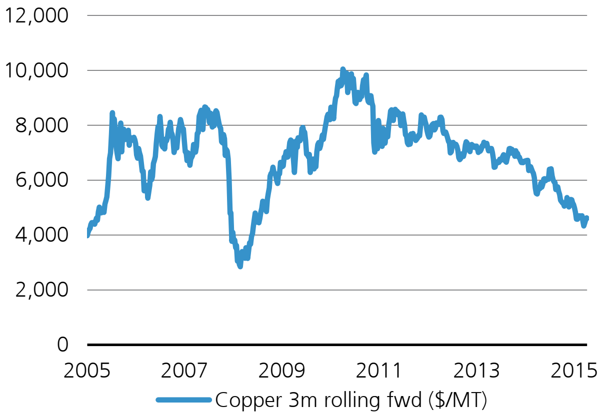
Source: Bloomberg

Figure 79: Graphite Electrode H.P. Dia 400 ($/MT)



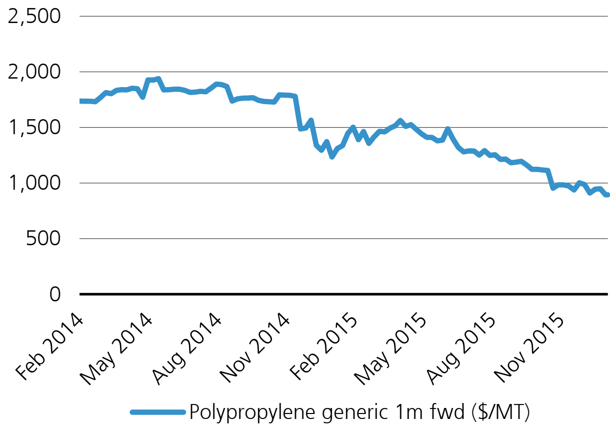
Source: Datastream

Figure 80: Copper 3m rolling fwd ($/MT)



Source: Bloomberg

Figure 81: Polypropylene generic 1m fwd ($/MT)



Source: Bloomberg

Figure 82: Estimated raw material demand for 10m BEVs (25/75% NCA/NMC technology) vs. market size, current reserves and estimated resources

					Demand in % of …		
Raw material	**Demand ('000 Mt)**	**Market size (2014)**	**Reserves***	**Estimated resources****	**Market**	**Reserves**	**Resources**
Lithium	227	36	13,500	39,500	632%	1.7%	0.6%
Cobalt	394	112	7,200	25,000	352%	5.5%	1.6%
Manganese	1,015	18,000	570,000	Sufficient	6%	0.2%	0.0%
Phosphorus	202	220,000	67,000,000	300,000,000	0%	0.0%	0.0%
Iron	2,187	3,220,000	87,000,000	230,000,000	0%	0.0%	0.0%
Nickel	626	2,400	81,000	130,000	26%	0.8%	0.5%
Aluminum	271	49,300	65,000,000	Sufficient	1%	0.0%	0.0%
Graphite	874	1,170	110,000	800,000	75%	0.8%	0.1%
Copper	581	18,700	700,000	5,600,000	3%	0.1%	0.0%
Polypropylene	98	55,000	109,000	165,000	0%	0.1%	0.1%

Source: USGS, Ceresana, Wood Mackenzie, UBS
* Reserves = Part of total resource that could be economically extracted or produced at the time of determination. (USGS)
** Estimated resources = Resources whose location, grade, quality, and quantity are known or estimated from specific geologic evidence. (USGS)

Lithium-ion battery production value chain

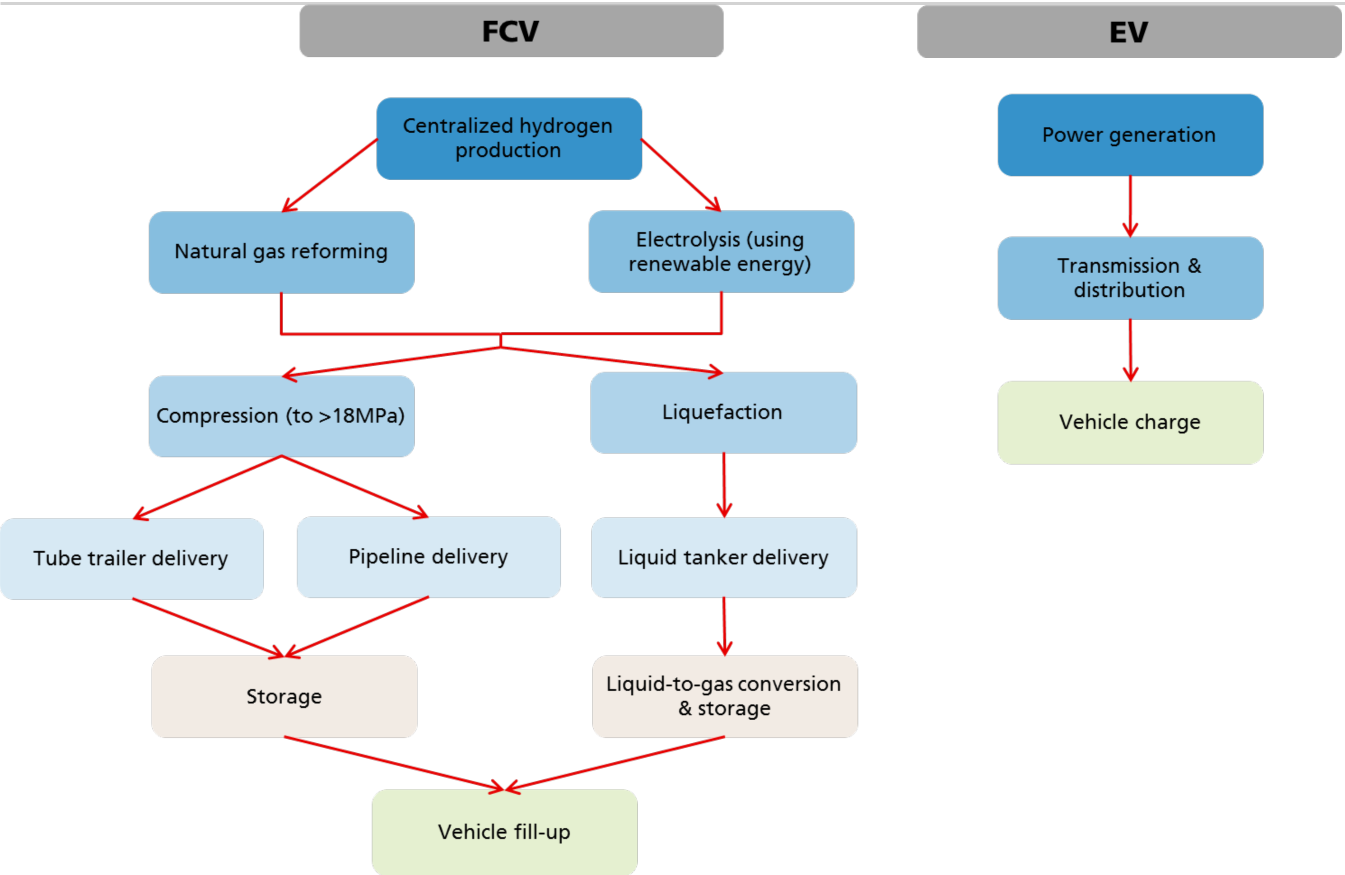
Figure 83: Lithium-ion battery production value chain – key players

			Active cell components					
			Cathode	**Anode**	**Electrolyte**	**Separator**	**Cell assembly**	**Recycling**
Total amount of supply in 2015			105k tons	57k tons	44k tons	695m²		
Total value of supply in 2015 (US$m)			2,500	800	680	1,150		
Companies	**Region**	**UBS coverage**						
Umicore	**EU**	**X**	**Leader**					
Easpring	China							
Nichia	Japan							
Clariant	EU	X						
Shanshantech	China							
BASF	EU	X						
Dow-DuPont	US	X						
3M	US							
Mitsubishi Chemical	**Japan**	**X**		**No. 2**	**No. 2**			
Johnson Matthey	EU	X						
Samsung SDI	Korea	X	For own use	For own use				
Hitachi	**Japan**	**X**		**Leader**				
Nippon Carbon	Japan							
Shin-Etsu	Japan	X						
Envia	US							
UBE Industries	**Japan**				**Leader**			
Tokuyama	Japan							
Panax-Etec	Korea							
Jinnui	China							
Cap Chem	China							
Tomiyama	Japan							
LG Chemical	**Korea**	**X**					**Leader**	
Asahi Kasei	**Japan**	**X**				**Leader**		
Toray	**Japan**	**X**				**No.2**		
Arkema	EU	X						
Solvay	EU	X						
Evonik	EU	X						
Celgard	US							
Entek	US							
Panasonic	**Japan**						**for Tesla**	
AESC	**Japan**						**for Nissan**	

Source: Avicenne Energy, company data, UBS

Hydrogen/power infrastructure chain

Figure 84: FCV versus BEV infrastructure chain



Source: UBS

Model sensitivity analyses

Figure 85: Detailed sensitivity analysis – TCO versus oil price (2021E)

	Unit	Oil price (price/bbl) US$30	US$75 (base case)	US$120
(1) BEV-to-ICE TCO gap 2021E				
US	US$	26%	21%	16%
Europe	€	6%	0%	-5%
China	CNY	8%	6%	4%
Japan	¥	15%	10%	5%
(2) TCO break-even battery cost				
US	US$/kWh	55	75	95
Europe	€/kWh	127	159	191
China	CNY/kWh	813	910	975
Japan	¥/kWh	11,500	13,800	16,675
(3) Battery cost reduction (per kWh) versus today required to reach TCO parity between BEVs and ICE cars				
US	%	-82%	-75%	-65%
Europe	%	-49%	-36%	-22%
China	%	-55%	-49%	-45%
Japan	%	-64%	-56%	-47%
(4) UBS forecast for achievability of TCO parity				
US		New technology	New technology	New technology
Europe		New technology	2021E	2019E
China		New technology	2025E	2024E
Japan		New technology	New technology	2025E

Source: UBS estimates
Note: All values based on our 2021E assumptions as outlined in Figure 29 – sensitivities built only around oil differing oil prices.

Valuation Method and Risk Statement

The automobile sector has in the past shown high levels of volatility in terms of profitability and valuation. Sector earnings and performance are highly sensitive to variations in volume, pricing, raw material costs and currency, all of which have been volatile recently. Long-term structural trends continue to improve as a result of higher demand in EM, early signs of sector concentration improving and structurally lower currency exposure, but near-term cyclical drivers have become more challenging after several years of strong earnings and share price performance. We are also concerned that in a macro recovery rising interest rates would become a material headwind for the industry. Below we list our valuation methods for each discussed stock in this report:

BMW	Average of a SOTP model and the cycle-average PE
Daimler	SOTP model, with target EV/EBIT multiples for each segment.
FCA	SOTP model
PSA	DCF valuation
Renault	DCF for core + DDM mid-point for associates
VW	SOTP model
Ford	4.5x multiple on 2016E EBITDA
GM	4x multiple 2016 EBITDA estimate
Tesla	DCF valuation
Nissan	FY17E PER of 8X
Honda	PBR of 0.75X
Toyota	PER of 10X normalized EPS in FY17E
Kia	6.8x 2016E PE and 2.9% dividend yield
Yutong Bus	DCF valuation
Jianghuai	DCF valuation
Autoliv	DCF valuation
Continental	DCF valuation
Faurecia	DCF valuation
Valeo	DCF valuation
Denso	15X FY16E PER
Lear	Blended 2016E EBITDA multiples
Delphi	Blended 2016E EBITDA multiples
Michelin	DCF/ROIC based PT
Nokian	DCF valuation
Umicore	DCF Valuation
Johnson Matthey	DCF and SOTP
Samsung SDI	12-month forward BV
LG Chemical	SOTP valuation

Required Disclosures

This report has been prepared by UBS Limited, an affiliate of UBS AG. UBS AG, its subsidiaries, branches and affiliates are referred to herein as UBS.

For information on the ways in which UBS manages conflicts and maintains independence of its research product; historical performance information; and certain additional disclosures concerning UBS research recommendations, please visit www.ubs.com/disclosures. The figures contained in performance charts refer to the past; past performance is not a reliable indicator of future results. Additional information will be made available upon request. UBS Securities Co. Limited is licensed to conduct securities investment consultancy businesses by the China Securities Regulatory Commission. UBS acts or may act as principal in the debt securities (or in related derivatives) that may be the subject of this report.

Analyst Certification: Each research analyst primarily responsible for the content of this research report, in whole or in part, certifies that with respect to each security or issuer that the analyst covered in this report: (1) all of the views expressed accurately reflect his or her personal views about those securities or issuers and were prepared in an independent manner, including with respect to UBS, and (2) no part of his or her compensation was, is, or will be, directly or indirectly, related to the specific recommendations or views expressed by that research analyst in the research report.

UBS Investment Research: Global Equity Rating Definitions

12-Month Rating	Definition	Coverage[1]	IB Services[2]
Buy	FSR is > 6% above the MRA.	48%	36%
Neutral	FSR is between -6% and 6% of the MRA.	39%	28%
Sell	FSR is > 6% below the MRA.	12%	22%
Short-Term Rating	**Definition**	**Coverage[3]**	**IB Services[4]**
Buy	Stock price expected to rise within three months from the time the rating was assigned because of a specific catalyst or event.	<1%	<1%
Sell	Stock price expected to fall within three months from the time the rating was assigned because of a specific catalyst or event.	<1%	<1%

Source: UBS. Rating allocations are as of 31 December 2015.
1:Percentage of companies under coverage globally within the 12-month rating category.
2:Percentage of companies within the 12-month rating category for which investment banking (IB) services were provided within the past 12 months.
3:Percentage of companies under coverage globally within the Short-Term rating category.
4:Percentage of companies within the Short-Term rating category for which investment banking (IB) services were provided within the past 12 months.

KEY DEFINITIONS: Forecast Stock Return (FSR) is defined as expected percentage price appreciation plus gross dividend yield over the next 12 months. **Market Return Assumption (MRA)** is defined as the one-year local market interest rate plus 5% (a proxy for, and not a forecast of, the equity risk premium). **Under Review (UR)** Stocks may be flagged as UR by the analyst, indicating that the stock's price target and/or rating are subject to possible change in the near term, usually in response to an event that may affect the investment case or valuation. **Short-Term Ratings** reflect the expected near-term (up to three months) performance of the stock and do not reflect any change in the fundamental view or investment case. **Equity Price Targets** have an investment horizon of 12 months.

EXCEPTIONS AND SPECIAL CASES: UK and European Investment Fund ratings and definitions are: Buy: Positive on factors such as structure, management, performance record, discount; **Neutral:** Neutral on factors such as structure, management, performance record, discount; **Sell:** Negative on factors such as structure, management, performance record, discount. **Core Banding Exceptions (CBE):** Exceptions to the standard +/-6% bands may be granted by the Investment Review Committee (IRC). Factors considered by the IRC include the stock's volatility and the credit spread of the respective company's debt. As a result, stocks deemed to be very high or low risk may be subject to higher or lower bands as they relate to the rating. When such exceptions apply, they will be identified in the Company Disclosures table in the relevant research piece.

Research analysts contributing to this report who are employed by any non-US affiliate of UBS Securities LLC are not registered/qualified as research analysts with FINRA. Such analysts may not be associated persons of UBS Securities LLC and therefore are not subject to the FINRA restrictions on communications with a subject company, public appearances, and trading securities held by a research analyst account. The name of each affiliate and analyst employed by that affiliate contributing to this report, if any, follows.

UBS AG: Patrick Hummel, CFA; Julian Radlinger. **UBS Limited:** David Lesne; Chervine Golbaz; Sabyasachi Niyogi. **UBS AG Hong Kong Branch:** Yankun Hou; Mark Leung; Bonil Koo. **UBS Securities LLC:** Colin Langan, CFA. **UBS Securities Japan Co., Ltd.:** Kohei Takahashi; Taisuke Hirose. **UBS Securities Pte. Ltd., Seoul Branch:** Young Chang.

Company Disclosures

Company Name	Reuters	12-month rating	Short-term rating	Price	Price date
Autoliv[16]	ALV.N	Sell	N/A	US$109.69	08 Mar 2016
BMW[7]	BMWG.F	Neutral	N/A	€80.06	08 Mar 2016
Continental	CONG.DE	Buy	N/A	€194.45	08 Mar 2016
Daimler	DAIGn.DE	Buy	N/A	€65.05	08 Mar 2016
Delphi Automotive Plc[16]	DLPH.N	Neutral	N/A	US$68.94	08 Mar 2016
Denso[7]	6902.T	Buy	N/A	¥4,403	09 Mar 2016
Faurecia	EPED.PA	Sell	N/A	€32.28	08 Mar 2016
Fiat Chrysler[2, 4, 5, 6a, 7, 16]	FCHA.MI	Neutral	N/A	€6.66	08 Mar 2016
Ford Motor Co.[7, 16, 18a]	F.N	Buy	N/A	US$13.23	08 Mar 2016
General Motors Company[6b, 6c, 7, 16, 18b]	GM.N	Buy	N/A	US$30.68	08 Mar 2016
Honda Motor[16]	7267.T	Neutral	N/A	¥3,110	09 Mar 2016
Jianghuai Automobile	600418.SS	Buy	N/A	Rmb10.01	09 Mar 2016
Johnson Matthey[5, 7]	JMAT.L	Neutral	N/A	2,572p	08 Mar 2016
Kia Motors	000270.KS	Buy	N/A	Won48,950	09 Mar 2016
Lear Corporation[6c, 7, 16]	LEA.N	Buy	N/A	US$105.69	08 Mar 2016
LG Chemical	051910.KS	Neutral	N/A	Won296,000	09 Mar 2016
Michelin	MICP.PA	Buy	N/A	€86.61	08 Mar 2016
Nissan Motor	7201.T	Buy	N/A	¥1,077.0	09 Mar 2016
Nokian[5]	NRE1V.HE	Neutral	N/A	€29.04	08 Mar 2016
Peugeot	PEUP.PA	Neutral	N/A	€14.68	08 Mar 2016
Renault[7]	RENA.PA	Buy	N/A	€83.70	08 Mar 2016
Samsung SDI[7]	006400.KS	Neutral	N/A	Won99,900	09 Mar 2016
Tesla Motors[16, 18c]	TSLA.O	Sell	N/A	US$202.60	08 Mar 2016
Toyota Motor[7, 16]	7203.T	Neutral	N/A	¥5,976	09 Mar 2016
Umicore	UMI.BR	Buy	N/A	€41.99	08 Mar 2016
Valeo	VLOF.PA	Buy	N/A	€132.30	08 Mar 2016
Volkswagen Preference[7]	VOWG_p.DE	Buy	N/A	€112.30	08 Mar 2016
Zhengzhou Yutong Bus	600066.SS	Buy	N/A	Rmb19.86	09 Mar 2016

Source: UBS. All prices as of local market close.
Ratings in this table are the most current published ratings prior to this report. They may be more recent than the stock pricing date

2. UBS AG, its affiliates or subsidiaries has acted as manager/co-manager in the underwriting or placement of securities of this company/entity or one of its affiliates within the past 12 months.
4. Within the past 12 months, UBS AG, its affiliates or subsidiaries has received compensation for investment banking services from this company/entity or one of its affiliates.
5. UBS AG, its affiliates or subsidiaries expect to receive or intend to seek compensation for investment banking services from this company/entity within the next three months.

6a. This company/entity is, or within the past 12 months has been, a client of UBS Securities LLC, and investment banking services are being, or have been, provided.

6b. This company/entity is, or within the past 12 months has been, a client of UBS Securities LLC, and non-investment banking securities-related services are being, or have been, provided.

6c. This company/entity is, or within the past 12 months has been, a client of UBS Securities LLC, and non-securities services are being, or have been, provided.

7. Within the past 12 months, UBS Securities LLC and/or its affiliates have received compensation for products and services other than investment banking services from this company/entity.

16. UBS Securities LLC makes a market in the securities and/or ADRs of this company.

18a. A U.S.-based global equity strategist, a member of his team, or one of their household members has a long common stock position in Ford Motor Co.

18b. A U.S.-based global equity strategist, a member of his team, or one of their household members has a long common stock position in General Motors Co.

18c. A U.S.-based global equity strategist, a member of his team, or one of their household members has a long common stock position in Tesla Motors Inc.

Unless otherwise indicated, please refer to the Valuation and Risk sections within the body of this report. For a complete set of disclosure statements associated with the companies discussed in this report, including information on valuation and risk, please contact UBS Securities LLC, 1285 Avenue of Americas, New York, NY 10019, USA, Attention: Investment Research.

Global Disclaimer

This document has been prepared by UBS Limited, an affiliate of UBS AG. UBS AG, its subsidiaries, branches and affiliates are referred to herein as UBS.

Global Research is provided to our clients through UBS Neo, the UBS Client Portal and UBS.com (each a "System"). It may also be made available through third party vendors and distributed by UBS and/or third parties via e-mail or alternative electronic means. The level and types of services provided by Global Research to a client may vary depending upon various factors such as a client's individual preferences as to the frequency and manner of receiving communications, a client's risk profile and investment focus and perspective (e.g. market wide, sector specific, long-term, short-term, etc.), the size and scope of the overall client relationship with UBS and legal and regulatory constraints.

When you receive Global Research through a System, your access and/or use of such Global Research is subject to this Global Research Disclaimer and to the terms of use governing the applicable System.

When you receive Global Research via a third party vendor, e-mail or other electronic means, your use shall be subject to this Global Research Disclaimer and to UBS's Terms of Use/Disclaimer (http://www.ubs.com/global/en/legalinfo2/disclaimer.html). By accessing and/or using Global Research in this manner, you are indicating that you have read and agree to be bound by our Terms of Use/Disclaimer. In addition, you consent to UBS processing your personal data and using cookies in accordance with our Privacy Statement (http://www.ubs.com/global/en/legalinfo2/privacy.html) and cookie notice (http://www.ubs.com/global/en/homepage/cookies/cookie-management.html).

If you receive Global Research, whether through a System or by any other means, you agree that you shall not copy, revise, amend, create a derivative work, transfer to any third party, or in any way commercially exploit any UBS research provided via Global Research or otherwise, and that you shall not extract data from any research or estimates provided to you via Global Research or otherwise, without the prior written consent of UBS.

For access to all available Global Research on UBS Neo and the Client Portal, please contact your UBS sales representative.

This document is for distribution only as may be permitted by law. It is not directed to, or intended for distribution to or use by, any person or entity who is a citizen or resident of or located in any locality, state, country or other jurisdiction where such distribution, publication, availability or use would be contrary to law or regulation or would subject UBS to any registration or licensing requirement within such jurisdiction. It is published solely for information purposes; it is not an advertisement nor is it a solicitation or an offer to buy or sell any financial instruments or to participate in any particular trading strategy. No representation or warranty, either expressed or implied, is provided in relation to the accuracy, completeness or reliability of the information contained in this document ('the Information'), except with respect to Information concerning UBS. The Information is not intended to be a complete statement or summary of the securities, markets or developments referred to in the document. UBS does not undertake to update or keep current the Information. Any opinions expressed in this document may change without notice and may differ or be contrary to opinions expressed by other business areas or groups of UBS. Any statements contained in this report attributed to a third party represent UBS's interpretation of the data, information and/or opinions provided by that third party either publicly or through a subscription service, and such use and interpretation have not been reviewed by the third party.

Nothing in this document constitutes a representation that any investment strategy or recommendation is suitable or appropriate to an investor's individual circumstances or otherwise constitutes a personal recommendation. Investments involve risks, and investors should exercise prudence and their own judgement in making their investment decisions. The financial instruments described in the document may not be eligible for sale in all jurisdictions or to certain categories of investors. Options, derivative products and futures are not suitable for all investors, and trading in these instruments is considered risky. Mortgage and asset-backed securities may involve a high degree of risk and may be highly volatile in response to fluctuations in interest rates or other market conditions. Foreign currency rates of exchange may adversely affect the value, price or income of any security or related instrument referred to in the document. For investment advice, trade execution or other enquiries, clients should contact their local sales representative.

The value of any investment or income may go down as well as up, and investors may not get back the full (or any) amount invested. Past performance is not necessarily a guide to future performance. Neither UBS nor any of its directors, employees or agents accepts any liability for any loss (including investment loss) or damage arising out of the use of all or any of the Information.

Any prices stated in this document are for information purposes only and do not represent valuations for individual securities or other financial instruments. There is no representation that any transaction can or could have been effected at those prices, and any prices do not necessarily reflect UBS's internal books and records or theoretical model-based valuations and may be based on certain assumptions. Different assumptions by UBS or any other source may yield substantially different results.

This document and the Information are produced by UBS as part of its research function and are provided to you solely for general background information. UBS has no regard to the specific investment objectives, financial situation or particular needs of any specific recipient. In no circumstances may this document or any of the Information be used for any of the following purposes:

(i) valuation or accounting purposes;

(ii) to determine the amounts due or payable, the price or the value of any financial instrument or financial contract; or

(iii) to measure the performance of any financial instrument.

By receiving this document and the Information you will be deemed to represent and warrant to UBS that you will not use this document or any of the Information for any of the above purposes or otherwise rely upon this document or any of the Information.

Research will initiate, update and cease coverage solely at the discretion of UBS Investment Bank Research Management. The analysis contained in this document is based on numerous assumptions. Different assumptions could result in materially different results. The analyst(s) responsible for the preparation of this document may interact with trading desk personnel, sales personnel and other parties for the purpose of gathering, applying and interpreting market information. UBS relies on information barriers to control the flow of information contained in one or more areas within UBS into other areas, units, groups or affiliates of UBS. The compensation of the analyst who prepared this document is determined exclusively by research management and senior management (not including investment banking). Analyst compensation is not based on investment banking revenues; however, compensation may relate to the revenues of UBS Investment Bank as a whole, of which investment banking, sales and trading are a part.

For financial instruments admitted to trading on an EU regulated market: UBS AG, its affiliates or subsidiaries (excluding UBS Securities LLC) acts as a market maker or liquidity provider (in accordance with the interpretation of these terms in the UK) in the financial instruments of the issuer save that where the activity of liquidity provider is carried out in accordance with the definition given to it by the laws and regulations of any other EU jurisdictions, such information is separately disclosed in this document. For financial instruments admitted to trading on a non-EU regulated market: UBS may act as a market maker save that where this activity is carried out in the US in accordance with the definition given to it by the relevant laws and regulations, such activity will be specifically disclosed in this document. UBS may have issued a warrant the value of which is based on one or more of the financial instruments referred to in the document. UBS and its affiliates and employees may have long or short positions, trade as principal and buy and sell in instruments or derivatives identified herein; such transactions or positions may be inconsistent with the opinions expressed in this document.

United Kingdom and the rest of Europe: Except as otherwise specified herein, this material is distributed by UBS Limited to persons who are eligible counterparties or professional clients. UBS Limited is authorised by the Prudential Regulation Authority and regulated by the Financial Conduct Authority and the Prudential Regulation Authority. **France:** Prepared by UBS Limited and distributed by UBS Limited and UBS Securities France S.A. UBS Securities France S.A. is regulated by the ACPR (Autorité de Contrôle Prudentiel et de Résolution) and the Autorité des Marchés Financiers (AMF). Where an analyst of UBS Securities France S.A. has contributed to this document, the document is also deemed to have been prepared by UBS Securities France S.A. **Germany:** Prepared by UBS Limited and distributed by UBS Limited and UBS Deutschland AG. UBS Deutschland AG is regulated by the Bundesanstalt fur Finanzdienstleistungsaufsicht (BaFin). **Spain:** Prepared by UBS Limited and distributed by UBS Limited and UBS Securities España SV, SA. UBS Securities España SV, SA is regulated by the Comisión Nacional del Mercado de Valores (CNMV). **Turkey:** Distributed by UBS Limited. No information in this document is provided for the purpose of offering, marketing and sale by any means of any capital market instruments and services in the Republic of Turkey. Therefore, this document may not be considered as an offer made or to be made to residents of the Republic of Turkey. UBS AG is not licensed by the Turkish Capital Market Board under the provisions of the Capital Market Law (Law No. 6362). Accordingly, neither this document nor any other offering material related to the instruments/services may be utilized in connection with providing any capital market services to persons within the Republic of Turkey without the prior approval of the Capital Market Board. However, according to article 15 (d) (ii) of the Decree No. 32, there is no restriction on the purchase or sale of the securities abroad by residents of the Republic of Turkey. **Poland:** Distributed by UBS Limited (spolka z ograniczona odpowiedzialnoscia) Oddzial w Polsce regulated by the Polish Financial Supervision Authority. Where an analyst of UBS Limited (spolka z ograniczona odpowiedzialnoscia) Oddzial w Polsce has contributed to this

document, the document is also deemed to have been prepared by UBS Limited (spolka z ograniczona odpowiedzialnoscia) Oddzial w Polsce. **Russia:** Prepared and distributed by UBS Bank (OOO). **Switzerland:** Distributed by UBS AG to persons who are institutional investors only. UBS AG is regulated by the Swiss Financial Market Supervisory Authority (FINMA). **Italy:** Prepared by UBS Limited and distributed by UBS Limited and UBS Italia Sim S.p.A. UBS Italia Sim S.p.A. is regulated by the Bank of Italy and by the Commissione Nazionale per le Società e la Borsa (CONSOB). Where an analyst of UBS Italia Sim S.p.A. has contributed to this document, the document is also deemed to have been prepared by UBS Italia Sim S.p.A. **South Africa:** Distributed by UBS South Africa (Pty) Limited (Registration No. 1995/011140/07), an authorised user of the JSE and an authorised Financial Services Provider (FSP 7328). **Israel:** This material is distributed by UBS Limited. UBS Limited is authorised by the Prudential Regulation Authority and regulated by the Financial Conduct Authority and the Prudential Regulation Authority. UBS Securities Israel Ltd is a licensed Investment Marketer that is supervised by the Israel Securities Authority (ISA). UBS Limited and its affiliates incorporated outside Israel are not licensed under the Israeli Advisory Law. UBS Limited is not covered by insurance as required from a licensee under the Israeli Advisory Law. UBS may engage among others in issuance of Financial Assets or in distribution of Financial Assets of other issuers for fees or other benefits. UBS Limited and its affiliates may prefer various Financial Assets to which they have or may have Affiliation (as such term is defined under the Israeli Advisory Law). Nothing in this Material should be considered as investment advice under the Israeli Advisory Law. This Material is being issued only to and/or is directed only at persons who are Eligible Clients within the meaning of the Israeli Advisory Law, and this material must not be relied on or acted upon by any other persons. **Saudi Arabia:** This document has been issued by UBS AG (and/or any of its subsidiaries, branches or affiliates), a public company limited by shares, incorporated in Switzerland with its registered offices at Aeschenvorstadt 1, CH-4051 Basel and Bahnhofstrasse 45, CH-8001 Zurich. This publication has been approved by UBS Saudi Arabia (a subsidiary of UBS AG), a Saudi closed joint stock company incorporated in the Kingdom of Saudi Arabia under commercial register number 1010257812 having its registered office at Tatweer Towers, P.O. Box 75724, Riyadh 11588, Kingdom of Saudi Arabia. UBS Saudi Arabia is authorized and regulated by the Capital Market Authority to conduct securities business under license number 08113-37. **Dubai:** The information distributed by UBS AG Dubai Branch is intended for Professional Clients only and is not for further distribution within the United Arab Emirates. **United States:** Distributed to US persons by either UBS Securities LLC or by UBS Financial Services Inc., subsidiaries of UBS AG; or by a group, subsidiary or affiliate of UBS AG that is not registered as a US broker-dealer (a **'non-US affiliate'**) to major US institutional investors only. UBS Securities LLC or UBS Financial Services Inc. accepts responsibility for the content of a document prepared by another non-US affiliate when distributed to US persons by UBS Securities LLC or UBS Financial Services Inc. All transactions by a US person in the securities mentioned in this document must be effected through UBS Securities LLC or UBS Financial Services Inc., and not through a non-US affiliate. UBS Securities LLC is not acting as a municipal advisor to any municipal entity or obligated person within the meaning of Section 15B of the Securities Exchange Act (the "Municipal Advisor Rule"), and the opinions or views contained herein are not intended to be, and do not constitute, advice within the meaning of the Municipal Advisor Rule. **Canada:** Distributed by UBS Securities Canada Inc., a registered investment dealer in Canada and a Member-Canadian Investor Protection Fund, or by another affiliate of UBS AG that is registered to conduct business in Canada or is otherwise exempt from registration. **Brazil:** Except as otherwise specified herein, this material is prepared by UBS Brasil CCTVM S.A. to persons who are eligible investors residing in Brazil, which are considered to be: (i) financial institutions, (ii) insurance firms and investment capital companies, (iii) supplementary pension entities, (iv) entities that hold financial investments higher than R$300,000.00 and that confirm the status of qualified investors in written, (v) investment funds, (vi) securities portfolio managers and securities consultants duly authorized by Comissão de Valores Mobiliários (CVM), regarding their own investments, and (vii) social security systems created by the Federal Government, States, and Municipalities. **Hong Kong:** Distributed by UBS Securities Asia Limited and/or UBS AG, Hong Kong Branch. **Singapore:** Distributed by UBS Securities Pte. Ltd. [MCI (P) 018/09/2015 and Co. Reg. No.: 198500648C] or UBS AG, Singapore Branch. Please contact UBS Securities Pte. Ltd., an exempt financial adviser under the Singapore Financial Advisers Act (Cap. 110); or UBS AG, Singapore Branch, an exempt financial adviser under the Singapore Financial Advisers Act (Cap. 110) and a wholesale bank licensed under the Singapore Banking Act (Cap. 19) regulated by the Monetary Authority of Singapore, in respect of any matters arising from, or in connection with, the analysis or document. The recipients of this document represent and warrant that they are accredited and institutional investors as defined in the Securities and Futures Act (Cap. 289). **Japan:** Distributed by UBS Securities Japan Co., Ltd. to professional investors (except as otherwise permitted). Where this document has been prepared by UBS Securities Japan Co., Ltd., UBS Securities Japan Co., Ltd. is the author, publisher and distributor of the document. Distributed by UBS AG, Tokyo Branch to Professional Investors (except as otherwise permitted) in relation to foreign exchange and other banking businesses when relevant. **Australia:** Clients of UBS AG: Distributed by UBS AG (Holder of Australian Financial Services License No. 231087). Clients of UBS Securities Australia Ltd: Distributed by UBS Securities Australia Ltd (Holder of Australian Financial Services License No. 231098). Clients of UBS Wealth Management Australia Ltd: Distributed by UBS Wealth Management Australia Ltd (Holder of Australian Financial Services Licence No. 231127). This Document contains general information and/or general advice only and does not constitute personal financial product advice. As such, the Information in this document has been prepared without taking into account any investor's objectives, financial situation or needs, and investors should, before acting on the Information, consider the appropriateness of the Information, having regard to their objectives, financial situation and needs. If the Information contained in this document relates to the acquisition, or potential acquisition of a particular financial product by a 'Retail' client as defined by section 761G of the Corporations Act 2001 where a Product Disclosure Statement would be required, the retail client should obtain and consider the Product Disclosure Statement relating to the product before making any decision about whether to acquire the product. The UBS Securities Australia Limited Financial Services Guide is available at: www.ubs.com/ecs-research-fsg. **New Zealand:** Distributed by UBS New Zealand Ltd. The information and recommendations in this publication are provided for general information purposes only. To the extent that any such information or recommendations constitute financial advice, they do not take into account any person's particular financial situation or goals. We recommend that recipients seek advice specific to their circumstances from their financial advisor. **Korea:** Distributed in Korea by UBS Securities Pte. Ltd., Seoul Branch. This document may have been edited or contributed to from time to time by affiliates of UBS Securities Pte. Ltd., Seoul Branch. **Malaysia:** This material is authorized to be distributed in Malaysia by UBS Securities Malaysia Sdn. Bhd (Capital Markets Services License No.: CMSL/A0063/2007). This material is intended for professional/institutional clients only and not for distribution to any retail clients. **India:** Prepared by UBS Securities India Private Ltd. (Corporate Identity Number U67120MH1996PTC097299) 2/F, 2 North Avenue, Maker Maxity, Bandra Kurla Complex, Bandra (East), Mumbai (India) 400051. Phone: +912261556000. It provides brokerage services bearing SEBI Registration Numbers: NSE (Capital Market Segment): INB230951431, NSE (F&O Segment) INF230951431, NSE (Currency Derivatives Segment) INE230951431, BSE (Capital Market Segment) INB010951437; merchant banking services bearing SEBI Registration Number: INM000010809 and Research Analyst services bearing SEBI Registration Number: INH000001204. UBS AG, its affiliates or subsidiaries may have debt holdings or positions in the subject Indian company/companies. Within the past 12 months, UBS AG, its affiliates or subsidiaries may have received compensation for non-investment banking securities-related services and/or non-securities services from the subject Indian company/companies. The subject company/companies may have been a client/clients of UBS AG, its affiliates or subsidiaries during the 12 months preceding the date of distribution of the research report with respect to investment banking and/or non-investment banking securities-related services and/or non-securities services. With regard to information on associates, please refer to the Annual Report at: http://www.ubs.com/global/en/about_ubs/investor_relations/annualreporting.html

The disclosures contained in research documents produced by UBS Limited shall be governed by and construed in accordance with English law.

UBS