ATTACHMENT LS-41

Part 1

International Energy Agency
Secure Sustainable Together

CLEAN ENERGY MINISTERIAL
Accelerating the Global Clean Energy Transition

Electric Vehicles Initiative

Global EV Outlook 2017

Two million and counting

INTERNATIONAL ENERGY AGENCY

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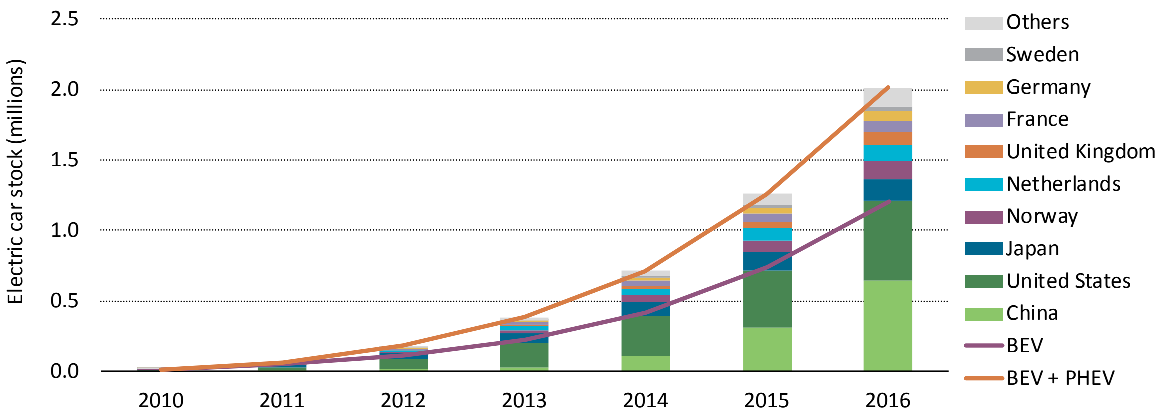
Executive summary

New registrations of electric cars[1] hit a new record in 2016, with over 750 thousand sales worldwide. With a 29% market share,[2] Norway has incontestably achieved the most successful deployment of electric cars in terms of market share, globally. It is followed by the Netherlands, with a 6.4% electric car market share, and Sweden with 3.4%. The People's Republic of China (hereafter, "China"), France and the United Kingdom all have electric car market shares close to 1.5%. In 2016, China was by far the largest electric car market, accounting for more than 40% of the electric cars sold in the world and more than double the amount sold in the United States.

The global electric car stock surpassed 2 million vehicles in 2016 after crossing the 1 million threshold in 2015 (Figure 1).

Figure 1 • Evolution of the global electric car stock, 2010-16



Notes: The electric car stock shown here is primarily estimated on the basis of cumulative sales since 2005. When available, stock numbers from official national statistics have been used, provided good consistency with sales evolutions.

Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2017a), IHS Polk (2016), MarkLines (2017), ACEA (2017a, 2017b) and EEA (2017).

Key point: The electric car stock has been growing since 2010 and surpassed the 2 million-vehicle threshold in 2016. So far, battery electric vehicle (BEV) uptake has been consistently ahead of the uptake of plug-in hybrid electric vehicles (PHEVs).

Until 2015, the United States accounted for the largest portion of the global electric car stock. In 2016, China became the country with the largest electric car stock, with about a third of the global total. With more than 200 million electric two-wheelers,[3] 3 to 4 million low-speed electric vehicles (LSEVs) and more than 300 thousand electric buses, China is also by far the global leader in the electrification of other transport modes.

As the number of electric cars on the road has continued to increase, private and publicly accessible charging infrastructure has also continued to grow. In 2016, the annual growth rate of publicly available charging (72%) was higher, but of a similar magnitude, than the electric car stock growth rate in the same year (60%).

[1] Electric cars include battery-electric, plug-in hybrid electric, and fuel cell electric passenger light-duty vehicles (PLDVs). They are commonly referred to as BEVs, PHEVs, and FCEVs in this report. Given their much wider diffusion, the scope of this report is limited to BEVs and PHEVs.

[2] Market share is defined, under the scope of this report, as the share of new registrations of electric cars in the total of all PLDVs

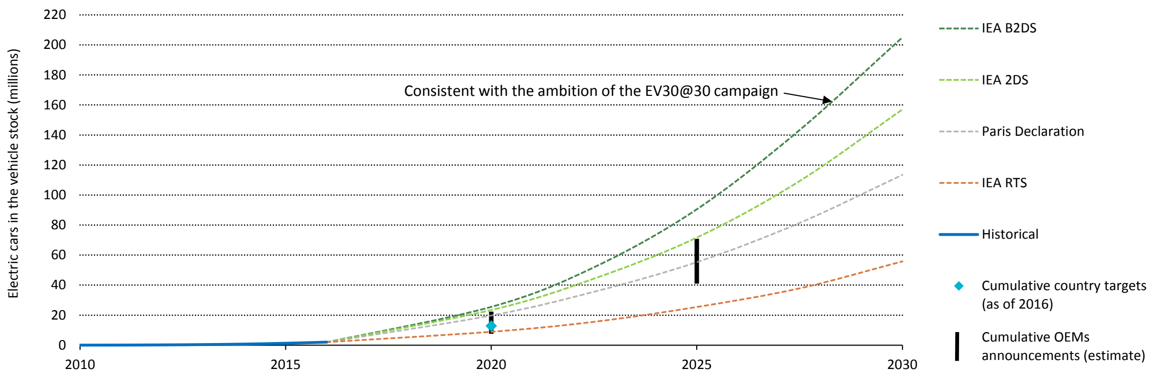
[3] In this report, the term "two-wheelers" refers to motorcycles and excludes bicycles.

Despite a continuous and impressive increase in the electric car stock, electric vehicle supply equipment (EVSE) deployment and electric car sales in the past five years, annual growth rates have been declining. In 2016, the electric car stock growth was 60%, down from 77% in 2015 and 85% in 2014. The year 2016 was also the first time year-on-year electric car sales growth had fallen below 50% since 2010.

Declining year-on-year increments are consistent with a growing electric car market and stock size, but the scale achieved so far is still small: the global electric car stock currently corresponds to just 0.2% of the total number of passenger light-duty vehicles (PLDVs)[4] in circulation. Electric vehicles (EVs) still have a long way to go before reaching deployment scales capable of making a significant dent in the development of global oil demand and greenhouse gas (GHG) emissions.

Research, development and deployment (RD&D) and mass production prospects are leading to rapid battery cost declines and increases in energy density. Signs of continuous improvements from technologies currently being researched confirm that this trend will continue, narrowing the cost competitiveness gap between EVs and internal combustion engines (ICEs). Assessments of country targets, original equipment manufacturer (OEM) announcements and scenarios on electric car deployment seem to confirm these positive signals, indicating a good chance that the electric car stock will range between 9 million and 20 million by 2020 and between 40 million and 70 million by 2025 (Figure 2).

Figure 2 • Deployment scenarios for the stock of electric cars to 2030



Notes: The RTS incorporates technology improvements in energy efficiency and modal choices that support the achievement of policies that have been announced or are under consideration. The 2DS is consistent with a 50% probability of limiting the expected global average temperature increase to 2°C. The B2DS falls within the Paris Agreement range of ambition, corresponding to an average increase in the global temperature by 1.75°C.

Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2017a), IHS Polk (2016), MarkLines (2017), ACEA (2017a, 2017b) and EEA (2017). Country targets in 2020 reflect the estimations made in EVI (2016a) and updates in 2016. Sources listed in Table 2 have been used here to assess the magnitude of OEM announcements. The methodology used for this assessment is discussed in the main text. Projections on the stock deployed according to the Paris Declaration are based on UNFCCC (2015a). Projections on the EV uptake in IEA scenarios were developed using the IEA Mobility Model, March 2017 version (IEA, 2017a).

Key point: The level of ambition resulting from the OEM announcements assessed here shows a fairly good alignment with country targets to 2020. To 2025, the range estimated suggests that OEM ambitions lie within the range corresponding to the Reference Technology Scenario (RTS) and 2DS projections from the IEA, broadly matching the Paris Declaration on Electro-Mobility and Climate Change and Call to Action (Paris Declaration).

4 PLDVs include passenger cars and passenger light trucks but exclude two-wheelers, three-wheelers, and low-speed/low-power four-wheeled vehicles. The classification used here attempts to match, to the extent possible, the "Category 1-1 vehicle" defined in UNECE (2005) and its following amendments, and, in countries where this regulation applies, "Category M_1" defined in UNECE (2016).

Despite this positive outlook, it is undeniable that the current electric car market uptake is largely influenced by the policy environment. Key support mechanisms currently adopted in leading electric car markets target both the deployment of electric cars and charging infrastructure:

- EV support typically takes the form of RD&D on innovative technologies, mandates and regulations, financial incentives and other instruments (primarily enforced in cities) that increase the value proposition of driving electric. Public procurement[5] (leading by example) is also well suited to facilitating early EV uptake.
- EVSE deployment is supported by the development of standards ensuring interoperability, financial incentives, regulations (including building codes) and permits.

A number of cities have been at the forefront of stimulating EV deployment, whether in the two-wheeler, PLDV or bus segments, and municipalities are important players in helping accelerate the transition to electric driving. By testing and demonstrating best-practice EV and EVSE support policies, cities can not only act as models for other cities that seek to accelerate their transition to electric driving but also provide an example for a wide application of best practices (e.g. at the national or global level), helping to improve the cost efficiency of the policy development process. The demand-based approach adopted by the metropolitan area of Amsterdam to deploy its EVSE network by providing publicly accessible chargers to electric car owners who request them, under certain conditions, is one of the most interesting examples in this respect.

Urban areas are also excellent platforms for the experimentation of novel passenger and freight transport services based on vehicle and ride-sharing concepts or autonomous driving capabilities. Given the high mileage of shared vehicles, these concepts have strong synergies with transport electrification.

Policy support will remain indispensable at least in the medium term for lowering barriers to electric car adoption. As electric car sales keep growing, governments will need to reconsider their policy tools. Even if differentiated taxes based on environmental performance, fuel economy regulations and local measures (such as differentiated access to urban areas) are likely to remain important, the need for vehicle purchase incentives will diminish, and subsidies for electric cars will not be economically sustainable with large sales volumes. Revenues collected from conventional fuel taxes will also shrink, requiring a transition in the way revenues aiming to develop the road transport infrastructure are collected.

EV charging could also have a sizeable impact on the loads applied to the grid at certain times and locations, with consequences for adequacy and quality of power supply, the risk of cost increases for consumers and negative feedback on transport electrification prospects. EVSE deployment needs to be conceived in a way that handles these risks and takes advantage of the options available for mitigating these impacts. Large-scale electric car charging and demand response will require the joint optimisation of the timing and duration of recharging events, the modulation of power delivered by charging outlets (defining the speed of charge) and may involve a reliance on vehicle-to-grid solutions. For fast chargers, managing power demand is also likely to require the deployment and use of stationary storage at the local or grid level.

[5] Public procurement refers to the procurement of vehicles by the public sector at the national, state, regional or municipal levels. These include government fleets as well as electric buses and dedicated fleets, such as police fleets or garbage trucks.

Introduction and scope

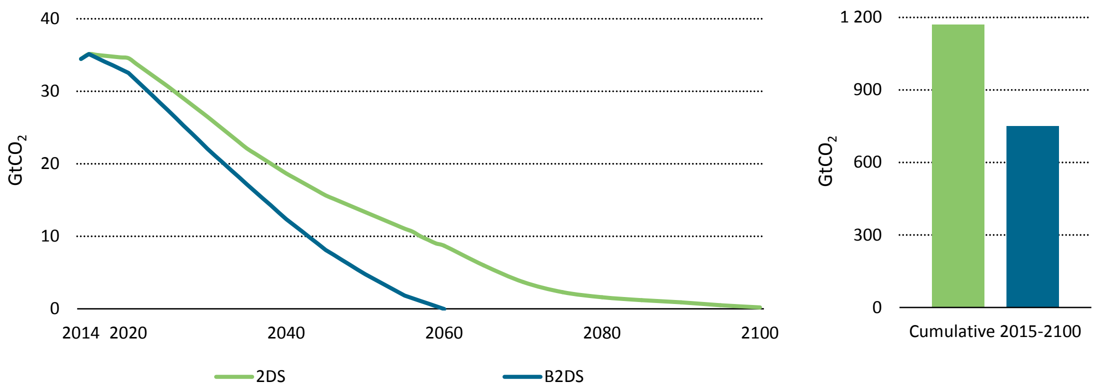
Introduction

Announced in December 2015 and enforced in November 2016, the Paris Agreement set the objective of limiting the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels (UNFCCC, 2015b). Figure 3 illustrates the GHG emissions reductions that could be compatible with this target by looking at two carbon budgets that reflect two possible IEA scenarios (IEA, 2017b):

- 1 170 GtCO_2 of cumulative emissions for the 2015-2100 period, as in the IEA Two Degree Scenario (2DS), providing a 50% chance of limiting average future temperatures increases to 2°C
- 750 Gt CO_2 of cumulative emissions for the 2015-2100 period, as in the Beyond Two Degree Scenario (B2DS), coupled with a 50% chance of limiting average future temperatures increases to 1.75°C.

In both cases represented in Figure 3, energy-related GHG emissions will need to reach net-zero in the second half of this century: close to 2060 for the B2DS and close to 2090 for the 2DS. The transport sector, which currently accounts for 23% of global energy-related GHG emissions, will need to deliver major emissions cuts for countries to achieve their goals.

Figure 3 • GHG emission budgets and emission trajectories to 2100 for the energy sector, 2DS and B2DS



Source: IEA (2017b).

Key point: Without net negative emissions, energy sector CO_2 emissions need to fall to zero in the second half of the century to meet the ambition of the Paris Agreement.

The electrification of transport plays a large role in all IEA scenarios aiming to achieve the decarbonisation of the energy system, where increasing transport electrification goes hand-in-hand with decarbonising the electricity sector (IEA, 2017b).[6] Electrification will be crucial in short-distance vehicles such as two- and three-wheelers and PLDVs, as well as public transport and freight delivery vehicles used in urban environments. In the 2DS, the plug-in PLDV stock exceeds

[6] Other relevant solutions capable of contributing to several sustainability goals for the transport sector are articulated under the "avoid, shift and improve" strategy (IEA, 2017b). They include: reducing travel distances (e.g. through compact city development and the application of integrated urban and transport planning and the optimisation of road freight deliveries) (avoid); increasing the share of public transport modes in urban passenger transport and shifting road freight activity to rail and shipping (shift); and accelerating the deployment of energy efficiency for all vehicles, increasing the share of zero-emission vehicles (including FCEVs) and promoting the use of low-carbon fuels (improve).

150 million units (10% of the total) by 2030. By 2060, the 2DS projects that 1.2 billion electric cars, representing more than 60% of the total PLDV stock, will be in circulation. In the same scenario, the stock of electric two-wheelers is projected to exceed 400 million in 2030 (around 40% of the global total), and two-wheelers become fully electrified by 2055 (IEA, 2017b). Under the B2DS, transport electrification happens at an even faster pace: electric cars represent 85% of the total PLDV stock by 2060, and two-wheelers are fully electrified by 2045.

With zero tailpipe emissions in the case of full-electric driving vehicles, EVs also offer a clean alternative to vehicles with ICEs by helping to reduce exposure to air pollution resulting from fuel combustion and limiting noise. This is especially relevant in urban areas and along major transportation axes.[7] The relevance of EVs for the reduction of air pollution and noise is well demonstrated by the leading role that cities assume in promoting EV deployment: in 2015, nearly a third of global electric car sales took place in just 14 cities (Hall et. al, 2017). Major global urban centres also tend to witness higher electric car market penetration compared to their country averages (Figure 16).

The EVI

The Electric Vehicles Initiative (EVI) is a multi-government policy forum established in 2009 under the Clean Energy Ministerial (CEM), dedicated to accelerating the deployment of EVs worldwide (CEM, 2017).

As of May 2017, the EVI counted ten member governments (Canada, China, France, Germany, Japan, the Netherlands, Norway, Sweden, the United Kingdom and the United States). China and the United States are currently co-leading the EVI,[8] and the IEA is the co-ordinator of the initiative. India and Korea are also engaged in the EVI's activities and in 2017 shared their national data on road-transport electrification. South Africa was an EVI member up to 2016 and remains an active observer of the initiative's activities.

Collectively, the EVI members account for most of the global EV market and stock (95% of all electric car registrations and 95% of the total stock monitored in this assessment).

The EVI has established partnerships with AVERE, the Climate Group, the German Corporation for International Cooperation (GIZ), GreenTech Malaysia, the ICCT (hosting the secretariat of the International Zero-Emission Vehicle Alliance), the IEA Hybrid and Electric Vehicle Technology Collaboration Programme (IEA HEV TCP), the International Renewable Energy Agency (IRENA), King Mongkut's University of Technology Thonburi (Thailand), the Lawrence Berkeley National Laboratory (LBNL), the United States National Renewable Energy Laboratory (NREL), the United Nations Environment Programme (UNEP), the United Nations Human Settlements Programme (UN Habitat), the United Nations Industrial Development Organization (UNIDO) and Urban Foresight.

The EVI brings together representatives of its member governments and partners twice per year. It has proven to be as an effective platform for the exchange of information, action and communication about EVs and has helped to inform policy makers and the public about EV deployment.

To date, the EVI has developed analytical outputs that include the *Global EV Outlook*, started in 2013 and now an annual series (EVI, 2016a, 2015a, 2013), and two editions of the *EV City Casebook* (EVI, 2014, 2012), with a focus on initiatives taking place at the local administrative

[7] Air quality issues are causing health problems in many cities globally, resulting in millions of premature deaths each year and inflicting major costs to the global economy (WHO, 2016; IEA, 2016).

[8] United States' leadership under review.

level. The EVI successfully engaged private sector stakeholders in roundtables in Paris in 2010, in Stuttgart in 2012 and at COP21 in 2015 (EVI, 2015b) to discuss the roles of industry and government in the EV market as well as the opportunities and challenges ahead. The EVI has also been instrumental in mobilising actions from participating governments, contributing major analytical inputs to the Paris Declaration on Electro-Mobility and Climate Change and Call to Action, released at COP21 (UNFCCC, 2015a), and developing the EVI Government Fleet Declaration (EVI, 2016b), announced at COP22 in Marrakech in 2016.[9]

The EV30@30 campaign

The EV30@30 campaign, launched at the Eighth Clean Energy Ministerial in 2017, redefined the EVI ambition by setting the collective aspirational goal for all EVI members of a 30% market share for electric vehicles[10] in the total of all passenger cars, light commercial vehicles, buses and trucks by 2030.

The campaign includes several implementing actions aimed at helping achieve this goal in accordance with the priorities and programmes developed in each EVI country. These actions include:

- supporting the deployment of chargers and tracking progress
- galvanising public and private sector commitments for EV uptake in company and supplier fleets
- the scale-up of policy research, including policy efficacy analysis, information and experience sharing, and capacity building
- establishing the Global EV Pilot City programme, a global co-operative programme aimed at facilitating the exchange of experiences and the replication of best practices for the promotion of EVs in cities.

Scope of this report

This report conveys information collected from EVI members and partners to analyse the global evolution of the EV market, the growth of the EV stock and the deployment of EVSE. It includes a review of policy actions on EVs and EVSE and analyses market developments in relation to changes in the policy framework. It also provides an update on RD&D developments, benefiting from the close relationship between the EVI and the IEA HEV TCP and the technology experts participating in it.

This report concerns mainly the electric car market and does not cover other transport modes at the same level of detail. The focus on the car market is due to both its dynamism and the wider availability of data for this vehicle group. Targeted details on two-wheelers, three-wheelers, LSEVs and buses, with a focus on some of the most significant cases, including those having implications for future market developments, complement the information on cars.

The countries covered include Canada, China, Iceland, India, Japan, Korea, Lichtenstein, Norway, Switzerland, Turkey, the United States and each of the member countries of the European Union (EU 28). Figure 4 provides a visual summary of this list, showing the EVI members, countries that

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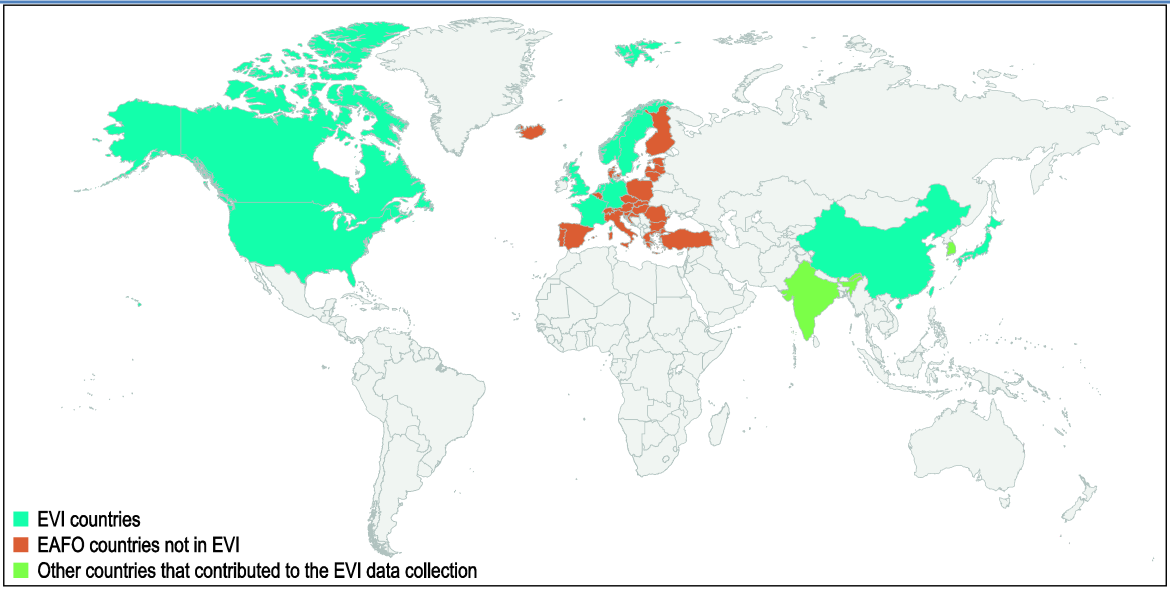
[9] The EVI Government Fleet Declaration gathers statements on measures aiming to introduce low-emissions vehicles, including electric vehicles, from eight EVI member countries. The IEA estimates that the commitments voiced in the EVI Government Fleet Declaration could lead to the introduction of approximately 200 000 low-emission vehicles between 2016 and 2020, accompanied by a large potential for raising awareness from the public and supporting EVSE deployment and the entry of new e-mobility service providers into the market.

[10] Including BEVs, PHEVs and FCEVs.

report data to the European Alternative Fuels Observatory and countries that reported data to the EVI for the preparation of this publication. The results in this publication cover all EVI members individually. With a few exceptions, data for all other countries have been reported and analysed as a single aggregate.

Figure 4 • EVI member countries and country coverage of the *Global EV Outlook 2017*



Note: This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Key point: The *Global EV Outlook 2017* covers 39 countries, accounting for most of the global electric car stock.

Data sources

The main sources of information used in this report include submissions from EVI members, statistics and indicators available from the European Alternative Fuels Observatory (EAFO, 2017a) for European countries that are not members of the EVI (Figure 4), data extracted from commercial databases (IHS Polk, 2016; MarkLines, 2017) and information released by relevant stakeholders (ACEA, 2017a, 2017b; EEA, 2017).

EV deployment

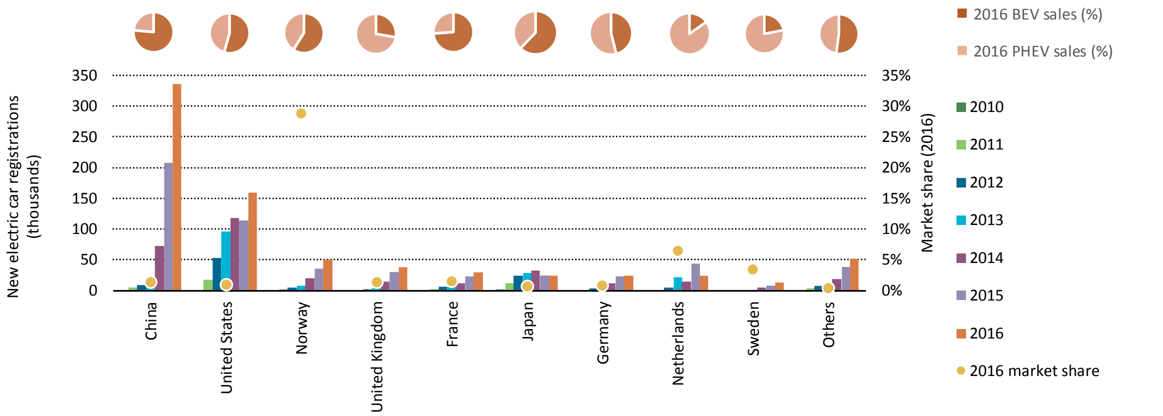
This section reviews the latest developments in new registrations and the stock of EVs, looking primarily at electric cars and focusing on the developments that took place in 2016 as well as the trends since 2010. Stock and sales figures are assessed against policy support schemes and international, national or private commitments on EV deployment for the 2020, 2025 and 2030 time horizons (depending on national settings). EV deployment is also assessed against the ambition of the EV30@30 campaign.

Electric cars

Market evolution

Registrations of electric cars hit a new record in 2016, with over 750 thousand sales worldwide. However, sales for 2016 showed a slowdown in the market growth rate compared with previous years to 40%, making 2016 the first year since 2010 that year-on-year electric car sales growth fell below 50%. Despite the decline, maintaining the 2016 rate of growth over the following years will still allow for meeting the sales and stock objectives of the 2DS for 2025.

Figure 5 • Electric car sales, market share, and BEV and PHEV sales shares in selected countries, 2010-16



Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2017a), IHS Polk (2016), MarkLines (2017), ACEA (2017a, 2017b) and EEA (2017).

Key point: The two main electric car markets are China and the United States. Six countries reached EV market shares of more than 1% in 2016: Norway, the Netherlands, Sweden, France, the United Kingdom and China.

China was by far the largest electric car market in 2016, with 336 thousand new electric cars registered. Electric car sales in China were more than double the amount in the United States, where 2016 electric car registrations rebounded to 160 thousand units after a slight drop in the previous year (Figure 5). European countries accounted for 215 thousand electric car sales.[11] Both globally and in the European Union, the electric car market is still concentrated in a limited number of countries. In Europe, most of the electric cars sold in 2016 were registered in just six countries: Norway, the United Kingdom, France, Germany, the Netherlands and Sweden. Globally, 95% of electric car sales are taking place in just ten countries: China, the United States, Japan, Canada and the six leading European countries.

[11] In this case, European countries include all the countries geographically located in Europe that report data to the EVI and the EAFO (see Figure 4).

In 2016, six countries achieved an electric car market share above 1% of their total PLDV sales. Among these, Norway was the incontestable global leader, with a 29% market share, the result of a favourable policy environment in recent years comprising a large range of incentives, from tax breaks and exemptions to waivers on road tolls and ferry fees. Norway was followed by the Netherlands, with a 6.4% electric car market share, and Sweden with a 3.4% share. China, France and the United Kingdom all had electric car market shares close to 1.5%. China and France also have BEV-oriented markets, and roughly three-quarters of their 2016 electric car sales were BEVs, and only one-quarter were PHEVs. In contrast, in the Netherlands, Sweden and the United Kingdom, the majority of electric cars registered in 2016 were PHEVs. In Japan, Norway and the rest of the world, on average, electric car sales were more equally split between BEVs and PHEVs (Figure 5).

Year-on-year developments between 2015 and 2016 will be further discussed in the following section, with assessments – to the extent possible – against changes in policy support mechanisms.

Policy support

Overview of existing support mechanisms for electric car deployment

At this stage of electric car market deployment, policy support is still indispensable for lowering barriers to adoption. A supportive policy environment enables market growth by making vehicles appealing for consumers, reducing risks for investors and encouraging manufacturers willing to develop EV business streams on a large scale to start implementing them. In particular, these factors enable a wider model offer range to consumers, which is key to spurring sales growth. Policy support mechanisms can be grouped into four major categories: support for the research and development of innovative technologies; targets, mandates and regulations; financial incentives; and other instruments (primarily enforced in cities) for allowing increases in the value proposition of EVs. Public procurement (leading by example) is also well suited to facilitating EV uptake.

Research support

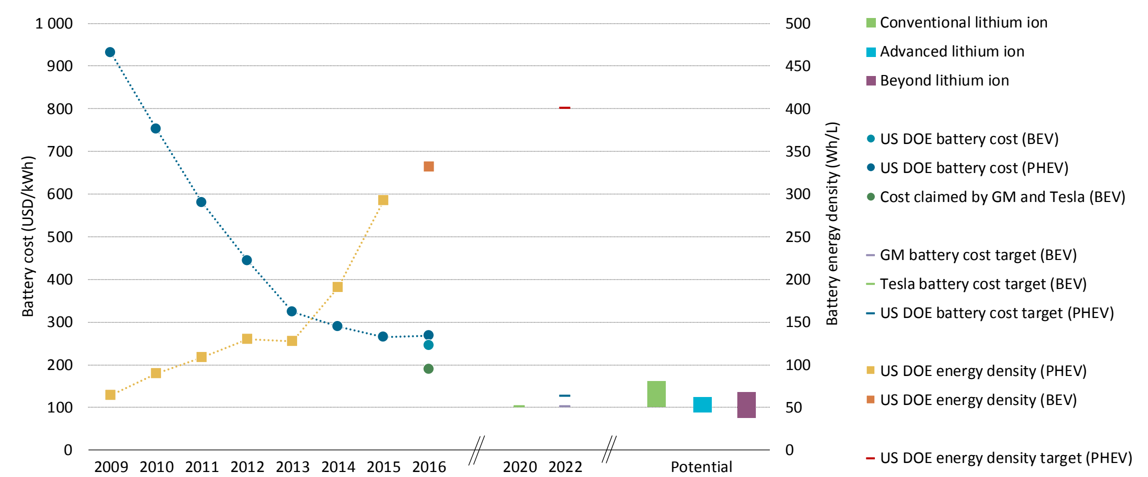
Research support is key to achieving cost declines and performance improvements and is best conceived when coupled with other instruments that allow the scale-up of production. Box 1 provides an assessment of the recent developments in battery cost and performance. RD&D and mass production prospects are leading to rapid cost declines and performance improvements. This is confirmed by the gap between commercial applications and batteries currently being researched, increasing production volumes resulting from electric car market growth, the larger pack sizes that are accompanying increased electric driving ranges, and cost reductions expected for all families of battery technologies assessed by the United States Department of Energy (US DOE) (see Figure 6). These same elements provide encouraging signs for achieving the targets set by carmakers and the US DOE for the early 2020s.

Box 1 • Recent developments in battery cost and performance

Figure 6 shows an updated assessment of the battery cost developments already included in earlier editions of the *Global EV Outlook*. This update includes information for 2016 on the costs and volumetric energy densities of batteries currently being researched, as well as the ranges of cost reductions that can be expected from the three main families of battery technologies: conventional lithium ion; advanced lithium ion, using an intermetallic anode (i.e. silicon alloy-composite); and technologies going beyond lithium ion (lithium metal, including lithium sulphur and lithium air).

The 2016 cost and energy density assessment draws from the results developed by the US DOE (Howell, 2017). The assessment aims to reflect the production cost of technologies that are currently being researched once they achieve commercial-scale, high-volume production (US DOE, 2017). The US DOE estimate is higher than the USD 180/kWh to USD 200/kWh range of battery pack costs announced recently by GM and LG Chem (Ayre, 2015) or Tesla and Panasonic (Field, 2016; Lambert, 2016a, 2016b) for batteries that will be used in new EV models. The estimates are also lower than the costs estimates for commercially available technologies reported in other assessments, which range between USD 300/kWh (Slowik et al., 2016) and USD 500/kWh (US DOE, 2017). Overall, this confirms that technologies currently in the R&D stage have better performance than those available on the market. Since the cost estimates for the scale-up of lab-scale technologies are projections of the expected costs in three to five years for high-volume production (US DOE, 2017),[12] the assessment suggests that battery costs will continue to decline.

Figure 6 • Evolution of battery energy density and cost



Notes: Contrary to the results assessed for 2009-15, which targeted PHEV batteries, the 2016 estimates of costs and volumetric energy density by the US DOE (costs are to be interpreted as projections for the high-volume production of technologies currently being researched) refer to a battery pack that is designed to deliver 320 km of all-electric range and is, therefore, suitable for BEVs. The latest update of this cost assessment was developed accounting for an advanced lithium-ion technology (with silicon alloy-composite anode). Being a technology that is still being researched today, this is currently deemed to have a greater cost but also a larger potential for cost reductions compared with conventional lithium-ion technologies.

Sources: Howell (2017), EV Obsession (2015) and Cobb (2015a).

Key point: Prospects for future cost reductions from the main families of battery technologies confirm the encouraging signs in cost and performance improvements observed over the past decade.

Expansions in production volumes and pack size bear the capacity to reduce unit costs (Howell, 2017). According to the US DOE, increasing production volumes from 25 000 units to 100 000 units for a BEV (100 kWh) battery pack allows a cut in battery pack production costs per kWh by 13%. Other studies confirm that production volume is a key factor in battery pack cost reduction: battery pack production volumes of over 200 000 battery packs per year are estimated to cost USD 200/kWh or less. This is roughly one-third lower than the USD 300/kWh estimated for production volumes ranging between 10 000 and 30 000 units in 2015 (Slowik et al., 2016).

Increasing the pack size from 60 kWh to 100 kWh (roughly reflecting, in the case of an average car sold in the United States, an increase in range from 200 km to 320 km) would also lead to a 17% reduction in cost per kWh at the pack level (Howell, 2017).

[12] Looking at the historical assessment of technologies being researched (Figure 6) against the costs estimated for commercially available applications today also suggests that lab-scale technologies tend to be three to five years ahead when compared with the average commercial technologies.

Targets, mandates and regulations

Targets are important in the policy-making process because they help move the focus of the discussion to policy implementation and capacity building, moving beyond the debate on the opportunity to regulate. In the transport sector, the Global Fuel Economy Initiative, which helped ensure that fuel economy regulations cover 80% of the global vehicle market, is an example of how this change in focus resulted in measurable progress towards the achievement of policy goals (GFEI, 2016). The EV30@30 campaign, which sets a collective aspirational goal for all EVI members of a 30% EV market share by 2030,[13] is a significant step in this direction.

Mandates and regulations build on the definition of regulatory targets to provide a clear signal to manufacturers and customers as they set a medium- to long-term vision for defining the evolution of vehicle characteristics. Key measures in this category include zero-emission vehicle (ZEV) mandates and fuel economy regulations.

- ZEV mandates are regulatory requirements (possibly embedding a system of tradable credits) for automakers to sell a set portion of ultra-low or zero-emission vehicles. They aim to promote RD&D efforts for marketing ultra-low and zero-emission vehicles. ZEV mandates were pioneered in California (CARB, 2017), are enforced in several states in the United States (UCS, 2016) in the province of Quebec, Canada, and are now being considered in China (Lambert, 2016c).
- Acting directly on one of the key vehicle design parameters, fuel economy regulations are effective in stimulating the adoption of energy-efficient and low-carbon technologies.[14] If tightened beyond the efficiency potential available from improved ICEs and hybrids, they will be one of the main policy drivers for enabling the transition to electric mobility.[15] The latter is also facilitated by clear, long-term indications of the evolution of the regulations and a coherent scope in terms of market coverage. Such signals are not always embedded in the existing frameworks.

Financial incentives

Financial incentives directed at electric car customers and users are essential for reducing the purchase cost and total cost of ownership (TCO) gap between electric and conventional cars. They are relevant for private customers, company cars and fleets, both in the public and private sectors.

Despite rapidly decreasing battery costs since 2009 (Figure 6), electric car battery packs are still a major cost component and drive up retail prices. Financial incentives are important in the current phase of electric car technology deployment to initiate and reinforce a positive feedback loop that, through increasing sales, production scale-ups and technology learning, will support cost reductions for batteries and other components.

EV incentives can take the form of direct rebates, tax breaks or exemptions, and can be framed in technology-neutral, differentiated taxation that favours low-emission vehicles according to their GHG and pollutant emission performance and penalises vehicles with high environmental costs. Many countries, including 20 EU member states – such as the Scandinavian countries, where

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[13] This includes BEVs, PHEVs and FCEVs and is a share of the total of all passenger cars, light commercial vehicles, buses and trucks.

[14] This is the case if reliable test procedures ensure consumer confidence and fair competition among OEMs.

[15] Fuel economy regulations can include provisions to give greater weight to electric cars in the calculation of corporate averages. This provides incentives to OEMs to start developing electric car production, but it also reduces the average fuel economy improvement (and associated benefits) delivered in the timeframe targeted by the regulations. In order to manage this drawback, these provisions shall be defined in conjunction with the definition of the overall policy target of the fuel economy regulation. In any case, they shall be limited to the early market deployment of electric cars.

vehicle taxes tend to be high (ACEA, 2016) – Brazil, Canada, China and South Africa (GFEI, 2017), currently impose differentiated taxes on vehicle registration and/or circulation based on their fuel economy or CO_2 emissions performance.

Although all EVI countries do apply purchase and circulation subsidies, a comparison of the purchase cost and the TCO for electric cars and vehicles using ICEs across European markets suggests that financial incentives are most effective when they minimise the EV purchase premium and come with a TCO advantage compared with ICEs (Hoy and Weken, 2017).

Policies for increasing the value proposition of electric cars

Electric car deployment can also be supported by increasing the appeal of electric cars over competing alternatives and providing advantages in terms of reduced fees, privileged access and time savings to electric car drivers. These targeted policies are best developed at the municipal level and adapted to the unique, local mobility conditions of each urban area, although they can be facilitated by national EV policy support frameworks. The following are examples of policies for increasing the value proposition of electric cars for drivers.

- **Waivers on regulations that limit the availability of licence plates for ICE vehicles**.

  These measures consist of total or partial exemption for low-emission vehicles, particularly electric cars, from increment control measures (such as lotteries or auctions, or a combination of both) restricting the availability of licence plates in urban agglomerations. They are in place in major Chinese cities.[16]

- **Exemptions from access restrictions to urban areas**.

  These measures take the form of access allowances, which are granted only to vehicles that meet strict exhaust emission standards and have already been widely applied in European cities (see Urban Access Regulations, 2017), and exemptions from other road space rationing measures, such as alternate-day travel based on licence plate numbers. The initiative recently announced by Paris and Mexico City to implement a diesel ban in 2025 (C40, 2017) and incentivise the use of electric, hydrogen and hybrid vehicles is also an example of action in this category.

- **Exemptions from usage fees for specific portions of the road network** (e.g. parking fees, road tolls and other fees incurred from vehicle use).

  One of the most iconic measures of this nature has been announced by the municipality of London. It consists of the Ultra Low Emission Zone (ULEZ), set to come into force in 2019 or 2020 at the latest (TfL, 2017a). The ULEZ is an area in central London within which all cars, motorcycles, vans, minibuses, buses, coaches and heavy-goods vehicles (HGVs) will need to meet exhaust emission standards (ULEZ standards) or pay a daily charge to travel. Improvement in air quality is the reason for the introduction of this measure. The ULEZ is complemented by actions aiming to promote walking, cycling, public transport and the use of sustainable freight deliveries. The London Congestion Charge (TfL, 2017b), already in place, also offers a 100% discount for electric cars.

- **Dedicated parking and access to publicly available charging infrastructure**.

  Electric car support measures relative to dedicated parking and public access to charging infrastructure are generally best implemented either at the local or municipality level or via private actions (possibly supported by public incentives and regulations) and are further discussed in the section on EVSE.

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[16] Chinese cities where such measures have been adopted include Beijing, Guangzhou, Guiyang, Hangzhou, Shanghai, Shenzhen and Tianjin. See Table 2 in EVI (2016a) for details.

- **Allowances to access bus lanes and high-occupancy vehicle (HOV) lanes**.
  Measures favouring EV access to the road network over ICEs can have sizeable impacts not only on the increased short-term value of electric cars (imputable to greater usage opportunities) but also on the economics of electric cars over time. Prospects of a travel ban for polluting vehicles, for instance, have the significant potential to lower the depreciation rate of electric cars compared to competing alternatives, increasing their economic competitiveness on the second-hand market.

Fleet procurement

Fleet operators, both in public authorities and the private sector, can contribute significantly to the deployment of EVs: first through the demand signals that they can send to the market, and second thanks to their broader role as amplifiers in promoting and facilitating the uptake of electric cars by their staff and customers.

Mandates and tenders from national and local authorities can foster EV uptake in large public fleets of vehicles, including municipal cars, service vehicles (such as garbage trucks) and vehicles used for public transport.

The EVI Government Fleet Declaration (EVI, 2016b) provides an overview of the actions that have already been undertaken by EVI countries regarding their public fleets, including measures taken by the central governments and local authorities. It also includes plans for the scale-up of public procurement and a call for action to non-state actors for the development of similar initiatives.

Partnerships between public authorities willing to mobilise the deployment of clean vehicle fleets can help to minimise the costs of public procurement. A concrete example of the cost opportunity is the joint action led by four cities in the United States – Los Angeles, Seattle, San Francisco and Portland, and now signed by 30 cities – to start a partnership to mass-purchase EVs for their public vehicle fleets (Lambert, 2017a; Ryan, 2017). The vehicles include not only regular passenger cars but also police cruisers, street sweepers and trash haulers. The order is currently seeking up to 114 thousand vehicles, a magnitude that is comparable with the 160 thousand EVs sold in the United States in 2016 and that will contribute to strengthening EV registrations.

Initiatives taken by public authorities can also be mirrored by commitments made by the private sector to embrace electric mobility. Initially, the rationale for this choice can be explained by the possibility to strengthen the environmental performance of companies and the capacity to show leadership in taking action on issues such as local air pollution, noise, energy diversification and climate change. As costs decline, this also translates into economic advantages, especially for fleets with high mileages.

The EV30@30 campaign builds on existing and forthcoming commitments on public and private fleets to stimulate EV deployment.

Key developments in 2016

The electric car market in 2016 experienced significant changes compared to 2015. Table 1 provides a high-level overview of these changes, bringing together qualitative indicators on the transformations of financial support mechanisms for electric car purchases between 2015 and 2016 and year-on-year changes in BEV and PHEV registrations.

Table 1 • BEV and PHEV incentives developments in a selection of countries, 2016

Country	2015 vs. 2016 policy developments		2015 vs. 2016 sales growth		2016 sales	
	BEV	PHEV	BEV	PHEV	BEV	PHEV
China	~		75%	30%	257 000	79 000
United States	~		22%	70%	86 731	72 885
Norway	~	↗	6%	164%	29 520	20 660
United Kingdom	~		4%	42%	10 509	27 403
France	~		26%	36%	21 758	7 749
Japan	~		48%	-34%	15 461	9 390
Germany	~		-6%	20%	11 322	13 290
Netherlands	~	↘	47%	-50%	3 737	20 740
Sweden	~	↘	0%	86%	2 951	10 464
Canada	~		19%	147%	5 220	6 360
Denmark	↘		-71%	-49%	1 218	182
Korea	~		75%	-40%	5 099	164

Notes: The symbol ~ indicates no major observed change in electric car support incentives between 2015 and 2016; an upward arrow indicates an increase in electric car support incentives; a downward arrow indicates a drop in electric car support incentives. The green and red colours indicate a probable correlation between the developments in electric car support incentives and BEV and PHEV sales in 2016 compared to the previous year. Greater details on the policy context are available in the main text.
PHEV sales in Denmark and Korea are available from primary data sources in conjunction with hybrid and electric vehicles (HEVs). Consequently, PHEV sales shown in this table for Denmark and Korea rely primarily on estimations based on the sources listed below and may be underestimated.

Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2017a), IHS Polk (2016), MarkLines (2017), ACEA (2017a, 2017b) and EEA (2017).

Key point: The capacity to couple key changes in electric car deployment policies effectively with the evolution of BEV and PHEV registrations between 2015 and 2016 broadly confirms that electric car market mechanisms are still largely driven by policy support.

The following section elaborates further on the information in Table 1 and summarises the key policy developments together with explanations on how some of the policy changes have influenced the evolution of BEV and PHEV registrations. The capacity to couple key changes in EV deployment policies and the evolution of BEV and PHEV registrations between 2015 and 2016 outlined here broadly confirm that EV market mechanisms are still largely driven by policy support.

- Chinese policies continued to provide strong financial and non-financial incentives to EV adoption in 2016. Exemptions from acquisition and excise taxes ranged between CNY 35 000 and CNY 60 000 (USD 5 000 to USD 8 500). Local and regional authorities can complement these within the limit of 50% of the central subsidies. Large Chinese cities also allow total or partial waivers from licence plate availability restrictions (EVI, 2016a). The combination of imposing licence plate restrictions, encouraging consumers to buy electric cars, and offering financial incentives – making electric cars financially accessible – explains the strong sales volumes (336 000 cars) and growth rate (40%) in 2016 compared to 2015 (Table 1). In its 2016-20 plan, Subsidy Schemes and Product Technology Requirements for the Promotion of New Energy Vehicles, the Chinese government announced that subsidies for EVs would be reduced by 20% from 2017 onwards, acknowledging the intention to constantly adjust and improve its policies for an optimised market response (MoF, 2017). Despite these changes, China's electric car market continued to grow in early 2017 (Pontes, 2017).

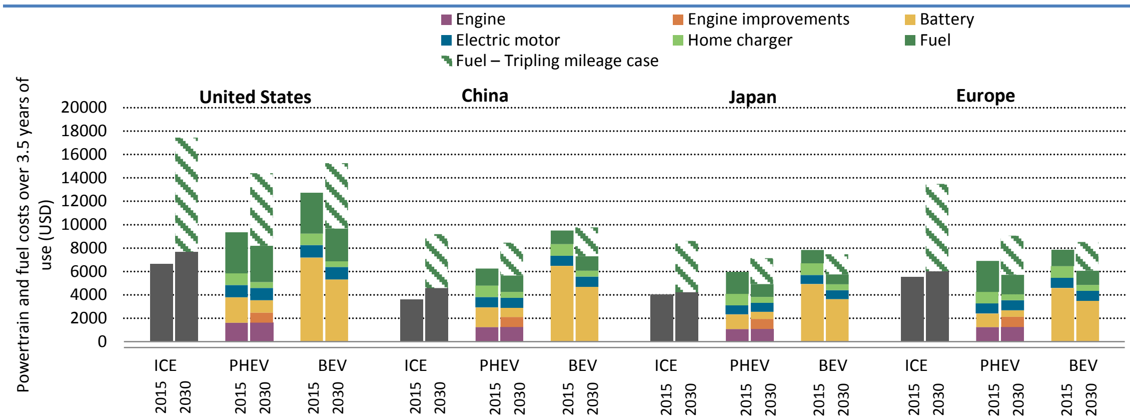
- In Norway, electric cars are exempt from acquisition tax, representing around NOK 100 000 (USD 11 600) (OECD, 2015). BEVs are exempt from the 25% value-added tax (VAT) on car purchases. This environment, coupled with a large number of waivers on fees such as road tolls and ferries, continues to provide a highly favourable environment for electric car uptake and for BEVs in particular. BEV taxation should remain unchanged until 2020, while higher purchase rebates and tax waivers were introduced for PHEVs in 2016 compared to 2015. Free parking for electric cars has no longer been applicable nationwide since 2016. BEV sales reached a record high in 2016 but did not grow significantly compared with 2015. On the other hand, PHEV sales registered remarkable growth and more than doubled in just one year. This was consistent with the change in policy support. Other factors that may have influenced sales include changes in BEV and PHEV model availability and an increased interest in electric cars from customers who more frequently cover long-distance trips (in this case potentially favouring PHEV sales).
- In Japan, a new subsidy scheme was introduced in 2016 that grants progressively higher subsidies as the electric range of the model increases, with the maximum subsidy set at JPY 850 000 (USD 7 700). For a Nissan Leaf with a 30-kWh battery, the purchase incentive amounts to JPY 330 000 (USD 3 000). BEV sales (typically with larger batteries and higher electric ranges than PHEVs) in 2016 increased by almost 50%, while PHEV sales dropped by 34%. Other factors that explain this market evolution include the introduction of the new Nissan Leaf in 2016, as well as the negative influence of allegations of falsifying fuel economy standards of Mitsubishi models.
- The Netherlands have a differentiated CO_2-based taxation scheme for which taxation rates are gradually evolving through 2020 (the rates for each year to 2020 have already been announced) (Energielabel, 2016). The changes primarily affect PHEVs, which will be subject to tax rates that will keep increasing compared with the rates in 2015. Zero-emission cars are exempt from registration tax, while cars with CO_2 emissions per km corresponding to a PHEV were subject to a EUR 6 per g CO_2/km tax rate in 2016 – this will increase to EUR 20 per g CO_2/km in 2017. Tax rates for BEVs will not change. Similar revisions are being made for the taxation of the private use of company cars, an important element in the Netherlands given that company car sales represented about the same proportion as private car sales in 2014. ZEVs pay 4% income tax on the private use of a company car, while the rate for PHEVs increased from a 7-14% range in 2015 to a 15-21% range in 2016, and will increase further to 22% (i.e. the same rate as conventional cars) by 2017. There is a strong likelihood that these changes in taxation are one of the reasons for the strong drop in PHEV sales, from a record-high 10% of total car sales in 2015 to 5% in 2016. This trend continued in early 2017 given the even larger tax rates applied in comparison to 2016 (EAFO, 2017b).
- The Swedish government decided to cut the purchase rebate offered to PHEVs, from SEK 40 000 (USD 4 500) in 2015 to SEK 20 000 (USD 2 250) in 2016 (for BEVs, this has been maintained at SEK 40 000 [USD 4 500] since 2011). This coincides with a large growth in PHEV sales in 2016 compared to 2015 (86%), while BEV sales have remained steady. The PHEV sales growth, in spite of the significant cut in purchase incentives, could be due to the large share of PHEVs sold as company cars and the incentives resulting from a reduction in value of the “fringe benefits” allowed for plug-in cars compared to conventional cars of the same class (estimated savings of SEK 1 000 [USD 110] or more per month). Additionally, the release of a larger offer of PHEV models in the past couple of years, such as the plug-in Volkswagen Passat, the Mitsubishi Outlander and the plug-in Volvo V60, likely influenced consumers’ interests (Kasche, 2017).

- Denmark initiated in 2016 the phasing-in of registration taxes for electric cars after several years of full exemption. In 2016, electric cars were subject to 20% of the full registration tax rate normally applied to conventional cars. This rate will be applicable to the next 5 000 electric car units sold or until the end of 2018. It will continue increasing until 2022 when full taxation will be applied to electric cars again. In parallel, Denmark, which had been a leader in electrification initiatives since 2008, mainly through public procurement programmes supported by the government, stopped these activities in 2016. Both these factors combined are likely to have been the main drivers of the drop in electric car sales (-68%) observed in 2016 (HEV TCP, forthcoming). As of 2017, Denmark will introduce a purchase tax rebate on electric cars based on battery capacity of USD 225/kWh applicable to a maximum of 45kWh, representing USD 10 000.

Future prospects

Figure 7 provides an overview of the TCO of PLDV technologies in major global regions in 2015, taking into account 3.5 years of fuel use and the same depreciation rate across all technologies. The figure also shows projections for 2030 developed according to the IEA 2DS.

Figure 7 • Comparative cost of PLDV technologies by country/region in the 2DS, 2015 and 2030



Notes: Vehicle travel per year, powertrain costs and fuel costs reflect the regional assumptions of IEA (2017b): 2015 powertrain investment costs for European vehicle characteristics range from USD 3 500 for ICEs to USD 7 800 for PHEVs and USD 12 400 for BEVs. The 2030 powertrain investment costs for European vehicle characteristics range from USD 4 700 for ICEs to USD 7 000 for PHEVs and USD 9 600 for BEVs. Powertrain costs in other countries are adapted to domestic vehicle characteristics. The results shown also reflect a 60% depreciation and a uniform assumption of a 20% tax on vehicle purchases. Insurance and maintenance costs are not included. A USD 1 000 cost for the installation of a home charger is included in the TCO for PHEVs and BEVs in 2015. By 2030, this cost drops to USD 500. In 2015, the battery pack cost is USD 200/kWh for BEVs and 255 USD/kWh for PHEVs. In 2030, the battery pack cost decreases to USD 100/kWh for BEVs and USD 125/kWh for PHEVs. BEV batteries have a range of 200 km in 2015; PHEV batteries have a range of 40 km. The electric range increases to 350 km for BEVs and 46 km for PHEVs by 2030. In 2015, PHEVs drive 30% of their annual mileage on the electric motor. This rate increases to 80% by 2030. "Fuel – tripling mileage case" refers to the fuel cost increment imputable to a tripling of the average annual mileages considered in the 2DS (this case assumes the same depreciation rate as the base case). The 2030 fuel cost includes a tax of close to USD 80/t CO_2. The oil price in 2030 is assumed to be USD 85/barrel.

Source: IEA (2017a), IEA Mobility Model, March 2017 version.

Key p oint: In 2015, electric car costs were higher than those for ICEs in all regions. By 2030, BEVs and PHEVs will become fully cost competitive with ICEs in Europe, where fuel taxes are estimated to be high and vehicle attributes (namely power) more favourable to electrification than in other regions. High yearly mileage electric cars have clearly lower first-owner TCOs for almost all cases when compared with ICEs. This underlines the interesting synergies between shared mobility services and vehicle electrification.

The 2015 assessment shows higher cost profiles for electric cars than ICEs in all regions. This is mainly due to battery costs, which despite their rapid decline in the past decade, are still responsible for higher purchase costs compared to ICEs of comparable power and size. This confirms that in the short-to-medium term, purchase subsidies, tax rebates and tax exemptions will remain key levers for influencing electric car market development. Subsidies will have a major influence on the possibility of lowering the TCO for first-car owners, bringing it closer to the competitiveness threshold with ICEs.

Under the 2DS, continuous improvements in battery costs and performance allow increased BEV ranges while reducing battery prices. At the same time, stringent emission regulations increase ICE costs, while increasing taxes on fossil fuels (reflecting their CO_2 content) increase ICE fuel costs. By 2030, BEVs and PHEVs become fully cost-competitive with ICEs in Europe, where fuel taxes are high and vehicle attributes (namely power) are more favourable to electrification than in other regions. The TCO of BEVs and PHEVs approaches the cost competitiveness threshold in other regions. The TCO gap between electric cars and ICEs tends to narrow as battery technologies deliver on cost and performance expectations. Given their energy efficiency and diversified energy mix used on power generation, leading to lower price fluctuations for electricity than for petroleum fuels, BEVs and PHEVs are favoured because of higher oil prices. CO_2 taxes on fossil fuels also favour the economic competitiveness of BEVs and PHEVs and reduce the uncertainty borne by oil price fluctuations.

The narrowing cost gap between electric cars and ICEs suggests that as electric car sales keep growing in the 2020s, governments will need to gradually revise their approach to electric car support, phasing out incentives in cases where BEVs and PHEVs actually rival ICE costs. Differentiated taxes based on environmental and health-related performance may need to remain in place, primarily to correct market failures (despite a cost increment for the first owner, electric cars deliver net societal savings over their entire lifetime). The difficulty in achieving full competitiveness for first owners in many of the global regions also suggests that other policy instruments (including fuel economy regulations and local measures, such as differentiated access to urban areas) will remain important in supporting the electric car uptake needed to meet the targets characterising a low-emission future.

Figure 7 also shows, in the tripling mileage case, that electric cars with a higher than average yearly mileage[17] have clearly lower first-owner TCOs by 2030 in almost all cases when compared with ICEs due to rapidly increasing fuel costs in the case of ICEs when mileages grow. This underlines interesting synergies between shared mobility services (particularly relevant in cities) and vehicle electrification. It also indicates that the support of concepts promoting urban mobility as a service (provided they are well integrated with public transportation) could be beneficial for supporting the transition to technologies enabling low-carbon and low-emission mobility.

Vehicle stock

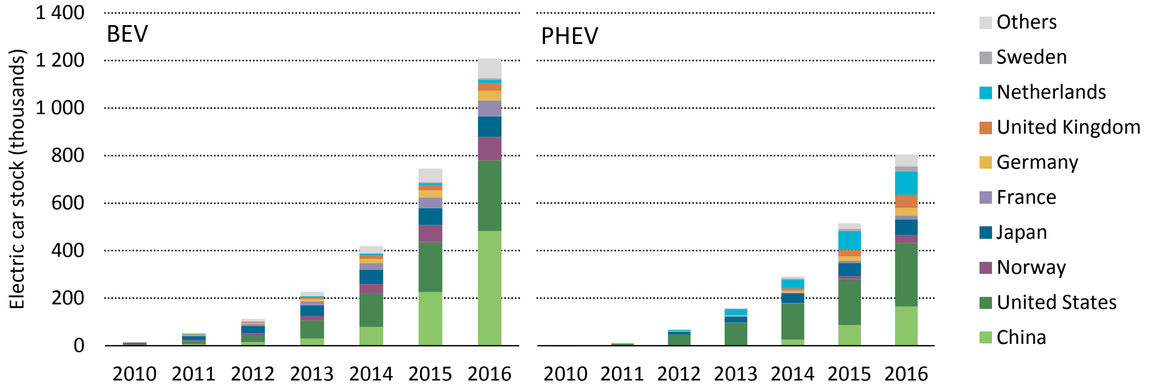
The global electric car stock surpassed 2 million units in 2016 after crossing the 1 million vehicle threshold in 2015 (Figure 8). Despite a continuous increase in the electric car stock, annual growth rates have been consistently decreasing since 2011. In 2016, stock growth was 59%, down from 76% in 2015 and 84% in 2014. BEVs still account for the majority of the electric car stock at 60%. Their share did not change significantly since 2012 and kept fluctuating around this value.

[17] The estimation for a higher yearly mileage (triple the average typical mileage in this analysis) does not attempt to include the effect on costs of larger battery capacity, battery repair or replacement that could be needed to accommodate a higher number of charge and discharge cycles, nor other costs that could be imputable to designs allowing compliance with this usage profile without compromising the performance of the battery. It also excludes (for all powertrain options) the effects on depreciation due to higher vehicle mileage.

When compared with the global car stock, the global electric car stock tracked in this report still accounts for a small fraction, 0.2%, of the total PLDVs in circulation worldwide.

China surpassed the United States in 2016 in total electric car stock, becoming the country with the most EVs on its road network. This evolution is primarily due to China's rapidly growing BEV market, where BEVs have continued to dominate over PHEVs. Since 2014, BEVs stabilised at about 75% of the Chinese electric car stock share. China and the United States make up 60% of the global electric car stock. European countries, combined, account for most of the rest, representing 28% of the global total. Like electric car sales, the global stock is still concentrated in a few markets. The top five countries account for 80% of the total, while the top ten countries account for 96%.

Figure 8 • Evolution of the global electric car stock, 2010-16



Notes: The electric car stock shown here is primarily estimated on the basis of cumulative sales since 2005. When available, stock numbers from official national statistics have been used, provided good consistency with sales evolutions.

Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2017a), IHS Polk (2016), MarkLines (2017), ACEA (2017a, 2017b) and EEA (2017).

Key point: The electric car stock has been growing since 2010 and surpassed the 2-million-vehicle threshold in 2016. So far, BEV uptake has been consistently ahead of PHEV uptake.

The global BEV stock has experienced a higher annual growth rate than that of PHEVs since 2013. In 2016, BEVs grew by 62%, while PHEVs grew by 59%. The narrative changes if China is not considered: when excluding China, the growth rate of the global PHEV stock has been higher than for BEVs since 2009, with only the exception of 2014.

As in the case of sales, different countries have different characteristics. The electric car stock in China, France and Norway is primarily composed of BEVs. The Netherlands is clearly the country with the largest share of PHEVs in its stock, at 88% of the total. A third group of countries, including Canada and the United States, have a fairly even distribution of PHEV and BEVs in their stock.

Progress towards deployment targets

Accelerating the deployment of electric cars until 2020 and during the 2020-30 decade will be essential for reaching the global EV deployment rates compatible with clean mobility and decarbonisation imperatives.

Starting from 2 million electric cars in circulation worldwide in 2016, all IEA scenarios on EV deployment suggest a significant scale-up by 2030 (IEA, 2017b):

- The Reference Technology Scenario (RTS), which reflects projections that respond to policies on energy efficiency, energy diversification, air quality and decarbonisation that have been announced or are under consideration, already projects to have 56 million electric cars in circulation by 2030, 28 times the 2016 stock.

- The 2DS increases the ambition for the number of electric cars in circulation to 160 million. This occurs in a context consistent with a 50% probability to limit the expected global average temperature increase to 2°C.
- Electric car stock projections in the B2DS, targeting the achievement of net-zero GHG emissions from the energy sector shortly after 2060 (see the introduction), reach 25 million by 2020 and exceed 200 million a decade later.

In both the 2DS and the B2DS, BEVs and PHEVs contribute to the decarbonisation of the energy system thanks to an increasing decarbonisation of the electricity grid and high electric driving rates for PHEVs (80% by 2030).

The Paris Declaration on Electro-Mobility and Climate Change and Call to Action, announced at COP21, expresses the ambition to exceed globally the threshold of 100 million electric cars and 400 million electric two-wheelers by 2030 (UNFCCC, 2015a), about a third below the number of electric cars projected in the 2DS and half the EV stock of the B2DS.

In recent years, a number of governments – many of which are involved in EVI activities – have also set national electric car deployment targets as part of their clean energy and mobility ambitions. In 2016, 14 countries had electric car targets in place: Austria, China, Denmark, France, Germany, India, Ireland, Japan, the Netherlands, Portugal, Korea, Spain, the United Kingdom and the United States (where targets have been defined for eight states). Korea is the only country that upgraded its target in 2016, from 200 000 to 250 000 electric cars by 2020, as per the Special Plan for Fine Dust Management, released in June 2016 (MoE, 2016). Denmark is no longer targeting 200 thousand electric cars by 2020 (Rask, 2017). The cumulative assessment of these targets, developed by the EVI (2016a), suggests the deployment of 13 million electric cars among these countries by 2020.[18] Achieving this cumulative target at a global level would require an annual electric car stock growth of 60% per year until 2020, a value comparable to the growth rate observed in 2016. On the other hand, meeting targets aligned with a 2DS pathway to 2020 would require a higher annual rate of increase of 85%. India is also looking at the 2030 horizon with ambitious engagements on vehicle electrification, as the country contemplates to have "most, if not all, vehicles in India […] powered by electricity" (PIB India, 2017). This statement implies that India would leapfrog to electric vehicles as the economy is driving a rapid expansion of the PLDV market in the country and bring over 50 million electric cars on its roads in less than 15 years, to reach just above 50% of the total PLDV fleet projected to be in circulation in the country under the B2DS (IEA, 2017a).

The year 2016 also recorded important announcements on electric car deployment targets from major global OEMs. These included announcements by Tesla, aiming to deploy at least 1 million sales by 2020, or Volkswagen, which unveiled a plan for a significant shift towards the production of electric powertrains and announced no less than 30 electric models to enter the market by 2025 (Volkswagen, 2016). Between 2015 and early 2017, nine global OEMs publicly announced their willingness to create or significantly widen their electric model offer over the next five to ten years. In China, which accounts for one-third of the global electric car stock by 2025 in the IEA 2DS, several Chinese OEMs also announced significant electric car production capacity scale-up plans (CNEV, 2017). A summary of all the announcements that were tracked in this assessment is provided in Table 2. Figure 9 provides an overview of electric car deployment for the next 15 years. The figure pools together indications derived from a range of different scenarios, including three IEA projections and the ambition outlined in the Paris Declaration, and

[18] In 2017 Germany has also expressed doubts on the likelihood of meeting the target of 1 million electric cars on the roads by 2020 (Reuters, 2017). The assessment made in EVI (2016a) includes the German target.

assesses them against targets established by individual countries and announcements from major OEMs.

The assessment of OEM announcements in terms of stock growth, as presented in Figure 9, was developed by taking into account cumulative sales targets at a given point in time, if they were available, or calculating them on the basis of sales targets, assuming a linear development of sales growth from now until the target year (typically 2020 or 2025). In cases where the target year was 2020, the lower bound of the stock growth for 2025 was calculated assuming constant sales, while the higher bound was derived from the application of RTS sales and stock growth to the available information on 2020. In the case of China, the lower bound estimate for 2020 matches the 2 million annual electric car capacity production government target by 2020. The upper bound estimate reflects the growth in production capacity announced by the OEMs, factoring in a 66% capacity utilisation rate.[19]

Table 2 • List of OEMs announcements on electric car ambitions, as of April 2017

OEM	Announcement	Source
BMW	0.1 million electric car sales in 2017 and 15-25% of the BMW group's sales by 2025	Lambert (2017b)
Chevrolet (GM)	30 thousand annual electric car sales by 2017	Loveday (2016)
Chinese OEMs	4.52 million annual electric car sales by 2020	CNEV(2017)
Daimler	0.1 million annual electric car sales by 2020	Daimler (2016a)
Ford	13 new EV models by 2020	Ford (2017)
Honda	Two-thirds of the 2030 sales to be electrified vehicles (including hybrids, PHEVs, BEVs and FCEVs)	Honda (2016)
Renault-Nissan	1.5 million cumulative sales of electric cars by 2020	Cobb (2015b)
Tesla	0.5 million annual electric car sales by 2018 1 million annual electric car sales by 2020	Goliya and Sage (2016), Tesla (2017a)
Volkswagen	2-3 million annual electric car sales by 2025	Volkswagen (2016)
Volvo	1 million cumulative electric car sales by 2025	Volvo (2016)

Note: Chinese OEMs include BYD, BJEV-BAIC Changzhou factory, BJEV-BAIC Qingdao factory, JAC Motors, SAIC Motor, Great Wall Motor, GEELY Auto Yiwu factory, GEELY Auto Hangzhou factory, GEELY Auto Nanchong factory, Chery New Energy, Changan Automobile, GAC Group, Jiangling Motors, Lifan Auto, MIN AN Auto, Wanxiang Group, YUDO Auto, Chongqing Sokon Industrial Group, ZTE, National Electric Vehicle, LeSEE, NextEV, Chehejia, SINGULATO Motors, Ai Chi Yi Wei and WM Motor.

Sources are indicated in the table.

Key point: By April 2017, nine global OEMs had publicly announced their willingness to create or significantly widen their electric model offer over the next five to ten years. Several Chinese OEMs also announced very significant electric car production capacity scale-up plans.

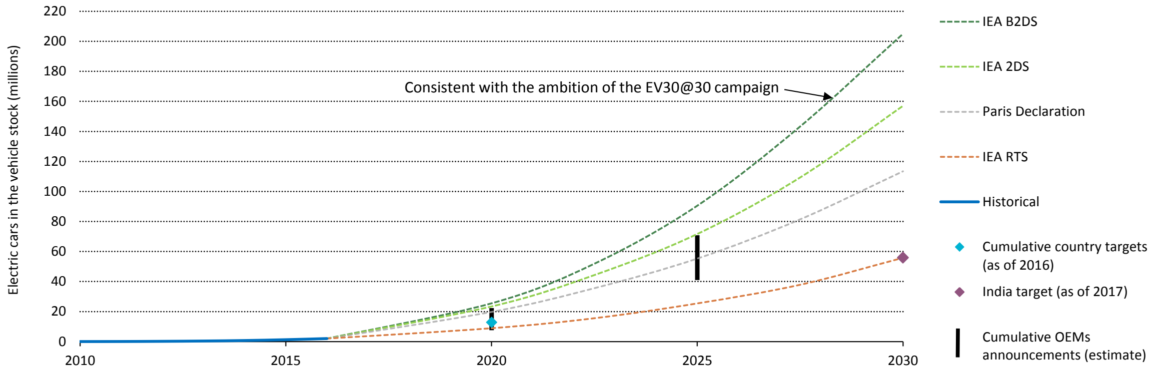
Overall, accounting for the global OEM announcements and targets listed in Table 2, the electric car stock stemming from the OEM targets could range between 9 million and 20 million by 2020. Considering announcements to 2025 and applying growth rates based on the RTS to targets announced to 2020, the OEM announcements listed in Table 2 could lead to 40-70 million electric cars on the road by 2025.

The level of ambition resulting from the OEM announcements assessed here shows a fairly good alignment with country targets to 2020. To 2025, the range estimated suggests that OEMs' ambitions lie within the range corresponding to the RTS and 2DS projections from the IEA, broadly matching the Paris Declaration. In order to see these ambitions materialise, EV (and

[19] This rate matches the indications currently available for the average capacity utilisation of Chinese auto manufacturing plants given the information available from CAAM (2017) and IHS (2017).

battery) production capacity needs to increase. The scale of this challenge can be illustrated by comparing the battery capacity additions needed against recent developments: attaining the mid-point of the estimated ranges for OEM announcements in 2025 would require the construction of roughly ten battery manufacturing facilities with the production capacity of the Tesla Gigafactory.[20]

Figure 9 • Deployment scenarios for the stock of electric cars to 2030



Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2017a), IHS Polk (2016), MarkLines (2017), ACEA (2017a, 2017b) and EEA (2017). Country targets in 2020 reflect the estimations made in EVI (2016a) and updates to date. India's target reflects a conservative interpretation of the announcement made by the government (PIB India, 2017): 50% of the PLDV stock of the country (in the B2DS) is electrified by 2030. The assessment methodology for OEM announcements included in Table 2 is discussed in the main text. Projections on the stock deployed according to the Paris Declaration are based on UNFCCC (2015a). Projections on the EV uptake in IEA scenarios were developed with the IEA Mobility Model, March 2017 version (IEA, 2017a).

Key point: The level of ambition resulting from the OEM announcements assessed shows a fairly good alignment with country targets to 2020. To 2025, the range estimated suggests that OEM ambitions lie between the range corresponding to the RTS and 2DS projections from the IEA, broadly matching the Paris Declaration.

The recent redefinition of the EVI ambition to reach a collective market share (in all modes except two-wheelers) of 30% by 2030 (as spelled out in the EV30@30 campaign), places the ambition of EVI countries in line with the B2DS,[21] provided that the carbon intensity of power generation declines rapidly (see Box 2 for insights on the CO_2 emissions reduction benefits stemming from a shift to electrified powertrains today and by 2030 while electric grids progressively decarbonise).

Box 2 • Progress towards decarbonisation targets

Electrifying road transportation has multiple benefits, including the reduction of emissions of local pollutants and noise and the promotion of energy security and decarbonisation through increased energy efficiency and diversification. If transport electrification goes hand-in-hand with the decarbonisation of the electricity supply, it will also be effective for significantly reducing GHG emissions. Figure 10 aims to provide a comparative assessment of the CO_2 intensities of electric vehicles, benchmarking BEVs and PHEVs against other powertrain technologies. It does so by looking at major global regions characterised by variable average car sizes and grid carbon intensities under different grid decarbonisation scenarios. The broad spectrum of options covered in Figure 10 provides a good basis to discuss the advantages and disadvantages of EVs in different contexts.

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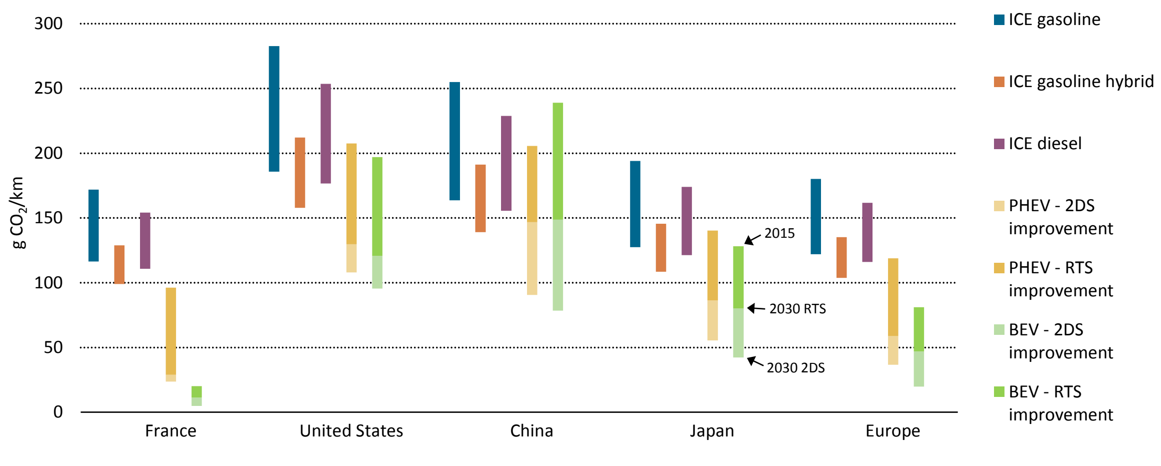
[20] This calculation is based on an annual 8 million EV production in 2025, equally shared between BEVs and PHEVs, one Gigafactory-type plant being able to deliver 0.5 million BEV batteries per year (Tesla, 2014).

[21] The B2DS is consistent with a 25% EV market share (for all road modes excluding two-wheelers) by 2030 worldwide and about 30% in EVI countries. These same shares grow to 30% and are in the 35-40% range when looking at PLDVs only. In the 2DS, the corresponding global EV market share is 18% and close to 25% in EVI countries.

France can be used as an example of a country characterised, in 2015, by fuel efficient vehicles with a fairly low average power rating and a low-carbon grid thanks to the high share of nuclear electricity.[22] Under these circumstances, electric cars lead to emissions per km that are lower than any other powertrain technology at any point in time between now and 2030 in all of the IEA scenarios. In 2015, BEVs and PHEVs were already a lower-carbon option than ICEs and HEVs in the United States, Japan and Europe as a whole (considering the GHG emission intensity per kWh of the average European electricity generation mix). In China, the high carbon intensity of the current electricity production mix (still exceeding 700 g CO_2/kWh in 2015, one of the highest in the world at the national level) hampers the benefits of EVs in terms of GHG emission reductions. In 2015, HEVs in China were the only technology that could achieve on-road stock average emissions below the 200 g WTW CO_2/km threshold. With the 2015 GHG intensity of the Chinese grid, BEVs are more CO_2 intensive than HEVs and diesel cars. Under the same conditions, PHEVs are a better alternative to both ICEs and BEVs, but they are still worse than HEVs.

Figure 10 • On-road well-to-wheel CO_2 emissions for PLDVs for various powertrain technologies by country or region: RTS and 2DS, 2015 to 2030



Notes: The upper limit of each bar shows the well-to-wheel (WTW) CO_2 emissions estimated for each powertrain technology in 2015. The lower limit of the dark shading in each bar shows the WTW CO_2 emissions from the technology in 2030, assuming technology and grid decarbonisation improvements aligned with the RTS. The bottom of the light-shaded part of the bars shows the WTW CO_2 emissions in 2030, assuming technology and grid decarbonisation improvements aligned with the 2DS. Vehicle powertrain characteristics reflect the regional assumptions of IEA (2017a). PHEV CO_2 emissions are calculated on the basis of an electric driving rate of 30% of the total mileage in 2015 and an electric driving rate of 80% of the total mileage in 2030.

Source: IEA (2017a), IEA Mobility Model, March 2017 version.

Key point: In order to deliver significant GHG emission reductions, transport electrification needs to go hand-in-hand with the decarbonisation of power generation.

Prospects for 2030 account for improved fuel economy for conventional passenger cars compared with 2015 and 15 years of grid decarbonisation efforts. Under an RTS trajectory, BEVs and PHEVs offer lower-carbon solutions than ICEs and HEVs in all regions shown in Figure 10, except China. For China, a decarbonisation ambition coherent with the RTS (with a grid intensity at 533 g CO_2/km) would not be sufficient to ensure that BEVs and PHEVs perform better, from a GHG emissions perspective, than HEVs and diesel cars. This suggests that there is a strong imperative for China to increase its grid decarbonisation efforts if it wants to transition to electric mobility (as the country's current developments and ambitions suggest – these are largely driven by a pressing need to address urban air pollution) while meeting global climate targets. Only a rapid decarbonisation trajectory (Figure 10 shows results for the 2DS, but the B2DS carbon intensities for power generation would also qualify for this) would allow electric cars to break the 100 g CO_2/km (well-to-wheel) threshold in 2030 in the country. In the 2DS, BEVs would emit under 20 g CO_2/km in Europe, five times less than comparable ICE and HEV options available in 2030.

[22] A similar assessment could also be made for Brazil or Norway, for example. Both are characterised by similar average vehicle sizes as France and by a low GHG-intensive grid thanks to high shares of hydroelectricity.

Although this assessment accounts for the full fuel lifecycle emissions of different powertrains on a real drive basis, it does not provide a comparative assessment of the GHG impact of vehicle manufacturing for the different powertrain options. A study carried out in the Netherlands suggests that an electric car provides a CO_2 benefit on a lifecycle basis – including car manufacturing and recycling – compared to a gasoline car in nearly all cases. This is not the case only when the electric car is entirely powered by coal, the most CO_2-intensive electricity source (935 g CO_2/kWh). When less-GHG-intensive grids are taken into account – which is the case for most national grids at the global level – the GHG benefit of BEVs on a full lifecycle basis becomes sizeable: electric cars are 54% less CO_2 intensive with a 200 g CO_2/kWh grid intensity than their gasoline counterparts (Van Gijlswijk et al., 2014; Verbeek et al., 2015; Willemsen, 2016).

Other modes

Low-speed electric vehicles

Low-speed electric vehicles (LSEVs) are gaining relevance primarily in China, where they have emerged as a competitor to both electric vehicles and two-wheelers. LSEVs generally have a maximum speed of between 40 km/h and 70 km/h, have short ranges and, in some cases, use lead-acid batteries and basic motor technology. Estimates for LSEV sales in 2016 were between 1.2 million and 1.5 million, and the year-on-year growth rate since 2014 was close to 50% for the third consecutive year (Auto Sohu, 2016, 2017a, 2017b; CIIN, 2016; Daily Economic News, 2016 and Jiren, 2017). Since LSEVs started to develop after 2011 (EVI, 2016a), their current stock is likely to be close to 3-4 million units.

The main attractions of LSEVs are their low cost, small size, and the lack of regulations (for instance, they do not require a driving licence or insurance to operate). This is especially advantageous for low-income consumers who live in small or medium-sized cities, the elderly, and those in cities where the number of new licence plates is restricted. In China's Shandong province, the growing LSEV industry has also contributed significantly to job creation.[23]

The growing use of LSEVs has not materialised without concerns. The use of lead-acid batteries has had negative environmental effects, and the lack of regulations for LSEV manufacturers has led to poor safety performance. Traffic safety is also at stake. LSEVs struggle in large cities due to their poor acceleration and low top speeds. They are often used in bike lanes, and, since both the drivers and the LSEVs themselves do not require specific documentation to operate, are difficult to control. Lastly, LSEVs could jeopardise the market for electric cars, one of China's priorities for industrial policy development.

Legislation to regulate and standardise LSEVs is currently being discussed by the Chinese government (MIIT, 2016). According to the China Electrical Car Network (CNEV), some of the issues that will be addressed by regulations include battery types (lead-acid versus lithium-ion batteries), mandatory safety tests and vehicle dimensions (Yang, 2016). The high-level objective is to upgrade the LSEV fleet in circulation, regulate and standardise the vehicles and eliminate the LSEVs that do not comply with these standards.

Two-wheelers and three-wheelers

China continued to dominate both new registrations and the global stock of electric two-wheelers in 2016, with estimates of sales that are in line with those reported in EVI (2016a) (roughly 26 million, according to the EVI data submission from China). Given the development of

[23] In Shandong province, more than 0.6 million LSEVs were sold in 2016, almost 50% of the national LSEV sales in China (Diandong, 2017).

two-wheeler sales over time and scrappage ages that should be reasonably close to eight to ten years, the vehicle stock should also be in the same magnitude of the values estimated for 2015, in the 200-230 million range. While data quality and collection remain an issue, it is evident that China is by far the global leader. The high growth rate in electric two-wheelers is partially due to the country's policies to limit air pollution hazards, such as its ban on gasoline-powered motorcycles, limits on the issuing of licences, and the division of lanes (Yang et al., 2014). Additionally, two-wheelers have reached cost parity with ICE models, making them affordable and attractive to consumers.

Further data collection is necessary to validate and compare more countries and rationalise information for international comparison. The few data points available suggest that the United Kingdom experienced a positive growth in the number of two-wheelers from 2015 to 2016.[24] Sweden also witnessed an increase in 2015 from 2014, but data were unavailable for 2016.

Three-wheelers, widespread in Asian countries and mainly known as *tuk-tuks*, are also attracting the attention of policy makers and are bound to become increasingly electrified. For example, the Thai government is planning to start electrifying its vehicle fleet by tackling *tuk-tuks* through a subsidy programme aimed at supporting the introduction of 100 of them by 2018. The policy goal is to fully replace the 22 000 *tuk-tuks* currently on the roads within five years (Thai Rath, 2016).

Electric buses

The global battery-powered electric bus stock grew to about 345 000 vehicles in 2016, double the number in 2015. Despite potentially significant data classification issues, China emerges as the global leader in the electrification of buses. According to available statistics, the stock of electric buses in China reached 343 500 units in 2016, and included about 300 000 BEVs. Within China, Shenzhen is one of the most ambitious cities globally regarding the electrification and modernisation of its bus systems. In 2016, hundreds of electric buses were already in operation. Shenzhen has also set the goal of having a 100% electric bus fleet in 2017 (Hall et al., 2017).[25]

Europe accounted for 1 273 vehicles in the global electric bus stock in 2016, while the United States accounted for 200. The European electric bus stock more than doubled from 2015, suggesting that the market is moving beyond the demonstration phase into commercial development. As an example, the public transport operator of the city of Paris opened its first electric bus line in 2016. Meanwhile, the same operator is getting ready for widespread electrification and plans to replace 80% of its existing bus fleet with electric buses by 2025 – this translates to roughly 4 000 electric buses being deployed in the next eight years (RATP, 2017). In the United States, the electric bus manufacturer Proterra doubled its sales in 2016 compared to 2015 but has only sold 380 vehicles since the company's founding in 2004 (Proterra, 2017).

[24] In the United Kingdom, electric two-wheelers are eligible for a GBP 1 500 (USD 2 000) grant under certain conditions (Gov.uk, 2017b).

[25] In addition to buses, Shenzhen also uses minibuses on several routes, combined with on-demand electric bus services, (potentially upgraded to new routes) to connect the last mile between homes and regular bus and metro stations, with the aim of maximising the efficiency and effectiveness of its bus services.

Electric vehicle supply equipment

Charging infrastructure, whether at home, at work or at public locations, is indispensable for operating EVs. Analysis looking at early EV market developments shows that the availability of chargers emerged as one of the key factors for contributing to the market penetration of EVs. Ensuring the availability of chargers is also essential for enabling the diversification of the transport fuel mix and catalysing its transition towards clean energy.

This section focuses on the electric charging infrastructure needed to supply electric vehicles. It looks primarily at EVSE deployments for electric cars. This is for two reasons:

- The importance, in terms of the number of vehicles, of electric cars for the growth prospects of electric mobility: the number of electric cars deployed in all the scenarios for the next 15 years is comparable to the magnitude projected for two- and three-wheelers but is significantly larger than the values imputed for buses, other public transport vehicles and trucks, given that these modes constitute a fairly small fraction of the total vehicle stock.
- The power requirements needed for the energy supply of electric cars clearly exceed those needed to charge smaller vehicles, such as two-wheelers and, therefore, are more likely to require the deployment of novel components of the electricity production, transmission and distribution infrastructure.

The section is structured as follows:

- First, it looks at the nature of the EVSE needed by electric cars and briefly summarises the existing standards and types of chargers in the main global EV markets: China, Europe, Japan, and North and Central America (including Canada, Mexico and the United States).
- Second, it provides a numerical overview of the status of EVSE deployment.
- Third, it considers existing policy support mechanisms, looking specifically at the deployment of charging infrastructure in cities and the role of local authorities.
- Finally, it presents prospects for EVSE developments that could match the scenarios on electric car uptake discussed previously, building on the information available on electric cars and charging infrastructure discussed in this report.

Standards and types of chargers

Charging electric vehicles requires the use of cables, connectors and communication protocols between the vehicles and the EVSE, as well as the EVSE-grid communication, i.e. the communication between the EVSE and the distribution system operator (DSO). The EVSE suitable for electric cars has three main characteristics:

- **level**, describing the power output of an EVSE outlet
- **type**, referring to the socket and connector being used for charging
- **mode**, which describes the communication protocol between the vehicle and the charger.

International standardisation bodies and other associations define these characteristics through standards. Standards may focus on just one of the characteristics or a combination of them. Key standardisation entities involved in the development of these standards include the International Organization for Standardization (ISO); the International Electrotechnical Commission (IEC); the Society of Automotive Engineers (SAE) of the United States; and the Standardization Administration of China (SAC), which issues Chinese national standards (GuoBiao, GB).

CHAdeMO, an association of vehicle manufacturers and utilities, also became active in this area in 2009 through the development of a DC quick-charging standard, which was started in Japan and uses a specific type of connector and communication protocol. In 2016, the association announced an amendment to the current protocol, enabling charging up to 150 kW and the development of technical analyses for fast chargers with a higher power rating (350 kW) (CHAdeMO, 2016). Currently, several mass-produced electric cars are equipped with connecting devices enabling the use of CHAdeMO chargers,[26] and adaptors are available for most models using different connectors (CHAdeMO, 2012).

CharIN is a similar association with a broader scope in terms of membership and representation across the automotive sector. It was established in 2015 with the aim of promoting a global charging standard (CharIN, 2015) and now promotes the combined charging system (CCS) and the combo connectors used in Europe and the United States, suggesting a vision for future developments. This approach enables fast charging at 200 kW and developments are now targeting 350 kW (CharIN, 2017a).

In addition to these standard-setting bodies and associations, Tesla has been using its own standard to support all levels and modes of charging through the same connector type. The exception is now Europe, where Tesla needs to comply with the mandate regarding interoperability objectives to use specific standards for sockets and connectors for normal (Level 2) and high-power (Level 3) recharging points (EC, 2014). In 2016, Tesla also became a member of CharIN.

Table 3 • Overview of the level (power output) and type (socket and connector) of EVSE used in China, Europe, Japan and the United States

<table>
<tr><th rowspan="2">Classification in use here</th><th rowspan="2">Level</th><th rowspan="2">Current</th><th rowspan="2">Power</th><th colspan="4">Type</th></tr>
<tr><th>China</th><th>Europe</th><th>Japan</th><th>North America</th></tr>
<tr><td></td><td>Level 1</td><td>AC</td><td>≤ 3.7 kW</td><td colspan="3">Devices installed in private households, the primary purpose of which is not recharging electric vehicles</td><td>SAE J1772 Type 1</td></tr>
<tr><td rowspan="2">Slow chargers</td><td>Level 2</td><td>AC</td><td>> 3.7 kW and ≤ 22 kW</td><td>GB/T 20234 AC</td><td>IEC 62196 Type 2</td><td>SAE J1772 Type 1</td><td>SAE J1772 Type 1</td></tr>
<tr><td>Level 2</td><td>AC</td><td>≤ 22 kW</td><td colspan="4">Tesla connector</td></tr>
<tr><td rowspan="3">Fast chargers</td><td>Level 3</td><td>AC, triphase</td><td>> 22 kW and ≤ 43.5 kW</td><td></td><td>IEC 62196 Type 2</td><td></td><td>SAE J3068 (under development)</td></tr>
<tr><td>Level 3</td><td>DC</td><td>Currently < 200 kW</td><td>GB/T 20234 DC</td><td>CCS Combo 2 Connector (IEC 62196 Type 2 & DC)</td><td>CHAdeMO</td><td>CCS Combo 1 Connector (SAE J1772 Type 1 & DC)</td></tr>
<tr><td>Level 3</td><td>DC</td><td>Currently < 150 kW</td><td colspan="4">Tesla and CHAdeMO connectors</td></tr>
</table>

Sources: IEA elaboration based on AFDC (2017), Bohn (2011), CHAdeMO (2012), CharIN (2017a), CharIN (2017b), EC (2014), Electric Vehicle Institute (2017), HK EMSD (2015) and State Grid Corporation of China (2013).

Key point: Various sockets and connectors are in use across the main global regions. Two main combined charging systems (CCSs) were recently developed to standardise the connections. They are the current standards adopted in Europe and the United States.

Table 3 provides an overview of the level (power output) and type (socket and connector) of EVSE used in China, Europe, Japan and the United States. Overall, it is important to highlight

[26] Manufacturers including Peugeot and Mitsubishi, Renault-Nissan and Hyundai Kia use CHAdeMO connectors and protocols for fast charging, regardless of the market.

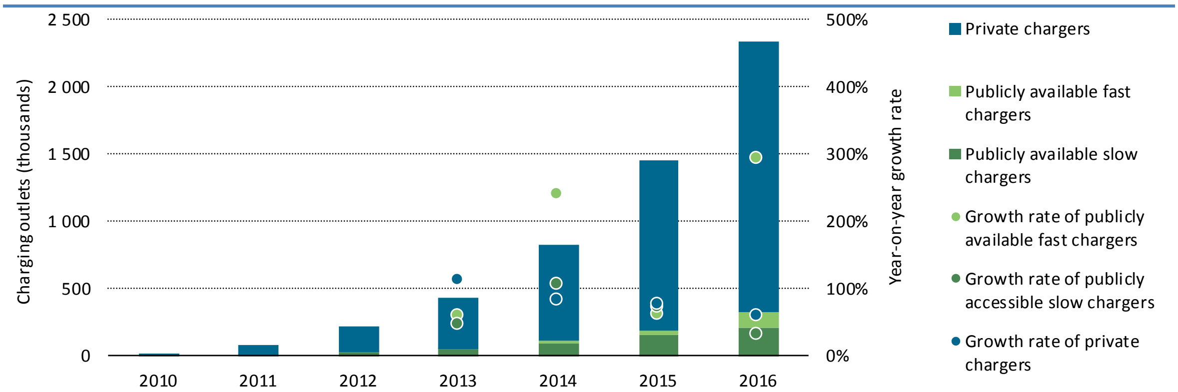
connectors for two main CCSs, which have been recently developed to minimise differences and are gaining relevance. They are currently suitable for the Level 2 and 3 standards adopted in Europe and the United States. These standards, coupled with the HomePlug PHY communication protocol and the global standard for communication between charging stations and electric cars, are emerging as the most interesting recent developments towards a global charging solution.[27]

To date, there are few standardised protocols for EVSE-grid communication, but efforts to develop them have started. Elaad's work on the Open Smart Charging Protocol is amongst the most interesting developments in this area (Montes Portela et al., 2015).

Historical developments

Similarly to the global electric car stock, global EVSE outlets surpassed 2 million in 2016.[28] Electric cars still outnumber public charging stations by more than six to one, indicating that most drivers rely primarily on private charging stations (Figure 11).[29]

Figure 11 • Global EVSE outlets, 2010-16



Note: Private chargers in this figure are estimated assuming that each electric car is coupled with a private charger.

Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2017a).

Key p oint: Publicly accessible infrastructure is growing to support the emerging EV market, especially publicly accessible fast chargers.

The growth of publicly accessible chargers accompanies the increase in the number of electric cars on the road: the growth rate in the number of publicly accessible chargers in 2016 (72%) was higher, but of similar magnitude, to that of the electric car stock growth in the same year (60%). The higher rate of growth for chargers than electric cars is consistent with the need to deploy

[27] The HomePlug PHY was developed as an industry-led initiative comprising 60 member companies to create specifications for using power lines for reliable broadband home networking and smart grid applications. Recently updated to version Green PHY, it has been specified as the base technology for data exchange in the global standard for communication between charging stations and electric cars developed by ISO/IEC 15118 (Homeplug, 2012; ISO, 2015).

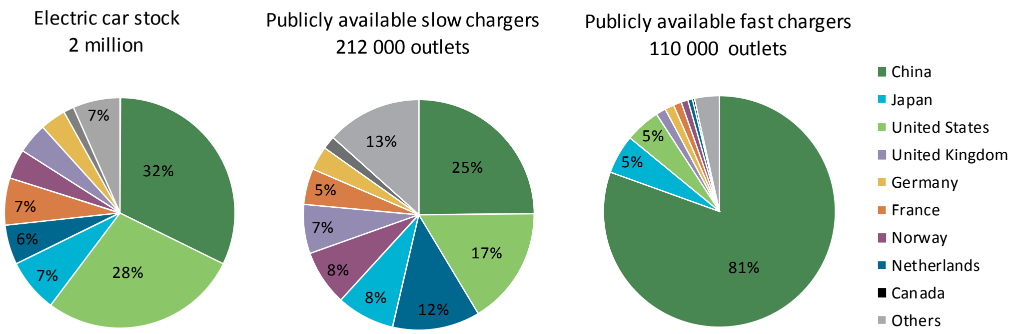
[28] The discussion on EVSE deployment developed here refers to two main categories of chargers, defined as slow and fast chargers, corresponding to Levels 2 and 3 in Table 3.

[29] As in EVI (2016a), this assessment still relies on the assumption that each EV on the road is coupled with a private charger. Statistics regarding the installation of private chargers are often inexistent or incomplete at an aggregated level as it is the choice of each individual to install a private charger at home when buying an EV. Since the installation of a home charger is usually supported by the OEM for each EV sold (by direct installation by the OEM, for example), it is estimated that, to date, each EV has access to a dedicated private charger. EV owners that do not have the possibility of installing a home charger (because they do not have a dedicated parking spot if they live in urban centres, for example), and must, therefore, rely on publicly accessible charging, also have the option to rely on a growing number of workplace chargers. These workplace chargers are also not accounted for in the statistics regarding publicly accessible outlets.

chargers as a prerequisite for EV adoption and the nascent nature of most of the electric car markets.[30]

Publicly accessible EVSE growth was primarily driven by the rapid increase in the number of fast chargers, largely attributable to China, where fast chargers grew sevenfold to nearly 90 thousand units.[31] Even when China is not considered, the growth rate for publicly accessible fast chargers in 2016 was still greater than publicly available slow chargers.

Figure 12 • Electric car stock and publicly available EVSE outlets, by country and type of charger, 2016



Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2017a).

Key point: Electric cars still outnumber public charging stations by more than six to one, indicating that most drivers rely primarily on private charging stations. Publicly available EVSE shares are not evenly distributed across markets. This is consistent with the early stage of electric car deployment.

Figure 12 shows the regional distribution of electric cars (left-hand chart), publicly accessible slow chargers (centre chart) and fast chargers (right-hand chart). Figure 12 indicates that the shares of publicly available EVSE are not evenly distributed across markets, reflecting large variations in EV/EVSE ratios across counties. This is consistent with the early stage of EV deployment in most markets. In the case of fast chargers, the large global share for China could be the result of the rapid growth of electric buses (significantly larger than in any global region so far) and significant uncertainty about the share of fast chargers actually dedicated to bus services. Japan, where 50-kW fast chargers were deployed early in order to address range anxiety (i.e. the fear that a vehicle has insufficient energy stored on board to reach the next available recharging point or its destination), but where EV sales have not experienced recent, significant year-on-year growth, also has high shares of fast chargers per EV compared with other countries.

EVSE policy support

Overview

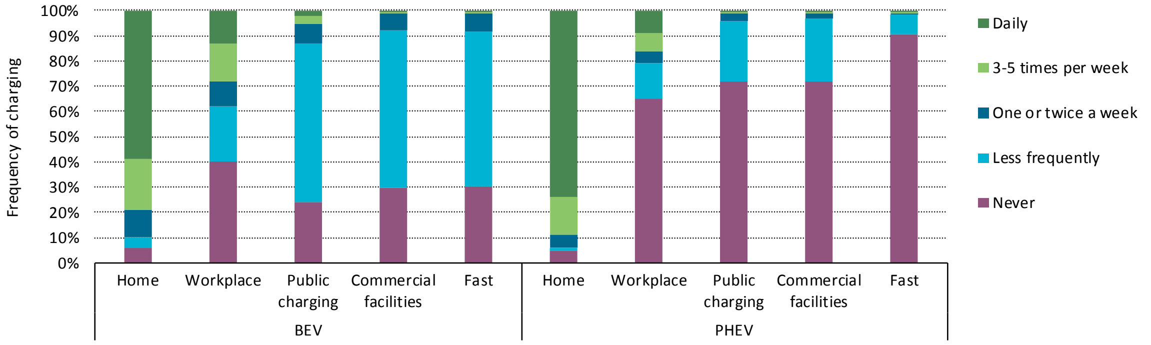
Evidence from Norwegian BEV and PHEV users (Norway is the country with the highest electric car penetration) suggests that electric car charging does not match refuelling habits for internal combustion engines even when electrified powertrains substitute for ICEs of a similar category (Figure 15). Unlike ICE drivers, electric car owners most frequently charge their vehicles at home

[30] The case of Norway, which has a larger EV market and stock shares than any other country, suggests that markets that have already deployed a sizeable share of EVs in their stock tend to require a lower average number of chargers per EV, reflecting higher capacity utilisation rates for EVSE.

[31] By the end of 2016, China accounted for 44% of publicly accessible chargers in the world and 80% of the world's publicly accessible fast chargers. It is unclear whether a part of these fast chargers could be dedicated to electric buses, the numbers of which are also increasing quickly in the country.

or at work, relying on slow chargers. The third most frequent charging choice is publicly available slow chargers, followed by chargers located in commercial facilities (charging at a destination). Fast charging is not used frequently, and it primarily takes the form of planned stops for long-distance trips (Figenbaum and Kolbenstvedt, 2016).

Figure 13 • Charging habits for a sample of Norwegian electric car users, 2016



Source: IEA elaboration based on results from Figenbaum and Kolbenstvedt (2016).

Key point: electric car owners charge their vehicles most frequently at home or at work. The third most frequent charging option is publicly accessible slow charging. Fast charging is not frequently used.

The importance of the availability of charging infrastructure on the prospects for electric car market growth calls for continued support for EVSE deployment. The need to minimise deployment costs suggests that the deployment of charging infrastructure should be tailored to the evolution of the electric car stock growth. Successful EVSE deployment strategies also need to match consumer preferences. EV charging could also have a sizeable impact on the capacity required by the grid at certain times and locations, with consequences for the adequacy and quality of the power supply, risks of cost increases for consumers and negative feedback on transport electrification prospects. EVSE deployment needs to be conceived in a way that handles these risks while taking advantage of the options available for mitigating these impacts.

The discussion that follows attempts to outline policy recommendations taking into account these constraints. It does so by looking at measures needed to support EVSE deployment at different administrative levels. First, it identifies topics that need to be addressed by national or cross-national actions. Second, it looks at the role of local administrations, providing examples of good practices from the existing policy context. Finally, it elaborates on the challenges posed by EVSE deployment for the power system and discusses the options for dealing with them.

National and supra-national policy frameworks

National and international policy frameworks aiming to support the deployment of EVSE are well suited to achieving significant progress. Key instruments available to national and supranational institutions for this purpose include standards to ensure the interoperability of EVSE nationwide and across country borders, definitions of EVSE deployment targets, financial incentives, regulations (including building codes) and permits. Energy companies, utilities and distribution system operators (DSOs) also deploy electric vehicle charging. Box 3 provides a brief overview of their initiatives in this context.

Standards ensuring the interoperability of EVSE nationwide and across country borders

Given the importance for drivers of operating vehicles across different jurisdictions, access and the interoperability of charging infrastructure and payment methods are key enablers for the deployment of electric cars. The provision of an integrated and interoperable EVSE network is especially important in regions characterised by a multinational structure, like the European Union.

The case of the CCSs coupled with the HomePlug PHY communication protocol is suitable for the Level 2 and 3 in Europe – mandated through the European Directive on the Deployment of Alternative Fuels Infrastructure (EC, 2014) – and is well suited to evolve in the direction of a success story for overcoming physical barriers to interoperability.

A number of web-based applications are emerging to facilitate the access, use and payment of EVSE. The added value of these services is the possibility to overcome the significant barriers to interoperability posed by the local focus of charging infrastructure, typically relying on specific identification systems (e.g. based on radio frequency identification), contracts and payment methods. Examples of platforms allowing drivers to unlock charging stations with their navigation system or an app and to pay for the electricity based on agreements established with charging providers include Ladenetz, Hubject and Plugsurfing (Kafyeke, 2017; Hall and Lutsey, 2017).

EVSE deployment targets

Defining EVSE deployment targets also helps speed up policy action. The advantage of setting targets is the ability to focus on the development of instruments for meeting them and moving beyond the need to decide upon their ambition. EVI (2016a) provides an overview of EVSE deployment targets. A summary is reported here:

- China aims to deploy, by 2020, 4.3 million private EVSE outlets, 0.5 million public chargers for cars and 850 intercity quick-charge stations, among other targets for buses and taxis.
- The EU Directive on the Deployment of Alternative Fuels Infrastructure (EC, 2014) required EU member countries to define electric charging point targets for 2020 by November 2016.[32] France has stated its ambition to deploy 7 million charging outlets by 2030.
- In 2016, Korea upgraded its former target for deploying countrywide, publicly accessible fast chargers by 2020 from 1 400 to 3 000, with the aim of making all parts of the country accessible with an electric vehicle (MoE, 2016).

Financial incentives, fiscal advantages and other forms of monetary incentives

National legislative frameworks are also important for providing financial incentives, fiscal advantages and other forms of monetary incentives for individuals, businesses and local authorities willing to invest in the installation of EVSE. Several EVI countries have a range of measures falling in this category:

- In China, the central government supports municipalities deploying public charging infrastructure by subsidising the construction of charging stations.
- In France, financial incentives can take the form of a tax credit equivalent to 30% of a home charger or subsidies for the installation of residential or workplace chargers (MEEM, 2016a).
- In the Netherlands, the Green Deal has resulted in a governmental contribution for the joint deployment of publicly accessible EVSE with municipalities and a third party. This is

[32] Despite this, not all EU member states submitted their plans, and an assessment summarising the results of those already submitted is not yet available.

accompanied by a tax incentive for businesses investing in EVSE deployment (Munnix, 2017).

- Norway provides EVSE public funding for fast-charging stations every 50 km (on average) on main roads and contributes to deployment incentives for public chargers.
- Sweden offers financial support for the development of charging infrastructure. In 2015, the funding amounted to SEK 130 million.
- In the United Kingdom, individuals receive GBP 500 (USD 650) for the installation of a dedicated home charger for an electric car, and businesses are entitled to grants of GBP 300 (USD 400) per socket to fund charge points for fleets and/or employees (Gov.uk, 2017a) and receive tax breaks for investment on large EVSE deployment (Gov.uk, 2016a). Local authorities also receive refunds to install roadside charge points in residential areas.
- In the United States, most EVSE support takes place at the state level. For example, the state of Colorado provides grants of up to 80% of the costs for an EVSE unit and installation (Hodge, 2017).

Regulations and permits

Policy areas where national or international action can be especially effective are the integration of EVSE charging infrastructure in building codes and the adaptation of property and tenancy laws to simplify EVSE deployment. To date, an increasing number of countries has provided specific policies to include EVSE infrastructure in building codes, tenancy and property regulations:

- In France, recent legislation mandated that 50-75% of parking bays in any new or renovated residential building must be pre-installed with conduits that allow the easy installation of EVSE ranging between 7 kW and 22 kW. In commercial buildings, 5-10% of parking bays must have conduits suitable for installing EVSE with a power rating of at least 22 kW (Legifrance, 2016). The European Commission included similar provisions in a proposal aiming to revise the EU Directive on the Energy Performance of Buildings (EC, 2016a).
- In France, Spain, Portugal and the United States (California), steps have been taken to adapt property laws to simplify and accelerate the process of approval procedures for electric car owners to deploy (private) EVSE infrastructure, notably in rented and/or owned multi-unit dwellings, including in parking garages (Legifrance, 2014; BOE, 2009; Diario da Republica, 2010; WXY Architecture, 2012).

Direct investments and public-private partnerships

National governments are also well placed to enable nationwide EVSE deployment, either in the form of direct investment or through public-private partnerships (PPPs). One example is allowing private parties to construct fast-charging networks on highways.

- The company Fastned has already built more than 60 fast-charging stations in the Netherlands. It will be building 14 more in Germany (Fastned, 2017) and others in the United Kingdom (Munnix, 2017).
- In the United States, the states of Washington, Oregon and California together organised an extensive network of DC fast-charging stations, the West Coast Electric Highway, which connects the three states through stations along major roadways located every 40-80 km. This project is structured as a PPP whereby the costs are shared by the public

sector, the private sector and users, with significant shares of seed funding from the public sector (West Coast Green Highway, 2017).

Box 3 • Industry initiatives on EVSE deployment

Energy companies, utilities and distribution system operators (DSOs) deploy electric vehicle charging networks to diversify their business, capitalising on the access to the power distribution infrastructure and unique expertise in the electrical system, enabling them to anticipate or enable opportunities likely to emerge from demand-side management. Having direct access to the customers they serve for stationary electricity applications, they are well positioned to deploy private chargers at home (where they also compete with OEMs) or at the workplace.

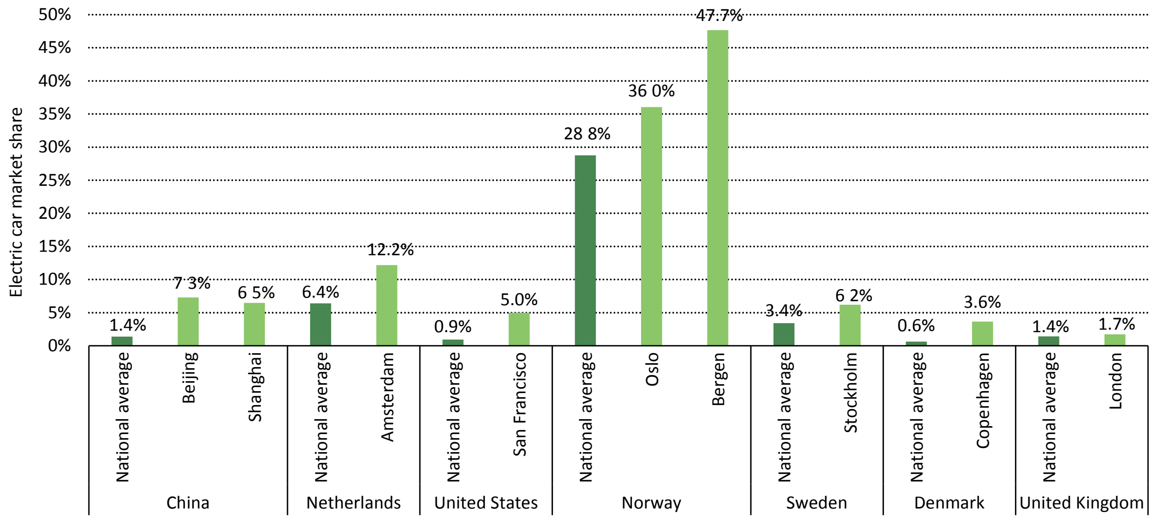
Large energy companies have also been responsible for a significant portion of all public charging stations. In Germany, power companies, including RWE, Vattenfall, E.ON and EnBW, account for 35% of all public charging stations (Hall and Lutsey, 2017). Utilities and DSOs have also collaborated to open nationwide networks through partnerships. Examples include the Elaad Foundation in the Netherlands, pulling together seven network operators (Hall and Lutsey, 2017; Elaad, 2017), and Clever, a company owned by major Scandinavian energy companies and aiming to stablish Europe's first ultra-fast charging network for electric vehicles (Hall and Lutsey, 2017; Clever, 2017). Local municipal utilities have also entered the EVSE market. In China, the State Grid Corporation of China and China Southern Power Grid have together opened more than 27 000 charging stations and more than 800 electric vehicle battery-swapping stations for buses (Hall and Lutsey, 2017). In North America, utility investment in public electric vehicle charging networks is still in its early phases but is showing signs of growing quickly.

OEMs have also taken the initiative to deploy charging services. Tesla's supercharger network consists of more than 5 000 fast-charging points at dedicated locations along major highways. The company plans in 2017 to double its destination charging network of more than 9 000 connectors, which are located in public destinations, such as hotels, resorts and restaurants (Tesla, 2017b, 2017c; EC, 2016b). BMW, Daimler, Ford and Volkswagen recently announced a plan to develop a joint European network of fast chargers for electric cars along major highways in Europe (Daimler, 2016b).

Policy needs best addressed by cities and local administrations

Cities have been at the forefront of stimulating EV deployment and are important players in helping to accelerate the transition to electric driving. Leading EV cities have shown that, as a result of dedicated local policies complementing national EV policy schemes, they can create a favourable environment for EV use and reduce consumer barriers. Nearly a third of global electric car sales took place in just 14 cities in 2015 (Hall et al. 2017), and major global urban centres often achieve higher electric car market shares compared to their country averages (Figure 16). Air quality issues are one of the main drivers for cities to stimulate EVs (IEA, 2016).

Figure 14 • Market share of electric cars in leading EV countries compared to high-performing EV cities, 2016



Notes: The data for specific cities refers to electric cars that are registered within the municipality. This does not exclude the possibility that the electric car is used in other areas.

Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2017a), IHS Polk (2016), MarkLines (2017), ACEA (2017a, 2017b) and EEA (2017). City shares were defined based on Johnsen (2017), Denver (2017), Gov.uk (2017c), Isbrand (2017), Kasche (2017), Munnix (2017), SIC (2017) and Visser (2017).

Key point: Major urban centres often achieve higher electric car market shares compared to their country averages.

Cities can have a leadership role in developing and testing innovative policy actions before more widespread adoption (Hall et al., 2017). By testing and demonstrating best-practice EV support policies, cities can not only act as models for other cities that seek to accelerate their transitions to electric driving but also provide an example for a wide application (e.g. at the national or global level) of best practices, helping to improve the cost efficiency of the policy development process. This includes a unique role to play in supporting EVSE deployment within urban areas in a way that best adapts to the characteristics of the urban mobility and geography of each city.

Parking ordinances and zoning actions are instruments that have a strict relationship with urban networks. Local authorities have a clear lead in the development of these networks and in making decisions on how they should be used. Cities are best placed to manage EVSE deployment in terms of geographical location and ensure adequate charging opportunities in urban areas.

- In Paris, the municipality has mandated that all electric cars are allowed to use the chargers of its Autolib electric car-sharing programme, with the additional benefits of free parking and dedicated parking spots (Hall et al., 2017).
- The metropolitan area of Amsterdam has adopted one of the most interesting policy strategies, which involves zoning actions via a demand-based approach for deploying its EVSE network (Vertelman and Bardok, 2016). This approach comprises the deployment of public charging infrastructure only upon the identification of user-based demand (citizens can sign up with the municipality to have a charger installed near their home when purchasing an EV), and only if there are no private or off-street alternative solutions. This innovative initiative allows the deployment of public charging infrastructure in an optimised way by installing new, publicly accessible charging outlets only when coupled with new EVs circulating in the area. This is likely to maximise use and, thus, optimise investment. Additionally, it supports an EVSE deployment strategy aligned with consumer preferences of prioritising private charging (at home and the

workplace), followed by publicly accessible slow charging when one of the former options is not available (Figure 15). The slow-charging feature of the scheme (7kW to 11kW) does not pose unmanageable risks for the distribution grid capacity. Such a scheme also contributes to lower EV adoption barriers for customers that do not have access to private parking and thus private charging.

With the exception of standardisation, which is clearly best addressed at the national and international levels, and measures strongly related with urban road networks, all other categories identified for national and international policy action also have relevance for cities and local administrations. The following list includes a selection of examples of city-level initiatives taken in each of the support action areas outlined in this report that have contributed to improving the EVSE offering in urban centres and have thus supported EV adoption:

- **Targets**

  Some cities have developed their own targets for direct investment or for the number of public charging points to be installed. For example, the municipality of Shanghai (China) aims to build 210 000 charging points by 2020 (Hall et al., 2017). Vancouver (Canada) has also been incorporating EVSE into its long-term goals for buildings, transportation and economic planning (WXY Architecture, 2012).

- **Financial incentives**

  Cities can also provide financial incentives for installing charging points. The municipality of Utrecht in the Netherlands offers a EUR 500 subsidy per private charging point and a subsidy of EUR 1 500 for a semi-public charging point (Hall et al., 2017). Other types of incentives have taken the form of attractive charging prices. For example, the municipality of Beijing has set an upper limit on the fee that needs to be paid to use public charging electricity infrastructure (net of the electricity price) at 15% of the price of gasoline (Beijing.gov.cn, 2015).

- **Building codes**

  In Vancouver, the city council has taken advantage of its unique ability among Canadian cities to modify its building code to require that each new, single-family dwelling is capable of supporting Level 2 charging infrastructure, and that 20% of the parking stalls in multifamily buildings (three or more dwelling units) are equipped with wire conduits for accommodating EVSE outlets. In doing so, Vancouver has become the first North American city to require EVSE connection capability in all new building developments (WXY Architecture, 2012).

  The recent EV Readiness Ordinance adopted in San Francisco also includes provisions to facilitate electric car charging in buildings, requiring, for new construction or major building renovation, the installation of Level 2 chargers in 10% of the parking spaces and conduits enabling additional installations in another 10%. The ordinance also requires the capacity to handle the simultaneous charging of vehicles in 20% of the parking spaces, and enabling the use of charging management systems to scale up and provide charging for up to 100% of the spaces (CLGEEP, 2017).

  Chinese cities have similar (and stronger) requirements: Beijing, Shanghai and Chongqing, among other cities, require 100% charging pre-equipment (CEC, 2016).

- **Direct EVSE deployment**

  Direct EVSE deployment is carried out, for example, through EVSE procurement contracts with charge point suppliers. An example of such direct investment is the case of Oslo, where the municipality has built two large parking garages dedicated to electric cars (Hall et al., 2017).

- **Public-private partnerships**

  Business relationships funded and operated through partnerships between the public sector and one or more private companies could be effective for raising additional finance in an environment of budgetary restrictions (EC, 2016b). One interesting example of synergy between the public sector and private operators is the case of Source London, a citywide electric-vehicle charge point network. Source London was started by Transport For London (the integrated transport authority for London) and is now managed by a private operator, which currently provides more than 850 charge points across London and plans to install another 4 500 by 2018 (Source London, 2017).

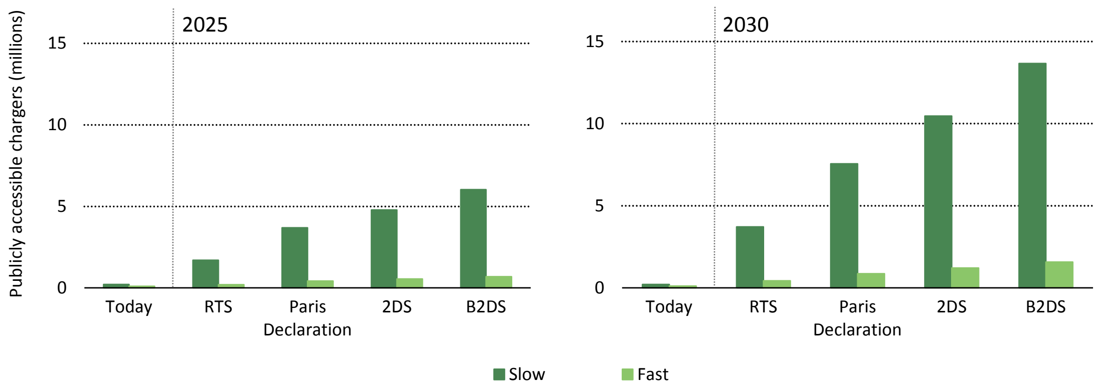
EVI City Casebook: 50 Big Ideas Shaping the Future of Electric Mobility provides an overview of other examples of other initiatives undertaken by cities to support EVs, including actions regarding EVSE deployment (EVI, 2014).

Prospects for future EVSE deployment

Estimates for EVSE deployment targets corresponding to the main scenarios on EV deployment are summarised in Figure 13.

The number of EVSE outlets that need to be installed in the next 15 years depends on the electric car deployment scenario. Publicly available EVSE outlets need to grow by a factor that ranges between 8 in the RTS and 25 in the B2DS by 2025, amounting to between 4 million and 14 million outlets globally in 2030. Projections for fast chargers suggest that EVI markets will need to see the deployment of 0.1 million additional outlets by 2025 in the RTS and 0.6 million in the B2DS. Extending the period to 2030 corresponds with 0.2 million outlets in the RTS and 0.7 million outlets in the B2DS.

Figure 15 • EVSE outlets by country and by type of charger, 2016

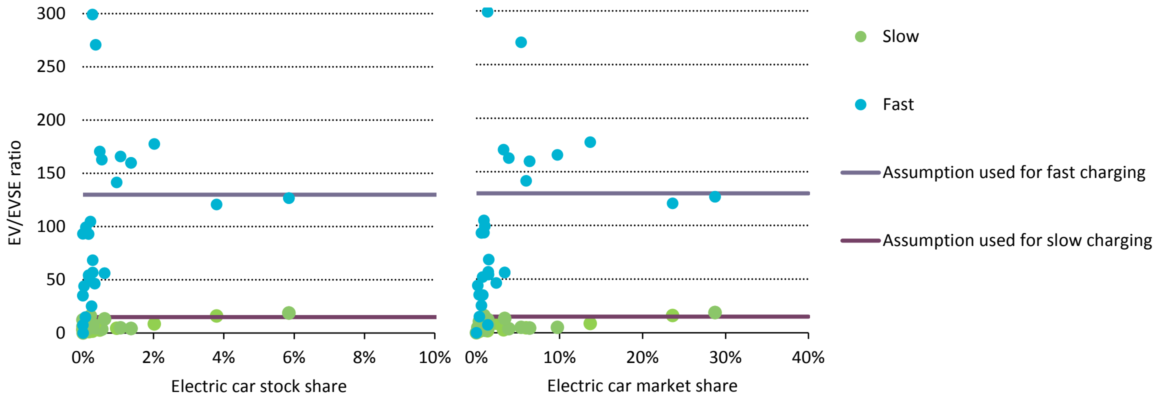


Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2017a), IHS Polk (2016), MarkLines (2017), ACEA (2017a, 2017b) and EEA (2017) and projections on EV uptake developed with the IEA Mobility Model, March 2017 version (IEA, 2017a).

Key point: EVSE outlets need to accompany EV deployment. Depending on the scenario considered, EVSE outlets will range between 1 million and 7 million in 2025 and double that in 2030.

These results were calculated on the basis of the electric car deployment projections outlined earlier and assumptions on the EV/EVSE ratios (by charger level). The assumptions were derived from the overview of the historical development of the EV/EVSE ratios, illustrated in Figure 14, where the EV/EVSE ratios for each country are plotted against both the electric car market share and the electric car stock share. Despite a wide variability at low electric car market and stock shares, the EV/EVSE ratios have been assumed here to converge towards 15 electric cars per publicly accessible slow charger and 130 electric cars per fast charger.

Figure 16 • EVSE outlets by country and by type of charger, 2016



Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2017a), IHS Polk (2016), MarkLines (2017), ACEA (2017a, 2017b) and EEA (2017).

Key point: Plotting the EV/EVSE ratios against both electric car market share and electric car stock share and giving priority to markets with higher electric car deployment suggests that, despite a wide variability at low electric car market and stock shares, EV/EVSE ratios could converge towards 15 electric cars per publicly accessible slow charger and 130 electric cars per fast charger.

Due to the wide variability of results for low electric car market and stock penetration, the average EV/EVSE ratios considered for the estimates of the EVSE requirements for 2025 and 2030 were heavily weighted towards the values observed in countries with comparatively high electric car market and stock shares, primarily Norway and the Netherlands. This rationale is also supported by the observation that the EV/EVSE values for Norway and the Netherlands tend to be on the high end of the range observed for all EVI countries. The EV/EVSE ratio used here is similar to the value of ten vehicles per charger indicated in the EU Directive on the Deployment of Alternative Fuels Infrastructure (EC, 2014). The choice to give greater weight to markets with larger market shares of electric cars is consistent with the idea that scale effects become more relevant when market shares grow, helping optimise the use of charging infrastructure in comparison with early market deployment phases.[33]

Compared with the EVSE deployment scenarios suggested in the *Global EV Outlook 2016* (EVI, 2016a), the current estimates are similar to the lower EVSE range estimates. This is because the more developed electric car markets weighted in this analysis have high EV/EVSE ratios compared to the range of values taken into account in the previous *Global EV Outlook* edition.

[33] Given the variability and gaps between the current EV/EVSE ratios in each individual country and the choice to focus on the EV/EVSE ratios of Norway and the Netherlands to assess future developments, the estimations developed here are more likely to be accurate within the 2025-30 timeframe, when electric car market and stock shares are projected to grow. The accuracy of this assessment is lower in earlier years as the estimates are more strongly influenced by the current status of the EV/EVSE ratio. Projections on EVSE development also depend on the technologies and charging modes used. The assumptions made here do not account for major developments in this respect and implicitly consider that consumer behaviour will broadly reflect current preferences. Monitoring these developments will be important for refining this approach over time.

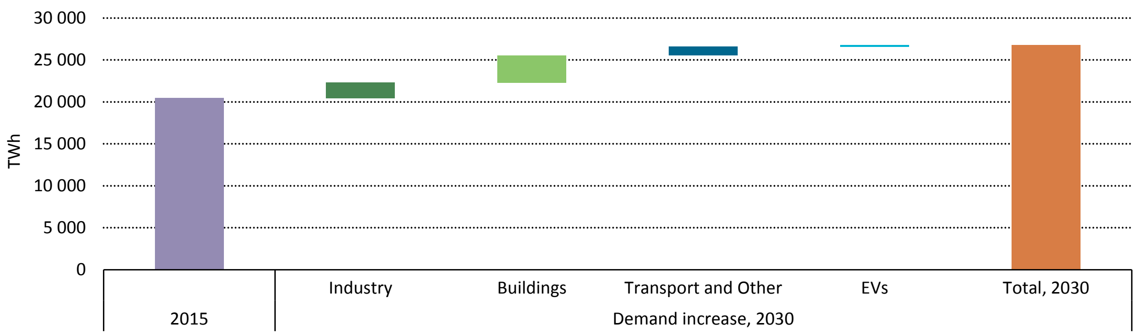
Challenges and opportunities for the power sector

Impact of EVs on the power system

Electricity systems need to ensure both system adequacy and quality of service. The extent to which higher shares of EVs and their demand for charging will impact electricity networks will depend highly on the technologies and charging modes used. The bulk of electric car charging is expected to occur at homes and businesses or in public charging facilities. Rising EV penetration is thus likely to have an impact on low-voltage distribution grids in residential or commercial areas first. In addition, EVs, in contrast with other loads on distribution networks, are not stationary. A greater understanding of EV charging patterns and technologies will thus be necessary to ensure their appropriate integration into distribution grids.

When new loads are incorporated into the grid, this translates into guaranteeing both sufficient energy and capacity are available on demand. IEA analysis shows the additional energy demand from EV loads is sizeable but largely manageable (IEA, 2017b). In the IEA 2DS, the additional generation required to meet the EV and PHEV demand amounts to 1.5% of the total electricity demand by 2030 – which would represent only 6% of the increase in demand due to new loads from electrification in industry and the residential and commercial sectors (Figure 17).

Figure 17 • Impact of electric car deployment on global electricity demand, 2DS



Source: IEA (2017b).

Key point: The additional energy demand from electric car loads is sizeable but largely manageable in comparison with total energy use and additional loads arising from the industry, other transport and buildings sectors

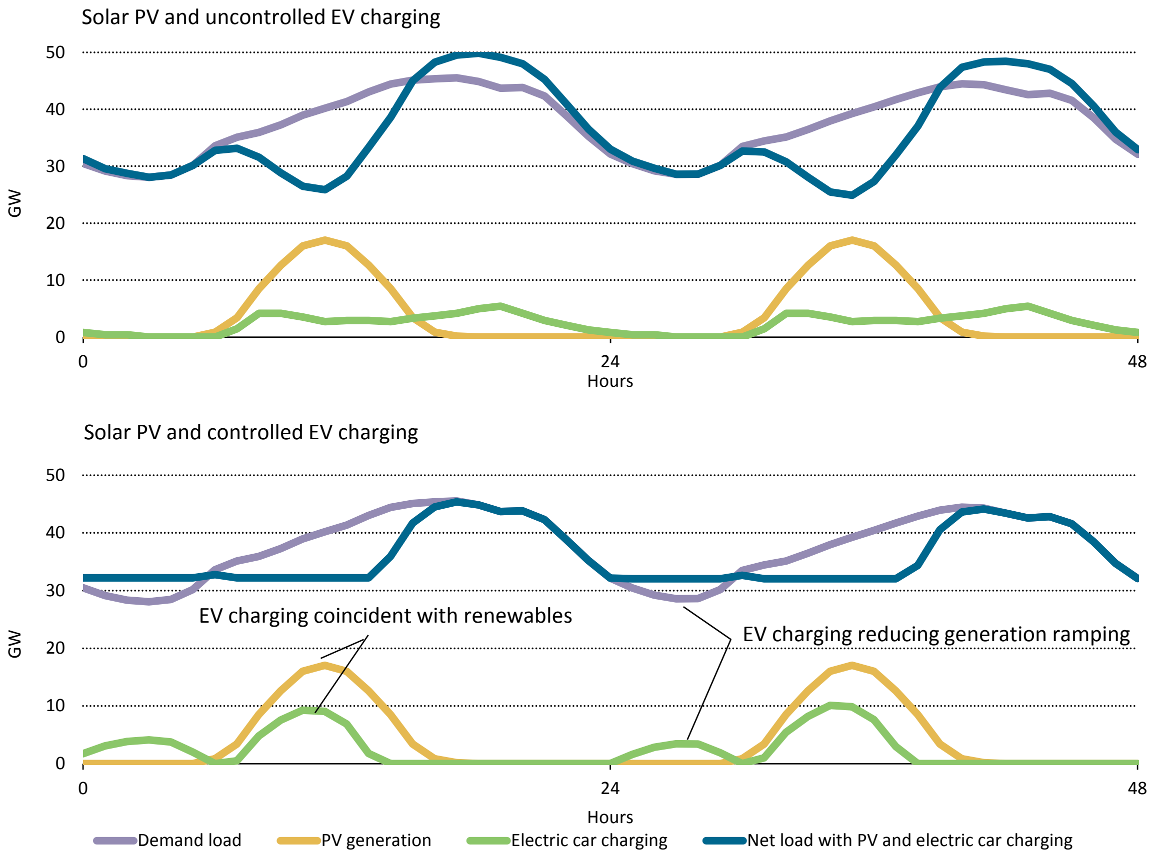
Depending on the electric car usage patterns, i.e. when, where and how much power is drawn from what type of charging infrastructure, higher shares of electric cars could have a sizeable impact on the capacity required at certain times and locations, with consequences for both adequacy and quality at different levels:

- at the generation/wholesale market level, where high demand and scarce capacity could increase prices
- at the transmission/system operator level, where stress on the system during peak times requires more system services, such as frequency control, and the need to maintain reserve power capacity
- at the distribution level, where the overloading of power lines and transformers and voltage drops could occur.

The impact of EV charging will be felt first at local hotspots on distribution grids before the other two levels are affected. In such local situations, network overloads can result in the accelerated ageing of grid infrastructure and eventually cause service interruptions, which could require investments for upgrading lines and transformers.

To place these concepts in context, Figure 18 shows the additional residential load from electric cars during a typical day under the B2DS in the European Union in 2030, comparing the impact of standard usage patterns with those that could be enabled through price and control signals without impacting travel demand according to current best knowledge. According to this assessment, unmanaged charging would result in an increase in peak power draw of roughly one-third.

Figure 18 • Local demand profile and electric car charging in the European Union on a typical day, B2DS, 2030



Sources: IEA (2017b).

Key point: In a scenario with high electric car market penetration, unmanaged charging could result in a sizeable increase (over 30%) in peak power draw.

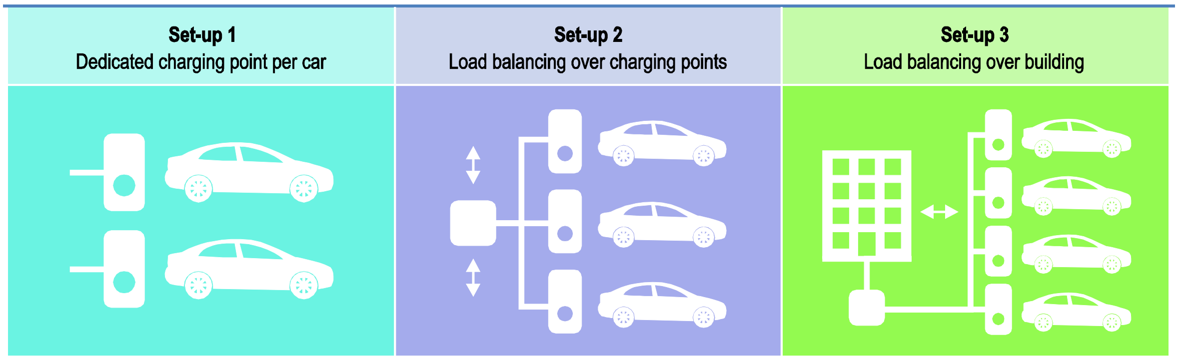
Mitigating the potential impacts of EV charging

Three options are particularly relevant for mitigating the negative impacts of electric car charging. One option is the buildout of charging infrastructure itself and deploying it both at locations and with technologies that minimise any negative impacts. At homes and businesses, connecting local charging points generally requires some form of connection from the low-voltage grid, and the additional load could require subscribing to a higher power capacity tariff and/or reinforcement of the network at the point of connection. It is thus critically important to install charging points in areas where both the projected impact is low and the utilisation throughout the day is expected to be high. An early example of such robust planning of EVSE is in the Netherlands, where the installation of charging points is tied to residential areas where electric car owners request parking permits.

A second option is through incentivising end users to maximise self-consumption through solar systems installed on consumers' homes combined with the available storage and recharging infrastructure. As utilities transition to distributed energy, such business models could be deployed as an integrated service combining energy efficiency, distributed energy resources and the minimisation of EV charging costs – and, on the utility side, provide system benefits by reducing the impact of the charging profiles seen by the grid. The combination of reducing EV battery costs, increased EV uptake and spillovers into stationary battery technology will require regulators to monitor and balance the adoption by consumers of such distributed electric car charging options with networked charging.

Charging infrastructure can also be scaled up in phases that follow the growth of electric car uptake (Figure 19). Careful planning for this could bring economic advantages as well as advantages for grid stability. The first set-up phase of EVSE deployment, which can be identified as the present phase of most urban areas, can be handled with a few initial charging points. In the second phase, as electric cars become more numerous, a typical parking garage (or a suburban road) is needed to distribute the available power between a number of charging points. In this second phase, challenges start to arise as the number of charging points must be limited to the available power in the building (or neighbourhood). In the third phase, in which there is a large demand for charging from electric cars, the available power of the entire building needs to be distributed between the apartments in the building (or the network of dwellings in the neighbourhood) and the charging points.

Figure 19 • Development of charging infrastructure in buildings with rising numbers of electric cars



Source: IEA elaboration based on emerging commercial concepts such as www.zaptec.com

Key point: Charging infrastructure can be scaled up in phases that follow the growth of the electric car market.

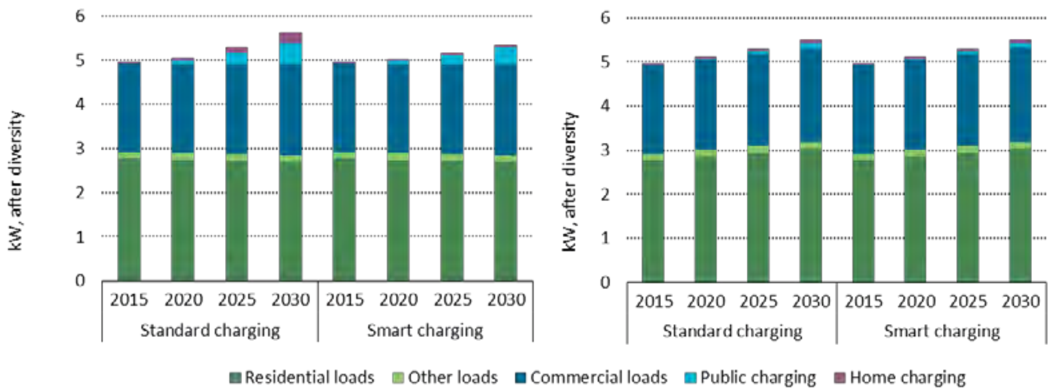
As EV penetration increases, such options could deliver lower costs for both charging infrastructure owners/operators and distribution grids. The question is thus whether the existing cost signals and regulations are sufficient to drive end users and owners/operators of charging stations to drive enough efficiency and flexibility at the system level. In multifamily dwellings, public charging stations and parking lots, for instance, higher capacities can be expected. The higher the charging capacity, the higher the need to manage charging – and yet, given the higher demand for it, users are likely to be less amenable to changing their charging profiles. If the demand-side operator (DSO) needs to reinforce lines and transformers, plus bear its share of the cost of the home grid connections due to regulations, it will then seek to pass on costs to consumers through the tariff system, exacerbating the issue without increasing flexibility.

Some form of additional regulation, generally in the form of digitally enabled, smart charging of electric cars, will be necessary. To enable smart charging, regulators and policy makers will have to enable business models that deliver some combination of price signals, control signals and aggregation enabled by data analytics and controls for a large numbers of users.

Price signals incentivise flexible electric car loads to respond to time-of-use, dynamic hourly prices. Control signals can be enabled by grid operators at the EVSE level or within vehicles. Either of these would require an underlying information and communications technology (ICT) infrastructure for communicating between charging points and back-end systems and for allowing operators to send requests to increase or reduce the power draw at certain times.

The savings from allowing delayed charging can be significant at the system level. An assessment of the realisable economic potential from flexible smart charging in the 2DS reveals nearly 350 GW of flexibility available from the deployment of nearly 600 million BEVs and PHEVs by 2030, resulting in an estimated USD 180 billion in generation, transmission and distribution capacity (Figure 20).

Figure 20 • Impact of electric car deployment on a generic local grid in the European Union, B2DS (left) and 2DS (right)



Source: IEA (2017b).

Key point: The savings from allowing delayed charging at an early stage of electric car deployment could allow for increased hosting capacity for loads from additional electric cars.

Providing price signals to consumers could deliver some of these savings by incentivising consumers to reduce peak loads. However, price signals in energy markets do not adequately reflect the condition of the network, particularly in distribution networks and particularly at times when the network is heavily constrained. As electric car penetration increases, aggregators to allow for delayed charging will be needed. Signals given to charging stations will have to consider the generation and grid constraints as well as enable customers to benefit from price opportunities. Such opportunities require aggregating large numbers of individual loads through analytics and local area control.

While aggregators could operate in wholesale markets, they could also trade with the local network operator to provide system services. Given that the impact of EVs is likely to emerge at the local level, such services should be evaluated and implemented early in their deployment. Meanwhile, who should provide these services is a question that is tied to specific systems and regulatory designs – options include public utilities, third parties and e-mobility service providers. These could provide, on a contractual basis, delayed charging of large numbers of ICT-enabled charging points with constraints and charging profiles set by the DSO, which could in turn provide increased hosting capacity to service providers without having to invest in upgrading the network.

Finally, as electric car penetration increases, charging infrastructure will require common standards and interoperable solutions between charging stations, distribution networks and the electric cars themselves. Interoperability is necessary both on the physical-electricity-network side but equally at the ICT interface, where information will need to flow efficiently across the range of stakeholders along the value chain of the charging service. At the network level, information includes grid conditions, available capacities and the instantaneous generation mix. At the end-user level, this would include information on battery usage and condition, state of charge and status. Interoperability and common standards are necessary to ensure compatibility and efficient communication and, fundamentally, to enable EVs as flexible roaming platforms where consumers can be aggregated as they drive and charge in different local distribution networks.

Conclusion

With record-high new electric car registrations in 2016 (over 750 thousand sales worldwide), the transition to electric road transport technologies that began only a decade ago is gaining momentum and holds promise for a low-emission future, provided that such dynamism can be sustained over the coming decades. As the global stock of electric cars surpasses 2 million units, a number of countries are coming forward as global leaders. Norway had the highest electric car market share globally (29%) in 2016. China experienced an extremely rapid market growth, from 100 thousand units in circulation in 2014 to 650 thousand units two years later. The provision of private and publicly accessible charging infrastructure has accompanied the growth of the electric car stock. In 2016, the number of publicly accessible charging points reached 320 000 units globally, representing a 72% growth since 2015. These successes are driven by the multiple benefits EVs can bring to governments and citizens: energy security (thanks to the energy efficient nature of electric mobility and reduced dependence to oil), urban air quality, noise mitigation and greenhouse gas reductions.

Governments and local authorities are implementing policies aimed at reaping the benefits of EVs. The tools currently available for policy makers include, among others, purchase subsidies, measures supporting EVSE deployment, fuel economy standards, ZEV mandates and access restrictions. RD&D and mass production are also delivering rapid cost declines and increases in energy density. Signs of continuing improvements in technologies currently being researched confirm that these trends will continue and that they will further improve performance and narrow the cost competitiveness gap between electric and ICE vehicles.

In the next 10 to 20 years the electric car market will likely transition from early deployment to mass market adoption. Assessments of country targets, OEM announcements and scenarios on electric car deployment seem to confirm these positive signals; indicating that the electric car stock may range between 9 million and 20 million by 2020 and between 40 million and 70 million by 2025.

As the number of EVs increases, charging could have a sizeable impact on the capacity required by the grid at certain times and locations, with consequences for the adequacy and quality of the power supply, risks of cost increases for consumers and the potential for negative feedback on transport electrification prospects. EVSE deployment needs to be conceived in a way that manages these risks while taking advantage of the options available for mitigating these impacts. The potential contribution of EVs to the decarbonisation of the global economy, among a variety of other benefits, is substantial. EVs are well suited to promote synergies with variable renewables. If charging practices strengthen demand-side management opportunities, EVs could allow a greater integration of these energy sources in the power generation mix. Large-scale electric car charging and demand response will require the joint optimisation of the timing and duration of recharging events, the modulation of power delivered by charging outlets (defining the speed of charge) and may involve a reliance on vehicle-to-grid solutions. For fast chargers, managing power demand is also likely to require the deployment and use of stationary storage at the local or grid level.

Moving beyond early market developments for electric cars will require policy adjustments. As battery pack costs decrease, electric vehicles will become increasingly cost competitive. The need for vehicle purchase incentives will diminish, and subsidies for electric cars will not be economically sustainable with large sales volumes. As the share of electric vehicles sold increases, revenues collected from conventional fuel taxes will also shrink. The decline will be largest in the countries with the highest fuel taxes, such as the European Union and Japan. Ensuring that infrastructure funded by these revenues (e.g. public transport infrastructure, road networks, and alternative fuel and low-carbon infrastructures) continues to be developed will require a transition in the way these revenues are collected. Applying taxes based on vehicle distance travelled rather than fuel consumed is likely to be the most suitable alternative (IEA, 2017b).

Growing EV sales will also stimulate the demand for commodities needed for battery manufacturing, such as lithium, cobalt and other materials required by future battery technologies. This will require understanding the distribution and accessibility of these resources, and, as in the case of other strategic commodities, may come with risks. Monitoring the price and availability of these resources, but also minimising the environmental impacts of their extraction and processing, will be necessary to put the EV market on an economically and environmentally sustainable trajectory. Battery reuse and material recycling will become increasingly important in this context. Policies will need to steer the use of batteries in secondary applications (such as stationary energy storage), and their end-of-life treatment. Policies will also be needed to deal with issues relating to battery ownership, transport and recycling requirements.

Statistical annex

This section provides electric car and EVSE time series data for the 39 countries covered in the scope of this report, i.e. EVI members, countries falling under the scope of activity of the European Alternative Fuels Observatory and countries that reported data to the EVI (Figure 4). These data were those used for the graphs and the discussions in this report.

In each of the tables below, "others" comprises Austria, Belgium, Bulgaria, Croatia, Cyprus,[34] the Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Iceland, Italy, Ireland, Latvia, Lichtenstein, Lithuania, Luxemburg, Malta, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Switzerland and Turkey.

The main sources of information used in this report include submissions from EVI members, statistics and indicators available from the European Alternative Fuels Observatory (EAFO, 2017a) for European countries that are not members of the EVI (Figure 4), data extracted from commercial databases (IHS Polk, 2016; MarkLines, 2017) and information released by relevant stakeholders (ACEA, 2017a, 2017b; EEA, 2017).

[34] 1. Footnote by Turkey: The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of United Nations, Turkey shall preserve its position concerning the "Cyprus issue". 2. Footnote by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

Electric car stock

Table 4 • Electric car stock (BEV and PHEV) by country, 2005-16 (thousands)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Canada							0.52	2.54	5.66	10.73	17.69	29.27
China					0.48	1.91	6.98	16.88	32.22	105.39	312.77	648.77
France	0.01	0.01	0.01	0.01	0.12	0.30	3.03	9.29	18.91	31.54	54.49	84.00
Germany	0.02	0.02	0.02	0.09	0.10	0.25	1.89	5.26	12.19	24.93	48.12	72.73
India				0.37	0.53	0.88	1.33	2.76	2.95	3.35	4.35	4.80
Japan					1.08	3.52	16.14	40.58	69.46	101.74	126.40	151.25
Korea						0.06	0.34	0.85	1.45	2.76	5.95	11.21
Netherlands				0.01	0.15	0.27	1.14	6.26	28.67	43.76	87.53	112.01
Norway			0.01	0.26	0.40	3.35	5.38	9.89	20.37	44.21	84.18	133.26
Sweden							0.18	1.11	2.66	7.32	15.91	29.33
United Kingdom	0.22	0.55	1.00	1.22	1.40	1.68	2.89	5.59	9.34	24.08	48.51	86.42
United States	1.12	1.12	1.12	2.58	2.58	3.77	21.50	74.74	171.44	290.22	404.09	563.71
Others					0.64	0.83	3.25	6.90	12.76	25.35	52.63	87.48
Total	1.37	1.69	2.15	4.54	7.47	16.81	64.58	182.64	388.07	715.39	1 262.61	2 014.22

Table 5 • Battery electric cars, stock by country, 2005-16 (thousands)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Canada							0.22	0.84	2.48	5.31	9.69	14.91
China					0.48	1.57	6.32	15.96	30.57	79.48	226.19	483.19
France	0.01	0.01	0.01	0.01	0.12	0.30	2.93	8.60	17.38	27.94	45.21	66.97
Germany	0.02	0.02	0.02	0.09	0.10	0.25	1.65	3.86	9.18	17.52	29.60	40.92
India				0.37	0.53	0.88	1.33	2.76	2.95	3.35	4.35	4.80
Japan					1.08	3.52	16.13	29.60	44.35	60.46	70.93	86.39
Korea						0.06	0.34	0.85	1.45	2.76	5.67	10.77
Netherlands				0.01	0.15	0.27	1.12	1.91	4.16	6.83	9.37	13.11
Norway			0.01	0.26	0.40	3.35	5.38	9.55	19.68	41.80	72.04	98.88
Sweden							0.18	0.45	0.88	2.12	5.08	8.03
United Kingdom	0.22	0.55	1.00	1.22	1.40	1.65	2.87	4.57	7.25	14.06	20.95	31.46
United States	1.12	1.12	1.12	2.58	2.58	3.77	13.52	28.17	75.86	139.28	210.33	297.06
Others					0.64	0.80	3.17	5.83	10.60	19.43	36.20	52.41
Total	1.37	1.69	2.15	4.54	7.47	16.42	55.16	112.94	226.78	420.33	745.61	1 208.90

Table 6 • Plug-in hybrid electric cars, stock by country, 2005-16 (thousands)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Canada							0.30	1.70	3.18	5.42	8.00	14.36
China						0.34	0.66	0.92	1.65	25.92	86.58	165.58
France							0.10	0.70	1.53	3.60	9.28	17.03
Germany							0.24	1.40	3.02	7.41	18.52	31.81
India												
Japan							0.02	10.98	25.11	41.28	55.47	64.86
Korea											0.27	0.44
Netherlands							0.02	4.35	24.51	36.94	78.16	98.90
Norway								0.34	0.69	2.41	12.14	34.38
Sweden								0.66	1.78	5.21	10.83	21.29
United Kingdom						0.02	0.03	1.02	2.09	10.02	27.55	54.96
United States							7.98	46.57	95.58	150.94	193.77	266.65
Others						0.02	0.08	1.07	2.16	5.92	16.43	35.07
Total						0.39	9.42	69.70	161.29	295.06	517.00	805.32

Electric cars: New registrations

Table 7 • Electric cars (BEV and PHEV), new registrations by country, 2005-16 (thousands)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Canada							0.52	2.02	3.12	5.07	6.96	11.58
China					0.48	1.43	5.07	9.90	15.34	73.17	207.38	336.00
France	0.01			0.00	0.10	0.19	2.73	6.26	9.62	12.64	22.95	29.51
Germany	0.02			0.07	0.02	0.14	1.65	3.37	6.93	12.74	23.19	24.61
India				0.37	0.16	0.35	0.45	1.43	0.19	0.41	1.00	0.45
Japan					1.08	2.44	12.62	24.44	28.88	32.29	24.65	24.85
Korea						0.06	0.27	0.51	0.60	1.31	3.19	5.26
Netherlands				0.01	0.03	0.12	0.88	5.12	22.42	15.09	43.77	24.48
Norway			0.01	0.24	0.15	0.39	1.84	4.51	8.52	19.76	35.61	50.18
Sweden						0.00	0.18	0.93	1.55	4.67	8.59	13.42
United Kingdom	0.22	0.32	0.45	0.22	0.18	0.28	1.22	2.69	3.75	14.74	29.34	37.91
United States	1.12			1.47		1.19	17.73	53.24	96.70	118.78	113.87	159.62
Others	0.53			0.08	0.03	0.18	2.43	3.64	6.05	12.77	26.62	35.31
Total	1.89	0.32	0.46	2.46	2.22	6.78	47.58	118.06	203.66	323.42	547.12	753.17

Table 8 • Battery electric cars, new registrations by country, 2005-16 (thousands)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Canada							0.22	0.62	1.64	2.83	4.38	5.22
China					0.48	1.09	4.75	9.64	14.61	48.91	146.72	257.00
France	0.01			0.00	0.10	0.19	2.63	5.66	8.78	10.57	17.27	21.76
Germany	0.02			0.07	0.02	0.14	1.40	2.21	5.31	8.35	12.08	11.32
India				0.37	0.16	0.35	0.45	1.43	0.19	0.41	1.00	0.45
Japan					1.08	2.44	12.61	13.47	14.76	16.11	10.47	15.46
Korea						0.06	0.27	0.51	0.60	1.31	2.92	5.10
Netherlands				0.01	0.03	0.12	0.86	0.79	2.25	2.66	2.54	3.74
Norway			0.01	0.24	0.15	0.39	1.84	4.18	8.20	18.09	27.79	29.52
Sweden						0.00	0.18	0.27	0.43	1.24	2.96	2.95
United Kingdom	0.22	0.32	0.45	0.22	0.18	0.26	1.21	1.71	2.68	6.81	10.10	10.51
United States	1.12			1.47		1.19	9.75	14.65	47.69	63.42	71.04	86.73
Others	0.53			0.08	0.03	0.16	2.38	2.65	4.96	9.00	16.11	16.67
Total	1.89	0.32	0.46	2.46	2.22	6.39	38.55	57.78	112.10	189.69	325.38	466.43

Table 9 • Plug-in hybrid electric cars, new registrations by country, 2005-16 (thousands)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Canada							0.30	1.40	1.48	2.24	2.58	6.36
China						0.34	0.32	0.26	0.73	24.27	60.66	79.00
France							0.10	0.60	0.83	2.07	5.68	7.75
Germany							0.24	1.16	1.62	4.39	11.11	13.29
India												
Japan							0.02	10.97	14.12	16.18	14.19	9.39
Korea											0.27	0.16
Netherlands							0.02	4.33	20.16	12.43	41.23	20.74
Norway								0.33	0.32	1.68	7.82	20.66
Sweden								0.66	1.12	3.43	5.63	10.46
United Kingdom						0.02	0.01	0.99	1.07	7.93	19.24	27.40
United States							7.98	38.59	49.01	55.36	42.83	72.89
Others						0.02	0.06	0.99	1.09	3.76	10.51	18.64
Total						0.38	9.03	60.28	91.56	133.73	221.74	286.75

Electric cars: Market share

Table 10 • Electric cars (battery electric and plug-in hybrid), market share by country, 2005-16

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Canada								0.15%	0.20%	0.29%	0.39%	0.59%
China						0.01%	0.04%	0.06%	0.09%	0.38%	0.99%	1.37%
France						0.01%	0.13%	0.34%	0.55%	0.72%	1.22%	1.46%
Germany						0.00%	0.05%	0.11%	0.23%	0.42%	0.72%	0.73%
India				0.02%	0.01%	0.01%	0.02%	0.05%	0.01%	0.02%	0.04%	0.02%
Japan					0.03%	0.06%	0.35%	0.53%	0.63%	0.68%	0.58%	0.59%
Korea							0.02%	0.04%	0.05%	0.09%	0.21%	0.34%
Netherlands					0.01%	0.02%	0.16%	1.02%	5.38%	3.89%	9.74%	6.39%
Norway			0.01%	0.22%	0.15%	0.31%	1.33%	3.27%	6.00%	13.71%	23.63%	28.76%
Sweden						0.00%	0.05%	0.31%	0.53%	1.44%	2.37%	3.41%
United Kingdom	0.01%	0.01%	0.02%	0.01%	0.01%	0.01%	0.06%	0.13%	0.17%	0.60%	1.11%	1.41%
United States	0.01%			0.01%		0.01%	0.17%	0.44%	0.75%	0.74%	0.67%	0.91%
Others	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.04%	0.06%	0.10%	0.21%	0.38%	0.52%
Total	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%	0.10%	0.23%	0.38%	0.54%	0.85%	1.10%

Note: The total market share is calculated on the basis of the total market size of all the countries covered in this report.

EVSE

Table 11 • Publicly accessible slow charger stock by country, 2005-16 (number of units)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Canada								722	1 172	2 266	3 361	3 900
China										21 000	46 657	52 778
France								800	1 700	1 700	10 122	14 612
Germany								1 500	2 400	2 606	4 787	16 550
India										328	328	328
Japan										8 640	16 120	17 260
Korea							29	59	115	151	449	1 075
Netherlands						400	1 250	2 782	5 770	11 860	17 786	26 088
Norway						2 800	3 105	3 688	4 511	5 185	5 289	7 105
Sweden								500	1 000	1 070	1 824	2 215
United Kingdom							1 503	2 804	5 515	7 431	8 716	10 736
United States			333	339	373	482	3 903	11 695	14 990	20 115	28 150	35 089
Others							1 129	5 068	6 829	9 142	15 483	24 658
Total			333	339	373	3 682	10 919	29 618	44 002	91 494	159 072	212 394

Note: Slow chargers include AC Level 2 chargers (> 3.7 kW and ≤ 22 kW).

Table 12 • Publicly accessible fast charger stock by country, 2005-16 (number of units)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Canada								2	7	55	147	315
China										9 000	12 101	88 476
France								9	102	127	543	1 231
Germany								18	47	317	784	1 403
India												25
Japan					95	312	801	1 381	1 794	2 877	5 990	5 990
Korea							33	118	177	237	489	750
Netherlands							15	63	106	269	528	701
Norway						1	18	58	144	249	698	1 052
Sweden								5	20	135	343	523
United Kingdom								36	176	481	1 121	1 523
United States			42	42	47	60	489	1 464	1 877	2 518	3 524	5 384
Others							13	11	589	862	1 753	2 498
Total			42	42	142	373	1 369	3 165	5 039	17 127	28 021	109 871

Note: Fast chargers include AC 43 kW chargers, DC chargers, Tesla Superchargers and inductive chargers.

EV support policies annex

	Main EV support policies in 2016, changes from 2015 and 2017	Source
Canada	Fuel economy standard including EV multipliers - Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations	CDOJ (2017)
	Waivers on fees (e.g. tolls, parking and ferries) in Ontario and Quebec Access to HOV lanes in British Columbia, Ontario and Quebec	EVI country submissions
	Provincial-based purchase incentives: British Columbia, Ontario and Quebec	British Columbia (2016); OMOT (2010); Quebec (2012)
China	In 2016, implementation of the fourth stage of the fuel consumption standard framework	EVI country submissions
	Acquisition tax and excise tax exemption (depending on engine displacement and price) (CNY 35 000 to CNY 60 000) (USD 5 100 to USD 8 700)	EVI (2016a)
	Circulation and ownership tax exemption	EVI (2016a)
	Possibility of local subsidies within the limit of 50% of the amount granted via central subsidies	MoF (2017)
	From 2017, 20% reduction from 2016 subsidies, with the plan to adjust policies according to market response until 2020	MoF (2017)
	In seven major urban centres, exemptions from licence plate access restrictions	EVI (2016a)
	Locally, access to bus lanes, exemption from access restrictions at peak times, free charging, free parking	EVI country submissions
Denmark	EU tailpipe emission standard (Euro 6 in 2016), EU fuel economy regulation	EVI (2016a)
	Registration tax exemption until 2015 and phase out between 2016 and 2022 (introduction of 20% of full tax rate for BEVs in 2016, full tax rate applicable by 2022) Starting in 2017, battery capacity-based purchase tax rebate (USD 225/kWh with maximum 45 kWh)	IEA HEV TCP (forthcoming)
France	EU tailpipe emission standard (Euro 6 in 2016), EU fuel economy regulation	EVI (2016a)
	CO_2/km-based eco bonus-malus scheme (bonus of EUR 6 300 (USD 6 900) for BEVs and EUR 1 000 (USD 1 100) for PHEVs, up to EUR 10 000 (USD 11 000) for BEVs and EUR 3 500 (USD 3 900) for PHEVs when returning an old diesel car)	EVI (2016a); Autonews (2016); MEEM (2016b)
	Company car tax credits Electricity and hydrogen tax exemption From 2017, government fleet commitment of 50% of renewals being EVs, and 20% for local authorities From 2017, government fleet commitment of 50% of renewals being EVs, and 20% for local authorities	EVI country submissions
Germany	EU tailpipe emission standard (Euro 6 in 2016), EU fuel economy regulation	EVI (2016a)
	Purchase rebates of EUR 4000 (USD 4 400) for BEVs and EUR 3 000 (USD 3 300) for PHEVs, at the limit of 400 000 cars until 2020 or EUR 600 million (USD 674 million) Automakers should provide half of the incentive amount, the government covering the other half	EAFO (2017a)
	Ten-year circulation tax exemption, reduced to five years from 2021	EVI (2016a); EAFO (2017a)
	Tax deduction for company cars	EAFO (2017a)
	Differentiated plates for EVs, allowing for differentiated measures	EAFO (2017a)
	Locally, free parking, dedicated parking and access to bus lanes	EAFO (2017a)

	Main EV support policies in 2016, changes from 2015 and 2017	Source
India	Tailpipe emission standard (Bharat 3, equivalent Euro 6)	EVI (2016a)
	FAME Scheme (includes several components, such as demand incentives and pilot projects) In some states, registration tax and VAT rebates or exemptions	EVI country submissions
Japan	Tailpipe emissions standard (PNLT 2009, equivalent to Euro 6) Battery capacity and electric range-based purchase subsidy of JPY 850 000 (USD 7 700) maximum, e.g. 30 kWh-battery Nissan Leaf: JPY 330 000 (USD 3 000) Locally, waivers on fees, access to restricted traffic	TransportPolicy.net (2016); EVI (2016a); EVI country submissions
Netherlands	EU tailpipe emission standard (Euro 6 in 2016), EU fuel economy regulation	EVI (2016a)
	In 2016, exemption from registration tax for BEVs, EUR 6/gCO_2/km for PHEVs. In 2017, increase of registration tax to EUR 20/gCO_2/km for PHEVs Ownership tax exemption for BEVs, 50% discount for PHEVs (EUR 400 to EUR 1 200 for conventional cars) CO_2/km-based taxation on the private use of a company car (in 2015, 4% income tax for BEVs, 7-14% for PHEVs; in 2016, increase to 15-21% for PHEVs; in 2017, increase to 22% for PHEVs (rate applicable to all powertrains except BEVs)) EVs are considered as tax deductible investments for companies	Energielabel (2016); EAFO (2017a); EVI country submissions
Norway	EU tailpipe emission standard (Euro 6 in 2016), EU fuel economy regulation Purchase tax exemption (NOK 100 000) (USD 11 600) VAT exemption for BEVs (25% of vehicle price before tax)	EVI (2016a)
	Further purchase rebates and purchase tax waivers introduced for PHEVs in 2016 (maintaining VAT) VAT exemption for leased BEVs Circulation tax exemption Plan to maintain BEV taxation schemes until 2020 while possibility of revision of PHEV taxation schemes Waiver on road tolls and ferry fees From 2016, leadership on free parking measures transferred from the central level to the municipal level	EVI country submissions
Korea	Tailpipe emission standard CARB NMOG (equivalent to Euro 6)	TransportPolicy.net (2016)
	Central purchase subsidies of KRW 14 million (USD 12 329) for BEVs, KRW 5 million (USD 4 400) for PHEVs (rates applicable in 2016 and 2017) Additional local purchase subsidies of KRW 3 million to KRW 12 million (USD 2 700 to USD 10 600 USD) Tax reduction of around KRW 4 million (USD 3 540) for BEVs, KRW 2.7 million (USD 2 389) for PHEVs (rates applicable in 2016 and 2017)	EVI country submissions
	Upwards revision of 2020 target for EV deployment, from 200 000 in 2015, to 250 000 in 2016, as per the Plan for Fine Dust Management	MoE (2016)

	Main EV support policies in 2016, changes from 2015 and 2017	Source
Sweden	EU tailpipe emission standard (Euro 6 in 2016), EU fuel economy regulation	EVI (2016a)
	Between 2011 and 2015, Super Green Car Premium purchase rebate of SEK 40 000 (USD 4 500) for BEVs and SEK 20 000 (USD 2 300) for PHEVs below 50 gCO_2/km; from 2016, reduction to SEK 20 000 for PHEVs	EAFO (2017a)
	Five-year exemption from annual circulation tax for EVs with a maximum fuel economy of 37 kWh/100km (equivalent to SEK 500 to SEK 3 000 per year (USD 57 to USD 340)	EAFO (2017a)
	For businesses, premium of 35% of the price difference between the purchased EV and the nearest comparable car, within the limit of SEK 40 000 (USD 4 500) for BEVs and SEK 20 000 (USD 2 300) for PHEVs	EVI country submissions
	For company cars, a reduction in fringe benefits value by 40% compared to a similar conventional car, within the limit of SEK 16 000 (USD 1 800) between 2012 and 2016 and SEK 10 000 (USD 1 100) from 2017	EVI country submissions
	Company car tax reduction	EAFO (2017a)
United-Kingdom	EU tailpipe emission standard (Euro 6 in 2016), EU fuel economy regulation	EVI (2016a)
	CO_2/km-based and zero-emission range-based purchase subsidy scheme (GBP 4 500 (USD 5 800) for BEVs, GBP 2 500 (USD 3 300) for PHEVs)	Gov.uk (2017d)
	Tax incentives: fuel duty exemption, vehicle excise duty exemption for BEVs and discount for PHEVs, reduced taxation for company cars	Gov.uk (2016b); Gov.uk (2016c)
	Planned government spending of more than GBP 600 million (USD 770 million) (2015-20) to support ultra-low emission vehicle (ULEV) manufacturing and adoption (objective of 100% new ZEV sales by 2040)	Gov.uk (2015), Gov.uk (2016d)
	Go Ultra-Low City scheme (ULEV-friendly measures in a number of UK cities, including London): e.g. exemption from congestion charging, EVSE deployment, free parking and bus lane access	EAFO (2017a); GoUltraLow (2016)
	Go Ultra-Low communication campaign supported by government and OEMs	
United States	Corporate Average Fuel Economy (CAFE) standard with multipliers for EVs and alternative powertrains	GPO (2015)
	Tax credit of USD 2 500 to USD 7 500 to be phased out after 200 000 units per manufacturer are sold for use within the country	EVI country submissions
	ZEV production mandates in place in nine states	
	In some states, purchase rebates and registration tax exemptions	

Notes: When no vehicle type is specified, the policy measure described refers to electric cars (both BEVs and PHEVs).
The ten US states following the California ZEV mandate are California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont.

References

ACEA (European Automobile Manufacturers Association), (2017a), "Alternative fuel vehicle registrations", www.acea.be/statistics/tag/category/electric-and-alternative-vehicle-registrations.

ACEA (2017b), "Consolidated registration figures", www.acea.be/statistics/tag/category/consolidated-figures.

ACEA (2016), "CO_2 based motor vehicle taxes in the EU in 2016", www.acea.be/uploads/publications/CO2_tax_overview_2016.pdf.

AFDC (Alternative Fuels Data Center) (2017), "Developing infrastructure to charge plug-in electric vehicles", www.afdc.energy.gov/fuels/electricity_infrastructure.html.

Auto Sohu (2017a), "Controversial low-speed electric car will soon become legitimate", http://auto.sohu.com/20170224/n481661543.shtml.

Auto Sohu (2017b), "Explanations regarding issues with the management of low-speed electric vehicles", http://auto.sohu.com/20161017/n470482712.shtml.

Auto Sohu (2016), "The final word: The dashed dream of legalisation of low-speed electric vehicles", http://auto.sohu.com/20161227/n477043638.shtml.

Autonews (2016), "Bonus-malus ecologique: le bareme 2016", www.autonews.fr/dossiers/industrie/204883-bonus-malus-bareme-2016-prime/.

Ayre, J. (2015), "$145 kWh battery cell costs at Chevy Bolt launch, GM says", http://evobsession.com/gm-145-kwh-battery-costs-bolt-ev-launch.

Beijing.gov.cn (Beijing Municipal Development and Reform Commission) (2015), "Beijing Municipal Development and Reform Commission notification regarding fees for electric vehicle charging services in Beijing", Notification 848, http://zhengce.beijing.gov.cn/library/192/33/50/45/438656/60869/index.html.

BOE (Boletín oficial del estado) (2009), "Ley 19/2009, de 23 de noviembre, de medidas de fomento y agilización procesal del alquiler y de la eficiencia energética de los edificios", http://www.boe.es/boe/dias/2009/11/24/pdfs/BOE-A-2009-18733.pdf.

Bohn, T. (2011), "Codes and Standards Support for Vehicle Electrification", US Department of Energy," https://energy.gov/sites/prod/files/2014/03/f10/vss053_bohn_2011_o.pdf.

British Columbia (2016), "Climate leadership plan 2016", www2.gov.bc.ca/gov/content/environment/climate-change.

C40 (2017), "C40 Mayors Air Quality Commitment", C40, http://c40-production-images.s3.amazonaws.com/other_uploads/images/1011_Mayors_Air_Quality_Commitment_Jan17.original.pdf?1485784551.

CAAM (2017), "The passenger cars enjoyed high-speed growth", http://www.caam.org.cn/AutomotivesStatistics/20170117/1405205545.html

CARB (California Air Resources Board) (2017), "Zero emission vehicle (ZEV) program", www.arb.ca.gov/msprog/zevprog/zevprog.htm.

CDOJ (Canadian Department of Justice) (2017), "Passenger automobile and light truck greenhouse gas emission regulations", http://laws.justice.gc.ca/eng/regulations/SOR-2010-201/FullText.html.

CEC (China Electricity Council) (2016), "An Interpretation of the differences in the distribution ratio of public charging facilities", China Electricity Journal, www.cec.org.cn/xinwenpingxi/2016-04-19/151780.html.

CEM (Clean Energy Ministerial) (2017), "Electric vehicles initiative (EVI)", www.cleanenergyministerial.org/Our-Work/Initiatives/Electric-Vehicles.

CEM (2016), "Government Fleet Declaration", IEA, www.iea.org/media/topics/transport/EVI_Government_Fleet_Declaration.pdf.

CHAdeMO (2016), "CHAdeMO announces high power (150kw)

version of the protocol", www.chademo.com/wp/wp-content/uploads/2016/06/2016-06-01_High_power_CHAdeMO.pdf

CHAdeMO (2012), "About CHAdeMO", www.chademo.com/wp/pdf/aboutus/Brolong.pdf.

CharIN (2017a), "The path to a global charging standard", http://charinev.org/fileadmin/Downloads/Presentations/2017_CharIN_Charge_Days_Bracklo.pdf.

CharIN (2017b), "DC charging power classes", http://charinev.org/fileadmin/Downloads/Papers_and_Regulations/170412_Nomenklaturvorschlag_für_AG4_Normungsroadmap_Leistungsklassen_SC.PDF.

CharIN (2015), "Articles of associate of charging interface initiative", http://charinev.org/fileadmin/Downloads/Association_Documents/ArticlesOfAssociation_CharIN .pdf.

CIIN (China Information Industry Network) (2016), "2016 China low-speed electric vehicle industry development profile analysis", www.chyxx.com/industry/201607/430412.html.

Clever (2017), "About CELVER", https://clever.dk/about.

CLGEEP (California's Local Government Energy Efficiency Portal) (2017), "Electric Vehicle Readiness Ordinance Introduced in SF", http://eecoordinator.info/electric-vehicle-readiness-ordinance-introduced.

CNEV (2017), "A survey of investment and capacity planning of new energy vehicles in China", www.chinanev.net/news/newscontent/id/9582.

Cobb, J. (2015a), "Tesla projects battery costs could drop to $100/KWH by 2020", www.hybridcars.com/tesla-projects-battery-costs-could-drop-to-100kwh-by-2020/.

Cobb, J. (2015b), "How Nissan and Nenault are Dominating the Electric Car Game". www.hybridcars.com/how-nissan-and-renault-are-dominating-the-electric-car-game/

Daily Economic News (2016), "Low-speed electric car sales this year", http://news.xinhuanet.com/auto/2016-12/29/c_1120209182.htm.

Daimler (2016a), "Interview Prof. Dr. Thomas Weber: 'Electric mobility at Daimler will be in the six figures by 2020'", http://media.daimler.com/marsMediaSite/en.

Daimler (2016b). "BMW Group, Daimler AG, Ford Motor Company and Volkswagen Group with Audi & Porsche plan a joint venture for ultra-fast, high-power charging along major highways in Europe", http://media.daimler.com/marsMediaSite/ko/en/14866747.

Denver, J. (2017), personal communications of the authors on EV deployment in San Francisco. 2017.

Diandong (2017), "2016 Shandong low-speed electric vehicle sales over 600,000, accounting for half of the country", www.diandong.com/zixun/2017011948181.shtml.

Diario da Republica (2010), "Decreto-Lei n.º 39/2010 (Law decree 39/2010)", www.umic.pt/images/stories/publicacoes4/DL_39_2010.pdf.

EAFO (European Alternative Fuels Observatory) (2017a), "European Commission initiative to provide alternative fuels statistics and information", www.eafo.eu.

EAFO (2017b), "Netherlands", www.eafo.eu/content/netherlands

EC (European Commission) (2016a), "Proposal for a Directive of the European Parliament and of the Council Amending Directive 2010/31/EU on the Energy Performance of Buildings, European Commission", https://ec.europa.eu/energy/sites/ener/files/documents/1_en_act_part1_v10.pdf.

EC (2016b), "Clean Transport - Support to the Member States for the Implementation of the Directive on the Deployment of Alternative Fuels Infrastructure", European Commission, http://ec.europa.eu/transport/sites/transport/files/themes/urban/studies/doc/2016-01-alternative-fuels-implementation-good-practices.pdf.

EC (2014), "Directive 2014/94/EU of the European Parliament and of the Council on the Deployment of Alternative Fuels Infrastructure, European Commission," http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0094&from=en.

EEA (European Environment Agency) (2017), "Monitoring of CO_2 emissions from passenger cars - Regulation 443/2009", www.eea.europa.eu/data-and-maps/data/co2-cars-emission-12.

Elaad (2017), "Over ons", www.elaad.nl/organisatie/over-ons.

Energielabel (2016), "Voordeel zuinige auto: BPM, wegenbelasting en bijtelling (Advantages of efficient vehicles: BPM, circulation tax and additional taxes)", www.energielabel.nl/autos/voordeel-zuinige-auto-bpm-wegenbelasting-en-bijtelling/.

EV Obsession (2015), "$145 kWh battery cell costs at Chevy Bolt launch, GM says", https://evobsession.com/gm-145-kwh-battery-costs-bolt-ev-launch/.

EVI (Electric Vehicle Institute) (2017), "Plug-in around the EV world", www.ev-institute.com/images/media/Plug_World_map_v4.pdf.

EVI (2016a), "Global EV Outlook 2016: Beyond One Million Electric Cars, OECD/IEA, Paris, www.iea.org/publications/freepublications/publication/Global_EV_Outlook_2016.pdf

EVI (2016b), "Government Fleet Declaration", OECD/IEA, Paris, www.iea.org/media/topics/transport/EVI_Government_Fleet_Declaration.pdf

EVI (2015a), "Global EV outlook 2015: key takeaways", www.iea.org/media/topics/transport/GlobalEV_Outlook2015Update_1page.pdf.

EVI (2015b), "High-level event on zero emission vehicles (ZEVs)", www.iea.org/workshops/high-level-event-on-zero-emission-vehicles-zevs.html.

EVI (2014), "EV City Casebook: 50 Big Ideas Shaping the Future of Electric Mobility", Urban Foresight, Newcastle upon Tyne, United Kingdom," www.iea.org/topics/transport/subtopics/electricvehiclesinitiative/EVI_2014_Casebook.pdf

EVI (2013), "Global EV Outlook – Understanding the Electric Vehicle Landscape to 2020". www.iea.org/publications/freepublications/publication/GlobalEVOutlook_2013.pdf.

EVI (2012), "EV city casebook – a look at the global electric vehicle movement", www.iea.org/publications/freepublications/publication/EVCityCasebook.pdf.

Fastned (2017), "Fastned breidt uit naar Duitsland (Fastned extends to Germany)", https://fastned.nl/nl/blog/post/fastned-breidt-uit-naar-duitsland.

Field, K. (2016), "UBS analyst dubs model 3 unprofitable, Tesla responds with battery pricing" https://cleantechnica.com/2016/04/27/tesla-model-3-pricing-battery-pricing-unveiled.

Figenbaum, E. and M. Kolbenstvedt (2016), "Learning from Norwegian Battery-electric and Plug-in Hybrid Vehicle Users, Institute of Transport Economics, Norwegian Centre for Transport Research, Oslo," www.toi.no/getfile.php?mmfileid=43161.

Ford (2017), "Media Ford", https://media.ford.com/content/fordmedia-mobile/fna/us/en/news/2017/01/03/ford-adding-electrified-f-150-mustang-transit-by-2020.html.

GFEI (Global Fuel Economy Initiative) (2017), "International Comparison of Light-Duty Vehicle Fuel Economy: Ten Years of Fuel Economy Benchmarking, OECD/IEA, Paris, www.globalfueleconomy.org/media/418761/wp15-ldv-comparison.pdf.

GFEI (2016), "Fuel Economy State of the World 2016, FIA Foundation," www.globalfueleconomy.org/media/203446/gfei-state-of-the-world-report-2016.pdf.

Goliya and Sage (2016), "Tesla puts pedal to the metal, 500,000 cars planned in 2018", http://www.reuters.com/article/us-tesla-results-idUSKCN0XV2JL

GoUltraLow (2016), "Go Ultra Low, about", www.goultralow.com/about/.

Gov.uk (2017a), "Workplace Charging Scheme guidance for applicants, installers and manufacturers", www.gov.uk/government/publications/workplace-charging-scheme-guidance-for-applicants-installers-and-manufacturers.

Gov.uk (2017b), "Plug-in car, motorcycle and van grants", www.gov.uk/plug-in-car-van-grants.

Gov.uk (2017c), "Statistics at DFT", www.gov.uk/government/organisations/department-for-transport/about/statistics

Gov.uk (2017d), "Plug-in car, motorcycle and van grants – what you'll get", www.gov.uk/plug-in-car-van-grants/what-youll-get.

Gov.uk (2016a), "Capital allowances: first-year allowance for electric charge-points", policy paper, www.gov.uk/government/publications/capital-allowances-first-year-allowance-for-electric-charge-points/capital-allowances-first-year-allowance-for-electric-charge-points.

Gov.uk (2016b), "Tax Benefits for Ultra Low Emission Vehicles, Office for Low Emission Vehicles," www.gov.uk/government/uploads/system/uploads/attachment_data/file/519209/factsheet-tax-implications-refresh.pdf.

Gov.uk (2016c), "Vehicle Tax (VED) Is Changing…", Driver and Vehicle Licensing Agency, www.gov.uk/government/uploads/system/uploads/attachment_data/file/534511/ved-reform-briefing-for-motor-industry.pdf.

Gov.uk (2016d), "Government pledges £290 million boost for low emission vehicles", www.gov.uk/government/news/government-pledges-290-million-boost-for-low-emission-vehicles.

Gov.uk (2015), "Spending Review and Autumn Statement 2015: documents", www.gov.uk/government/publications/spending-review-and-autumn-statement-2015-documents

GPO (Government Publishing office of the United States) (2015), "2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards", https://www.gpo.gov/fdsys/pkg/FR-2012-10-15/pdf/2012-21972.pdf

Hall, D. and Lutsey, N. (2017), "Literature review on power utility best practices regarding electric vehicles", www.theicct.org/sites/default/files/publications/Power-utility-best-practices-EVs_white-paper_14022017_vF.pdf.

Hall, D. et al. (2017), "Electric Vehicle Capitals of the World: Demonstrating the Path to Electric Drive," International Council on Clean Transportation, Washington, DC, www.theicct.org/sites/default/files/publications/Global-EV-Capitals_White-Paper_06032017_vF.pdf.

HEV TCP (IEA Technology Collaboration Programme on Hybrid and Electric Vehicles) (forthcoming), "Annual HEV TCP report".

HK EMSD(2015), "Technical Guidelines on Charging Facilities for Electric Vehicles, EMSD," www.emsd.gov.hk/filemanager/en/content_444/Charging_Facilities_Electric_Vehicles.pdf.

Hodge, C. (2017), personal communication of the authors with Cabell Hodge, National Renewable Energy Laboratory of the United States.

Homeplug (2012), The Standard for In-Home Smart Grid Powerline Communications: An Application and Technology Overview, Homeplug, www.homeplug.org/media/filer_public/92/3f/923f0eb3-3d17-4b10-ac75-03c3c2855879/homeplug_green_phy_whitepaper_121003.pdf.

Honda, (2016), "Honda adds all-new dedicated hybrid model to growing electrified lineup", http://news.honda.com/newsandviews/article.aspx?id=9463-en.

Howell, D. (2017), personal communications of the authors on the status and projections for EV batteries RD&D. March and April 2017.

Hoy, K. and H. Weken (2017), "I-CVUE Final Results", I-CVUE, http://frevue.eu/wp-content/uploads/2016/03/I-CVUE-.pdf.

IEA (International Energy Agency) (2017a), "Modelling of the transport sector in the mobility model (MoMo)", www.iea.org/etp/etpmodel/transport/.

IEA (2017b), *Energy Technology Perspectives 2017*, www.iea.org/etp/.

IEA (2016), "Energy and Air Pollution, OECD/IEA, Paris," www.iea.org/publications/freepublications/publication/WorldEnergyOutlookSpecialReport2016EnergyandAirPollution.pdf.

IHS (2017), "CAAM estimates Chinese vehicle production at 30 mil. in 2020", http://www.ihssupplierinsight.com/news/33016/caam-estimates-chinese-vehicle-production-at-30-mil-in-2020

IHS Polk (2016), Vehicle Registrations and Other Characteristics at Model Level (database), HIS Markit.

Isbrand, C. (2017), personal communications of the authors on EV deployment in Copenhagen. 2017.

ISO (International Organization for Standardization) (2015), "ISO 15118-3:2015", www.iso.org/standard/59675.html.

Jiren, T. (2017), "Low-speed electric car market: why more than a decade of ups and down?", http://shuoke.autohome.com.cn/article/563756.html.

Johnsen, A. (2017), personal communications of the authors on EV deployment in Oslo and Bergen. 2017.

Kafyeke, T. (2017), "PlugSurfing: Why Driving an Electric Car Is Already Paying Off", https://en.reset.org/blog/plugsurfing-why-driving-electric-car-already-paying-03092017.

Kasche, P. (2017), personal communications of the authors on the status and projections for the deployment of electric vehicles in the Sweden, March and April 2017.

Lambert, F. (2017a), "US cities' massive electric vehicles order increases to 114,000 vehicles, 40 companies competing", https://electrek.co/2017/03/15/electric-vehicle-order-114000-vehicles-40-companies-competing/.

Lambert, F. (2017b), "BMW explains its electric vehicle plans in more details and it's going in the right direction", https://electrek.co/2017/03/22/bmw-electric-vehicle-plans.

Lambert, F. (2016a), "Tesla confirms base model 3 will have less than 60 kWh battery pack option, cost is below $190/kWh and falling", https://electrek.co/2016/04/26/tesla-model-3-battery-pack-cost-kwh.

Lambert, F. (2016b), "Elon Musk on Tesla/Panasonic's new 2170 battery cell: 'highest energy density cell in the world…that is also the cheapest'", https://electrek.co/2016/11/02/tesla-panasonic-2170-battery-cell-highest-energy-density-cell-world-cheapest-elon-musk.

Lambert, F. (2016c), "China is pushing for aggressive new ZEV mandate: 8% of new cars to be electric by 2018 12% by 2020", https://electrek.co/2016/10/31/china-pushing-aggressive-zev-mandate-8-of-new-cars-to-be-electric-by-2018-12-by-2020/.

Legifrance (2016), "Décret n° 2016-968 du 13 juillet 2016 relatif aux installations dédiées à la recharge des véhicules électriques ou hybrides rechargeables et aux infrastructures permettant le stationnement des vélos lors de la construction de bâtiments neufs", www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000032894192&categorieLien=id.

Legifrance (2014), "Code de la construction et de l'habitation - Article L111-6-4", https://www.legifrance.gouv.fr/affichCodeArticle.do?idArticle=LEGIARTI000022495459&cidTexte=LEGITEXT000006074096&dateTexte=vig.

Loveday, E. (2017), "LG Chem expects Chevrolet Bolt sales to exceed 30,000 in 2017", http://insideevs.com/lg-chem-expects-chevrolet-bolt-sales-exceed-30000-2017/.

Marklines (2017), "Automotive industry portal", www.marklines.com/portal_top_en.html.

MEEM (Ministere de l'Environnement, de l'Energie et de la Mer) (2016a), "Développement des véhicules propres", www.developpement-durable.gouv.fr/developpement-des-vehicules-propres.

MEEM (2016b), "Bonus-malus écologique, prime à la conversion et bonus vélo", www.developpement-durable.gouv.fr/bonus-malus-ecologique-prime-conversion-et-bonus-velo.

MIIT (Ministry of Industry and Information Technology of the People's Republic of China) (2016), "Reply to the recommendation of the Fourth Session of the Twelfth National People 's Congress", www.miit.gov.cn/n1146295/n1146592/n3917132/n4545264/c5281913/content.html.

MoE (Ministry of Environment, Korea) (2016), "Government joint announcement, fine dust management special measures settlement", www.me.go.kr/home/web/board/read.do?boardMasterId=1&boardId=645030&menuId=286.

MoF (Ministry of Finance, China) (2017), “Notice on adjusting the financial subsidy Policy for the Promotion and Application of New Energy Vehicles”, http://jjs.mof.gov.cn/zhengwuxinxi/tongzhigonggao/201612/t20161229_2508628.html.

MoF (2016), “On policy of the adjustment of popularization and application of new energy vehicles financial subsidy”, http://jjs.mof.gov.cn/zhengwuxinxi/tongzhigonggao/201612/t20161229_2508628.html.

Montes Portela, C. et al. (2015), “OSCP - An open protocol for smart charging of electric vehicles”, http://cired.net/publications/cired2015/papers/CIRED2015_0106_final.pdf.

Munnix, S. (2017), personal communication of the authors with Sonja Munnix, Netherlands Enterprise Agency.

OECD (Organisation for Economic Co-operation and Development) (2015), “Domestic incentive measures for environmental goods with possible trade implications: electric vehicles and batteries”, www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=COM/TAD/ENV/JWPTE(2013)27/FINAL&docLanguage=En.

OMOT (Ontario Ministry of Transportation) (2010), “Transportation updates”, www.mto.gov.on.ca/english/.

PIB India (Press Information Bureau) (2017), “Shri Piyush Goyal reiterates India’s commitments to combat Climate Change at the 'World Conference on Environment 2017'“, http://pib.nic.in/newsite/PrintRelease.aspx?relid=159961.

Pontes, J. (2017), “China electric car sales keep soaring – March 2017”, https://evobsession.com/china-electric-car-sales-keep-soaring-march-2017/.

Proterra (2017), “Proterra names Matt Horton chief commerical officer, following rapid sales growth”, www.proterra.com/press-release/proterra-names-matt-horton-chief-commercial-officer-following-rapid-sales-growth/.

Quebec (2012), “Discover electric vehicles”, http://vehiculeselectriques.gouv.qc.ca/english/index.asp.

Rask, M. (2017), personal communications of the authors on the status and projections for the deployment of electric vehicles in Denmark. March and April 2017.

RATP (Régie Autonome des Transports Parisiens) (2017), “Bus2025: RATP’s plan for a 100% eco-friendly bus fleet by 2025”, www.ratp.fr/en/ratp/v_139993/bus-2025/.

Reuters (2017), “Germany likely to miss e-cars target, says Merkel”, www.reuters.com/article/us-autos-electric-germany-idUSKCN18B24Z.

Ryan, J. (2017), “Cities Shop for $10 Billion of Electric Cars to Defy Trump”, www.bloomberg.com/news/articles/2017-03-14/cities-shop-for-10-billion-of-electric-vehicles-to-defy-trump.

Shah, R. (2017), “Top 10 two-wheeler manufacturers in India in 2016”, Indiatimes, http://auto.economictimes.indiatimes.com/news/two-wheelers/scooters-mopeds/top-10-two-wheeler-manufacturers-in-2016/56491780.

SIC (State Information Center) (2017), “Center Profile”, www.sic.gov.cn.

Slowik, P., N. Pavlenko and N. Lutsey (2016), “Assessment of Next-Generation Electric Vehicle Technologies”, International Council on Clean Transportation, www.theicct.org/sites/default/files/publications/Next%20Gen%20EV%20Tech_white-paper_ICCT_31102016.pdf.

Source London (2017), "About Source London", www.sourcelondon.net/about-source-london.

State Grid Corporation of China (2013), "EV Infrastructure and standardization in China, State Grid Corporation of China," www2.unece.org/wiki/download/attachments/12058681/EVE-07-14e.pdf.

Tesla (2017a), "Tesla fourth quarter & full year 2016 update", http://files.shareholder.com/downloads/ABEA-4CW8X0/4066363333x0x929284/22C29259-6C19-41AC-9CAB-899D148F323D/TSLA_Update_Letter_2016_4Q.pdf.

Tesla (2017b), "Supercharger", www.tesla.com/supercharger.

Tesla (2017c), "Charging is our priority", www.tesla.com/blog/charging-our-priority.

Tesla (2014), "Tesla gigafactory", www.tesla.com/gigafactory.

TfL (Transport for London) (2017a), "Ultra low emission zone", https://tfl.gov.uk/modes/driving/ultra-low-emission-zone

TfL (2017b), "Discounts & exemptions", https://tfl.gov.uk/modes/driving/congestion-charge/discounts-and-exemptions?intcmp=2133

Thai Rath (2016), "Promoting electric tuk-tuk around the country in 5 years", www.thairath.co.th/content/865802.

TransportationPolicy.net (2016), "Global comparison: light-duty emissions", http://transportpolicy.net/index.php?title=Global_Comparison:_Light-duty_Emissions.

UNECE (2016), "Consolidated resolution on the construction of vehicles (R.E.3)", www.unece.org/fileadmin/DAM/trans/main/wp29/wp29resolutions/ECE-TRANS-WP29-78-r4e.pdf.

UNECE (United Nations Economic Commission for Europe) (2005), "Special resolution No. 1 concerning the common definitions of vehicle categories, masses and dimensions (S.R. 1)", www.unece.org/fileadmin/DAM/trans/doc/2005/wp29/TRANS-WP29-1045e.pdf.

UNFCCC (United Nations Framework Convention on Climate Change) (2015a), "Paris declaration on electro-mobility and climate change & call to action", http://newsroom.unfccc.int/media/521376/paris-electro-mobility-declaration.pdf.

UNFCCC (2015b), "Adoption of the Paris Agreement," United Nations Framework Convention on Climate Change, Paris, https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf .

Urban Access Regulations (2017), "Urban Access Regulations, home", www.urbanaccessregulations.eu/

USC (Union of Concerned Scientists) (2016), "What is ZEV?" www.ucsusa.org/clean-vehicles/california-and-western-states/what-is-zev#.WQmkrIVOKUm

US DOE (United States Department of Energy) (2017), "Cost and Price Metrics for Automotive Lithium-Ion Batteries", US DOE, https://energy.gov/sites/prod/files/2017/02/f34/67089%20EERE%20LIB%20cost%20vs%20price%20metrics%20r9.pdf.

Van Gijlswijk, R. et al. (2014), "Indirecte en directe CO_2-uitstoot van elektrische personenauto's", TNO 2014 R10665, www.tno.nl/media/4404/tno-2014-notitie-directe-en-indirecte-emissie-elektr-voertuig_-14072014.pdf.

Verbeek, R.P. et al. (2015), "Energie- en milieu-aspecten van elektrische personenvoertuigen", www.rvo.nl/sites/default/files/2015/04/TNO%20Factsheets%20Elektrische%20Voertuigen.pdf.

Vertelman and Bardok (2016), "Amsterdam's demand-driven charging infrastructure", www.amsterdam.nl/publish/pages/799470/planam-03-2016_art2_2_1.pdf.

Visser, W. (2017), personal communication of the authors with William Visser, Netherlands Enterprise Agency.

Volkswagen (2016), "New Group strategy adopted: Volkswagen Group to become a world-leading provider of sustainable mobility", www.volkswagenag.com/en/news/2016/6/2025.html.

Volvo (2016), "Volvo Cars announces new target of 1 million electrified cars sold by 2025", www.media.volvocars.com/global/en-gb/media/pressreleases/.

West Coast Green Highway (2017), "Alternative fuels corridor", www.westcoastgreenhighway.com/.

Willemsen, O. (2016), "CO_2 emissions electric cars", https://willemsenolivier.wordpress.com/2016/02/04/co2-emissions-electric-cars.

WHO (2016), *Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease, World Health Organization, Geneva,* http://apps.who.int/iris/bitstream/10665/250141/1/9789241511353-eng.pdf?ua=1.

WXY Architecture (2012), "EV-ready codes for the built environment", www.transportationandclimate.org/sites/default/files/EV-Ready_Codes_for_the_Built_Environment_0.pdf.

Yang, M. (2016), "National committee of the second meeting", CEVN, http://news.ddc.net.cn/newsview_70658.html.

Yang, J. et al. (2014), "A review of Beijing's vehicle registration lottery: Short-term effects on vehicle growth and fuel consumption", Energy Policy, Vol. 75, pp. 157-166, www.sciencedirect.com/science/article/pii/S030142151400370X.

Acronyms, abbreviations and units of measure

Acronyms and abbreviations

2DS	two-degree scenario
AC	alternating current
BEV	battery-electric vehicle
B2DS	beyond-two-degree scenario
CAFE	Corporate Average Fuel Economy
CCS	combined charging system
CEM	Clean Energy Ministerial
CO_2	carbon dioxide
COP21	21st Conference of the Parties to the United Nations Framework Convention on Climate Change
DC	direct current
DSO	demand-side operator
EU	European Union
EV	electric vehicle
EVI	Electric Vehicles Initiative
EVSE	electric vehicle supply equipment
FCEV	fuel cell electric vehicle
GHG	greenhouse gas
GIZ	German Corporation for International Cooperation
HEV	hybrid and electric vehicles
HGV	heavy-goods vehicles
HOV	high-occupancy vehicle
ICCT	International Council on Clean Transportation
ICE	internal combustion engine
ICT	information and communications technology
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IRENA	International Renewable Energy Agency
ISO	International Organization for Standardization
LSEV	low-speed electric vehicle
OEM	original equipment manufacturer
PHEV	plug-in hybrid electric vehicle

PLDV	passenger light-duty vehicle
PPP	public-private partnership
RD&D	research, development and deployment
RTS	Reference Technology Scenario
SAC	Standardization Administration of China
SAE	Society of Automotive Engineers
TCP	technology collaboration programme
TCO	total cost of ownership
UK	United Kingdom
US	United States
US DOE	US Department of Energy
ULEV	ultra-low emission vehicle
ULEZ	ultra-low emission zone
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
VAT	value-added tax
WTW	well-to-wheel
ZEV	zero-emission vehicle

Units of measurement

gCO_2	gramme of carbon dioxide per km
gCO_2/km	gramme of carbon dioxide per kilometre
gCO_2/kWh	gramme of carbon dioxide per kilowatt hour
Gt	gigatonne
GW	gigawatt
km/Lge	kilometre per litre of gasoline-equivalent
kW	kilowatt
kWh	kilowatt hour

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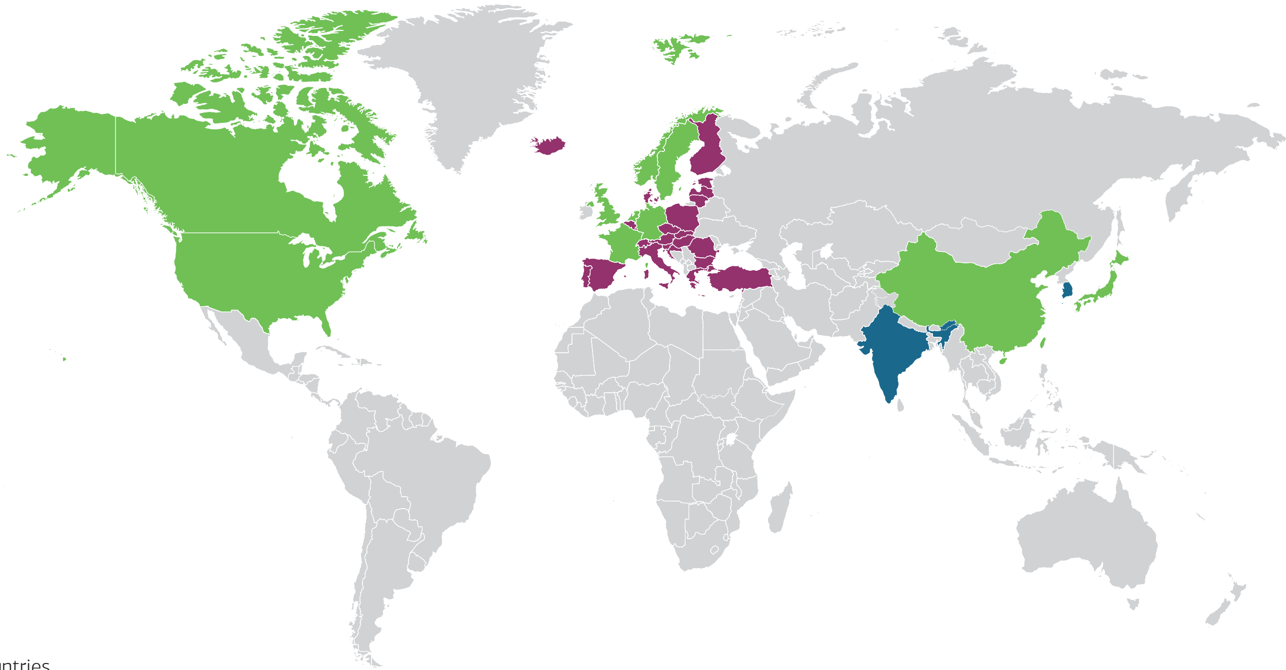
Electric Vehicles Initiative

The EVI is a multigovernment policy forum established in 2009 under the Clean Energy Ministerial, dedicated to accelerating the deployment of EVs worldwide. It brings together representatives of its member governments and partners twice per year and acts as an effective platform for knowledge sharing on policies and programmes that support EV deployment. In 2017, it launched the EV30@30 campaign, redefining its ambition by setting the collective aspirational goal for all EVI members of a 30% market share for electric vehicles in the total of all passenger cars, light commercial vehicles, buses and trucks, by 2030.

The EVI counts today ten member governments (Canada, China, France, Germany, Japan, the Netherlands, Norway, Sweden, the United Kingdom and the United States), representing most of the global EV stock and including the largest and most rapidly growing EV markets worldwide. China and the United States are currently co leading the EVI*, and the IEA is the co ordinator of the initiative.

* United States' leadership under review



EVI countries

European Alternative Fuels Observatory (EAFO) countries not in EVI

Other countries that contributed to the EVI data collection

Electric Vehicles Initiative

This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area

The Edison Foundation
INSTITUTE for ELECTRIC INNOVATION

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Report

Plug-in Electric Vehicle Sales Forecast Through 2025 and the Charging Infrastructure Required

June 2017

Prepared by:
Adam Cooper (IEI) and Kellen Schefter (EEI)

Executive Summary

Today, technology improvements are expanding the opportunity for electric transportation, and electric companies are leading efforts to advance electric transportation and move the market forward. Electric transportation is a win-win; it meets customer needs while also supporting America's energy security and sustainability.

The Edison Electric Institute (EEI) and the Institute for Electric Innovation (IEI) developed a plug-in electric vehicle (PEV) sales forecast through 2025, including both plug-in hybrid electric vehicles and battery electric vehicles, and identified the associated charging equipment infrastructure needs. This paper identifies both the scope and scale of charging infrastructure needed to support PEVs and the different approaches to infrastructure build-out.

The results show the following:

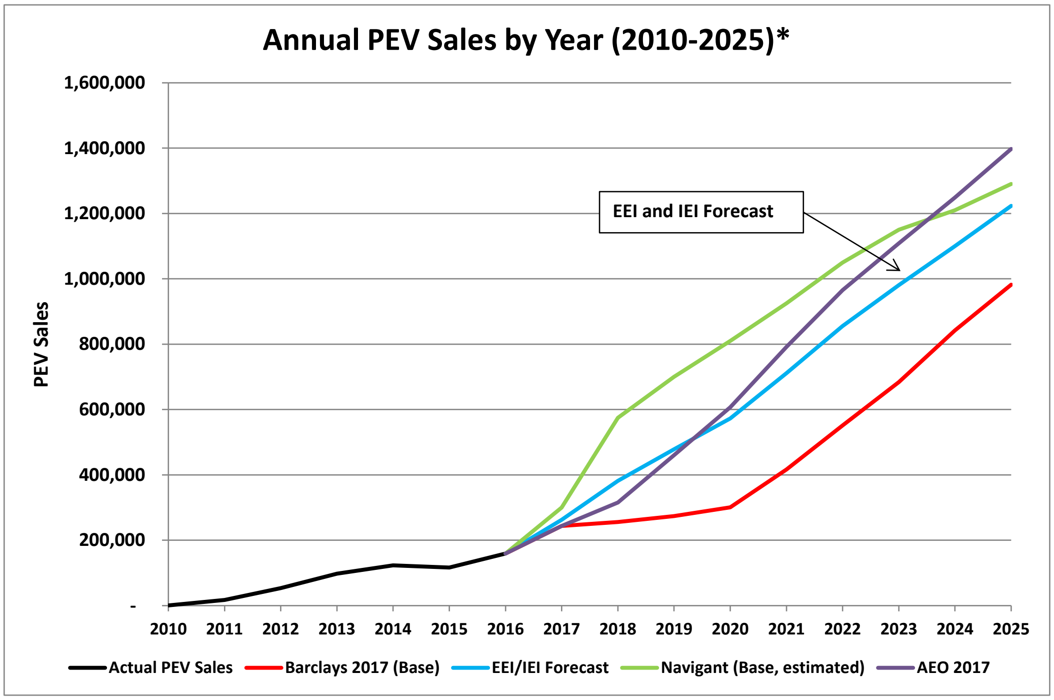
- **Annual sales of PEVs** will exceed 1.2 million vehicles in 2025, reaching more than 7 percent of annual vehicle sales by 2025 (see Figures 1 and 2).
- The **stock of PEVs** (i.e., the number of PEVs on the road) is projected to reach 7 million by 2025, up from 567,000 at the end of 2016 (see Figure 3). This is about 3 percent of the 258 million vehicles (cars and light trucks) expected to be registered in the United States in 2025.
- About **5 million charge ports will be required** to support 7 million PEVs in 2025 (see Figure 3). This represents a significant investment in PEV charging infrastructure.[1]

Growing customer demand, corporate average fuel economy (CAFE) standards, and declining battery costs are all major drivers of PEV sales. A continued decline in battery costs will result in increased cost- competitiveness of PEVs with internal combustion engine (ICE) vehicles. However, relaxing current CAFE standards (54.5 MPG by 2025) will put downward pressure on PEV sales. Regardless, customers are buying PEVs in record numbers, and the demand for charging infrastructure is increasing.

Most PEV charging infrastructure to date is paid for by the entity that "hosts" the charging equipment (the "site host"), such as a homeowner, a commercial property owner, or a public entity. The PEV charging marketplace is evolving, and different approaches to providing the charging infrastructure for the PEV market are being tested. Electric companies are well-positioned to help develop PEV charging infrastructure.

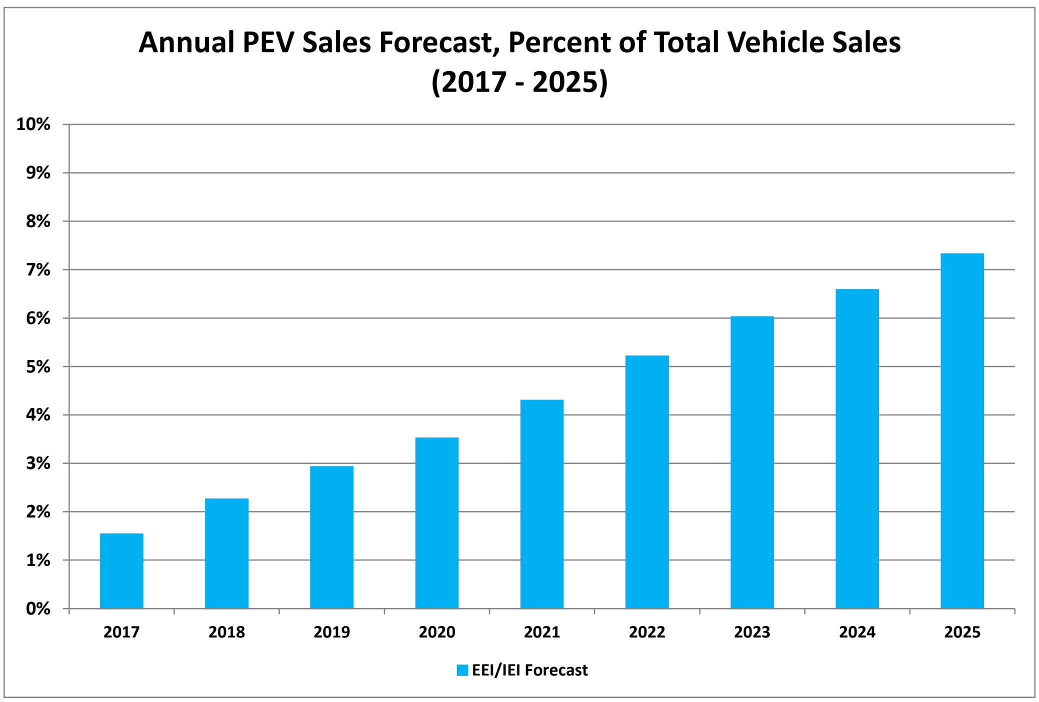
1. The share of battery electric vehicles is expected to increase from 52 percent of annual PEV sales in 2016 to more than 60 percent in 2025. This impacts charging infrastructure needs because BEVs directly influence the number of DC fast chargers.

Figure 1. EEI/IEI Annual PEV Sales Forecast Compared to Selected Forecasts[2]



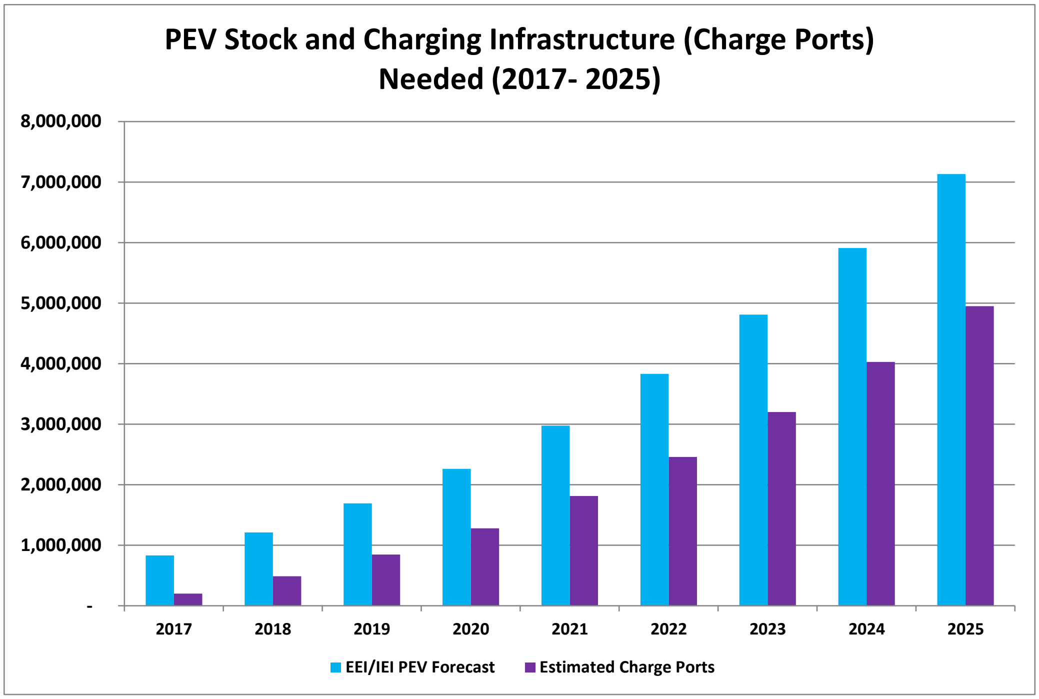
*Includes battery electric vehicles and plug-in hybrid electric vehicles

Figure 2. EEI/IEI Annual PEV Sales Forecast, Percent of Total Vehicle Sales



2. Applied Barclays' North American PEV sales forecast to estimate U.S. sales.

Figure 3. PEV Stock and Charging Infrastructure Needed By 2025 Based on EEI/IEI Forecast



Background

EEI and IEI developed a consensus forecast of PEV sales projections from 2017 to 2025 based on three independent forecasts:

- U.S. Energy Information Administration (EIA) Annual Energy Outlook 2017 Reference Case (January 2017).[3]
- Barclays Equity Research Note – Together in Electric Dreams (January 2017).[4]
- Navigant Research – Electric Vehicle Geographic Forecasts (June 2016).[5]

These forecasts were selected because they include three key factors: customer preference models that determine interest in PEVs; declining battery costs that influence PEV cost competitiveness with ICE vehicles and manufacturer profitability; and fuel efficiency standards and environmental regulations.

Declining battery costs and growing customer demand for PEVs act as an accelerant to PEV sales. Cost reductions in battery packs enable longer-range PEVs, increase cost-competitiveness with ICE vehicles, and result in automobile manufacturers producing a wider variety of PEVs across more vehicle segments to better meet customer demand.

- Between 2010 and 2016, battery pack costs [$ per kilowatt-hour (kWh)] declined by about 20 percent per year. The U.S. Department of Energy estimated battery pack costs in 2016 at $245 per kWh.
- Barclays projects that battery pack costs at $100 per kWh will create price parity with ICE vehicles.

Comparing the forecasted PEV sales to automaker announcements is a useful reality check. Based on public announcements by BMW, Mercedes, Tesla, Volkswagen, and Volvo (ranging from 20 percent to 100 percent) and on a conservative estimate of 5 percent PEV sales for other mainstream manufacturers (Fiat-Chrysler, Ford, General Motors, Honda, Hyundai-Kia, Nissan, and Toyota), **annual PEV sales** are expected to reach 1.2 million in 2025.

Table 1 shows the actual percent of PEV sales in 2016, the percent expected in 2025, and the likely number of PEV sales in 2025 projected by manufacturer. Given manufacturer projections, the EEI and IEI forecast is reasonable and likely conservative.

3. See https://www.eia.gov/outlooks/aeo/
4. Together in Electric Dreams. Energy & Autos. Barclays. January 27, 2017.
5. See https://www.navigantresearch.com/research/electric-vehicle-geographic-forecasts

Table 1. Annual PEV Sales in 2025 Projected by Vehicle Manufacturer

Manufacturer	% PEV Sales in 2016 (Actual)	All Vehicle Sales Expected in the U.S. in 2025	% PEV Sales Expected in 2025	Estimated PEV Sales in 2025
BMW	4.4	370,000	20	74,000
Mercedes	0.6	380,000	20	76,000
Tesla	100	200,000	100	200,000
Volkswagen	1.9	750,000	20	150,000
Volvo	2.4	80,000	20	16,000
Subtotal (Automaker announcements)	--	1,780,000	32	**516,000**
Fiat-Chrysler	0.2	2,200,000	5	110,000
Ford	1	2,600,000	7	182,000
General Motors	0.9	3,000,000	5	150,000
Honda	0	1,500,000	3	45,000
Hyundai-Kia	0.3	1,400,000	5	70,000
Nissan	0.9	1,750,000	6	105,000
Toyota	0.1	2,400,000	2	48,000
Subtotal (Estimated)	--	14,850,000	5	**710,000**
Total	--	**16,630,000**	7.4	**1,226,000**

CAFE & GHG Standards Compliance Issues

CAFE standards are a primary driver for the 31 PEV models available today in the United States from 17 automakers. Fuel efficiency standards and environmental regulations [i.e., CAFE and greenhouse gas (GHG) regulations] act as a floor for PEV sales (i.e., minimum compliance). To comply with CAFE & GHG standards, automakers have had to:

1. Advance technologically via improved vehicle aerodynamics, light-weight materials, turbo-charged engines, continuously variable transmissions, and stop-start technologies.

2. Offer a range of PEVs.

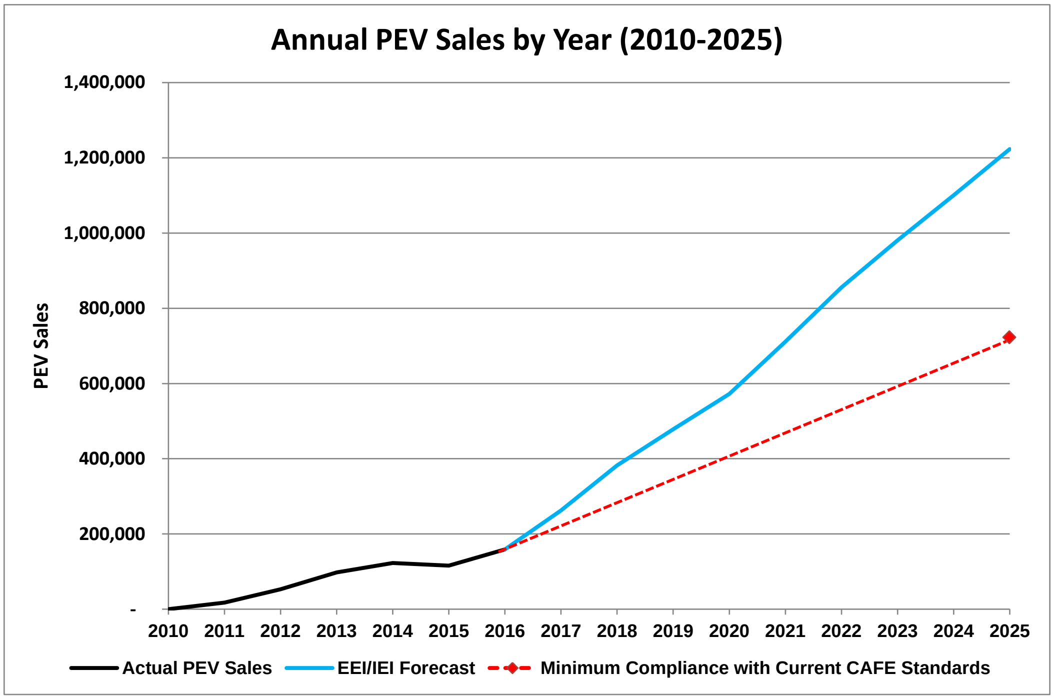
Figure 4 shows a comparison of the EEI/IEI forecast relative to PEV sales under minimum compliance with CAFE standards as projected by the U.S. Environmental Protection Agency (EPA), National Highway Traffic Safety Administration (NHTSA), and California Air Resources Board under the current regulation.[6]

Minimum compliance with CAFE is a floor for PEV sales, and any reduction in current CAFE standards likely will depress PEV sales. As part of the rulemaking that established model year

6. Draft Technical Assessment Report: Midterm Evaluation of Light-Duty Vehicle Greenhouse Gas Emissions Standards and Corporate Average Fuel Economy Standards for Model Years 2022-2025. U.S EPA, NHTSA, and CARB. July 2016.

(MY) 2017-2025 standards, EPA and NHTSA made a regulatory commitment to conduct a midterm evaluation of the standards for MY 2022-2025, which increase fuel economy from 46.8 MPG to 54.5 MPG. Recently, EPA Administrator Scott Pruitt and Department of Transportation Secretary Elaine Chao announced that EPA and NHTSA intend to reconsider the appropriateness of the MY 2022-2025 standards by no later than April 1, 2018.

Figure 4. PEV Sales: EEI/IEI Forecast vs. Minimum Compliance With Current CAFE Standards



PEV Charging Infrastructure

The availability of PEV charging infrastructure is fundamental to the growth of PEVs. Unlike conventional vehicles, which typically refuel only at gasoline stations, PEVs may charge while parked at home, at work, or in public spaces.

Charging equipment is needed to connect a vehicle to the energy grid. This charging equipment, which often is referred to as a charging station or a charge port, comes in a variety of types and configurations, but is generally categorized by power level:

- **Level 1 (L1):** 120-volt, alternating current (AC) power. Level 1 charging refers to charging stations, as well as typical electric outlets that a driver plugs into via a cord set included with the vehicle. A PEV connected to a Level 1 charger takes about 12 hours to charge a fully depleted 50-mile battery (about 4 miles of electric range per hour of charging).

- **Level 2 (L2):** 240-volt, AC power. Level 2 chargers typically are mounted on a wall or on a pedestal. A PEV connected to a Level 2 charger takes between 3 to 5 hours to charge a fully depleted 50-mile battery (about 10 to 20 miles of electric range per hour of charging depending on the PEV).

- **DC Fast Charger (DCFC)**: Converts AC electricity to direct current (DC) and delivers charge to the vehicle at higher power, typically 50 kilowatt or greater. A PEV connected to a DC fast charger takes about 30 minutes to charge a fully depleted battery to about 80 percent, depending on battery size. Not all PEVs are able to accept DC fast charging.

Table 2 summarizes likely PEV charging infrastructure locations, durations, and the charging equipment that is commonly installed at each location.

Table 2. PEV Charging Equipment By Use

Category	Use Case	Park/Charge Time	Charger Type
Home	Single family home	Overnight (~12 hours)	L1, L2
	Multi-unit dwelling	Overnight (~12 hours)	L1, L2
Work	Workplace charging	Work day (~8 hours)	L1, L2
Public	Short/medium-dwell (e.g., retail)	1-2 hours	L2
	Long-dwell (e.g., airports)	2-4 hours or longer	L1, L2
	Metro-based (intra-city)	~ 30 minutes or less	DCFC
	Long-distance (inter-city)	~30 minutes or less	DCFC

To date, the vast majority of PEV charging occurs at home. However, having charging infrastructure at workplaces or in public settings allows PEV owners to drive more miles on electric, enables longer trips, and reduces range anxiety. In addition, public charging infrastructure is important for PEV owners who do not have dedicated home charging, such as in multi-unit dwellings (e.g., apartment buildings) or those with street parking.

Charging Infrastructure Needs

EEI and IEI estimated the PEV charging infrastructure needed to support the projected 7 million-plus PEVs on the road in 2025 based on two models: the National Renewable Energy Laboratory (NREL) model, as described in the National Economic Assessment of Plug-In Electric Vehicles (December 2016)[7] and the Electric Power Research Institute's (EPRI's) Red Line/Blue Model (June 2014).[8]

The NREL and EPRI models typically are used by electric companies and state organizations to support PEV charging infrastructure analysis and to identify the need for at-home and away-from-home charge ports.[9] The NREL model estimates infrastructure needs separately for battery electric vehicles and plug-in hybrid electric vehicles, while the EPRI model estimates infrastructure needs for PEVs. Table 3 provides the number of charge ports by location and type per 1,000 PEVs.

Table 3. Estimated Charge Ports By Vehicle Type and Location per 1,000 PEVs: NREL and EPRI Models

Charger Location and Type	NREL Model (Charge ports per 1,000 PHEVs)	NREL Model (Charge ports per 1,000 BEVs)	EPRI Model (Charge ports per 1,000 PEVs)
Home	**327**	**328**	**500**
Single Family (Level 2)	283	*286*	*Unspecified*
Multi-unit Dwelling (Level 2)	*44*	*42*	*Unspecified*
Work	**334**	***332***	**270**
Level 1	*167*	*166*	*Not Included*
Level 2	*167*	*166*	*270*
Public	**3**	**11**	**72**
Level 1	*0.5*	*0.4*	*Not Included*
Level 2	*2.4*	*10.1*	*67*
DC Fast Charger	*0*	*0.5*	*5*

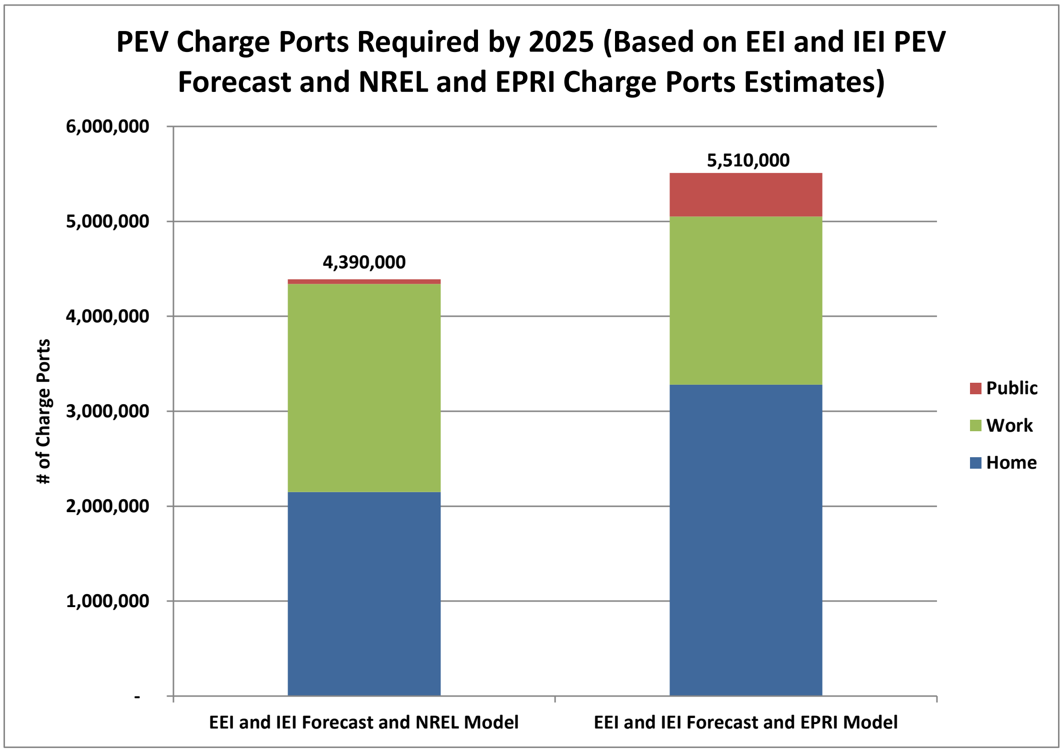
Both models assume most charging will occur at home. For the purposes of this analysis, the "home" charging accounted for here includes only Level 2 chargers, which have an incremental cost to the driver, and not home-based Level 1 chargers that are simple electrical outlets. These

7. See http://www.nrel.gov/docs/fy17osti/66980.pdf
8. See https://www.epri.com/#/pages/product/000000003002004096/
9. See filings from Avista Utilities, Pacific Gas & Electric Company, and Southern California Edison.

models predict about 327 to 500 charge ports at home per 1,000 PEVs, and 270 to 334 charge ports at work per 1,000 PEVs. Public charging infrastructure estimates vary widely between the two models, from 3 to 72 charge ports per 1,000 PEVs.

About 4.4 to 5.5 million charge ports will be needed by 2025 to support the EEI and IEI projected 7 million PEVs on the road. As shown in Figure 5, almost all charge ports are estimated to be at home or at work.[10]

Figure 5. Estimated Number of PEV Charge Ports Required By 2025 (Based on EEI and IEI PEV Forecast and NREL and EPRI Charge Ports Estimates)



Approaches to Deploying PEV Charging Infrastructure

The NREL and EPRI models used in this report simply estimate the charging infrastructure needed to support a certain level of PEVs. The PEV market is driven by a myriad of dynamics, including customer awareness and acceptance; the types of PEVs available; affordability; the availability of infrastructure; and other factors. It is well known that the lack of PEV charging infrastructure is a barrier to PEV adoption.[11]

10. For comparison purposes, EEI and IEI made the following clarifying assumptions: (1) DC fast chargers are built to serve the needs of battery electric vehicle owners. (2) Level 1 chargers for home use—simple electrical outlets—are not included in the estimate. Only Level 2 charges are included.
11. See for example: NREL, *Consumer Convenience and the Availability of Retail Stations as a Market Barrier for Alternative Fuel Vehicles*, https://www.afdc.energy.gov/uploads/publication/56898.pdf

The costs of PEV infrastructure can vary widely, from a few hundred dollars to install a Level 2 charger at home, to tens of thousands of dollars to install a multi-port DC fast charging station. The cost includes the equipment itself, as well as the installation, permit, and inspection needed to get power to the charging station. Much of the PEV charging infrastructure to date has been paid for by the customer or entity that hosts the charging equipment (the "site host"), whether that is a homeowner, a commercial property owner, or a public entity. (See Appendix for examples.)

The current charging infrastructure at workplaces and in public locations is estimated to be between 50,000 to 70,000 predominantly Level 2 charge ports.[12] Based on the NREL and EPRI models, Figure 5 shows a need for more than 2 million charge ports in work and public locations by 2025. The significant difference between the current availability of charging infrastructure and the expected charging infrastructure needed suggests a growing "infrastructure gap" that will need to be addressed.

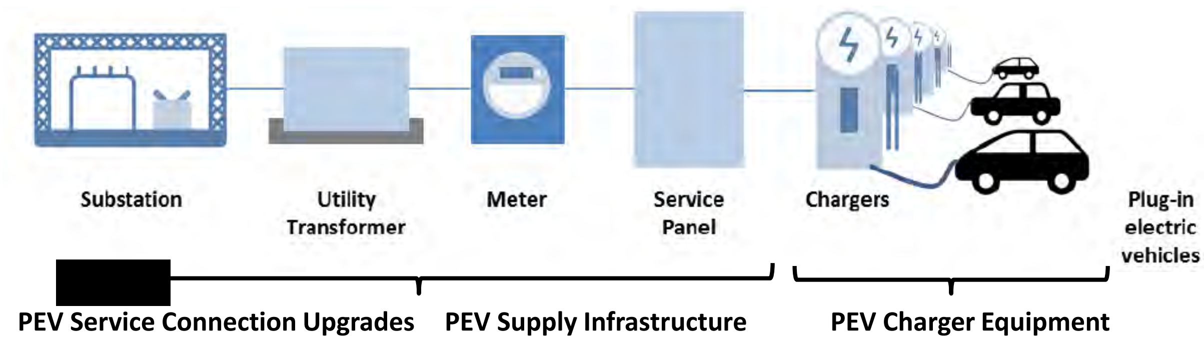
The PEV charging marketplace is evolving, and different approaches to providing the charging infrastructure for the PEV market are being tested.

Electric companies are well-positioned to help develop PEV charging infrastructure. Electric companies can support the development of PEV charging infrastructure and the smart integration of PEV charging load into the distribution grid in different ways, including:

- Developing "make-ready" grid infrastructure, which might include PEV service connection upgrades and new PEV supply infrastructure (see Figure 6);
- Owning and operating charging stations;
- Offering electric rates that incent PEV charging at specific times of the day (e.g., at off-peak times);
- Helping "site hosts" to connect with PEV charger equipment providers.

12. U.S. Department of Energy, Alternative Fuels Data Center.
http://www.afdc.energy.gov/fuels/stations_counts html
UBS Presentation, January 9, 2017.

Figure 6. Illustration of PEV Charging Infrastructure



Currently, electric companies in several states are engaged in PEV charging infrastructure development. In 2016, the California Public Utilities Commission approved PEV charging pilots for its regulated electric companies—Pacific Gas and Electric Company (PG&E), San Diego Gas & Electric (SDG&E), and Southern California Edison (SCE)—that will establish 12,500 new charging locations by 2020.

- PG&E will install "make ready" infrastructure, including PEV service connection upgrades and new PEV supply infrastructure for up to 7,500 Level 2 charge ports at multi-unit dwellings and workplaces. Multi-unit dwellings and installations in disadvantaged communities can choose to own the charging equipment or let PG&E own it (up to 35 percent of the chargers).

- SDG&E will install and own up to 3,500 Level 1 and Level 2 charge ports at multi-unit dwellings and workplaces, with a special rate that encourages off-peak charging.

- SCE will install "make ready" infrastructure including new PEV supply infrastructure for up to 1,500 Level 1 and Level 2 charge ports at workplaces, multi-unit dwellings, and other locations where vehicles are parked for extended periods of time.

In addition, electric companies in Georgia, Kansas, Missouri, and Washington State also are supporting the development of PEV charging infrastructure in the following ways:

- Avista is installing and owning 265 Level 2 charging stations in homes, workplaces, fleet yards, and multi-unit dwellings, as well as 7 DC fast chargers in Spokane.

- Georgia Power is installing and will own, operate and maintain more than 35 charging "islands" in public locations throughout Georgia, each consisting of a DC fast charger and a Level 2 charger, including both CHAdeMO and CCS combo connectors. However, the charging island at the new SunTrust Park (Atlanta Braves stadium) consists of one DC fast charger and eight dual port Level 2 charger.

- Kansas City Power & Light (KCP&L) is installing and owning approximately 1,000 Level 2 charging stations and 15 DC fast chargers in public locations in and around Kansas City as part of its Clean Charge Network. The first two years of the program provided free charging to PEV drivers who joined the Clean Charge Network.

Conclusion

With more than 7 million PEVs anticipated to be on the road in the United States by 2025, and every PEV owner expecting to be able to charge his or her car at home, on the street, at the office, at shopping malls, or along major highways, targeted deployment of charging infrastructure and coordinated collaboration among all stakeholders are required. Electric company participation in the development of PEV charging infrastructure supports state-level clean energy and transportation goals, expands customer choice, and helps to scale and ensure the availability of needed PEV charging infrastructure.

Appendix

A wide range of public and commercial funding has supported PEV charging infrastructure deployment to date. Table A-1 shows some of the major funding.

Table A-1. Examples of PEV Charging Infrastructure Funding Sources to Date

Funding Entity	Program	Description
Automakers	Tesla (2012-ongoing)	Deployed "SuperCharger" network of 2,400 DC fast chargers at 350 locations (net book value $215 million as of Q1 2017), and 3,900 "Destination Charging" L2 chargers at more than 2,000 public destinations.
	Automaker Funded Charging Networks (ongoing)	Includes Nissan and BMW partnership with EVgo to deploy nearly 300 DC fast chargers in 33 states; BMW and VW partnership with ChargePoint to install 100 DC fast chargers along coastal corridors.
	Electrify America (starting 2017)	VW subsidiary will invest $2 billion over 10 years on ZEV investments, the majority of which will fund PEV charging infrastructure, as part of the VW diesel settlement.
Electric Companies	Electric Company Programs (ongoing)	Electric company investment in EV charging infrastructure (rebates and/or capital investment in infrastructure); examples include Avista, Georgia Power, KCP&L, PG&E, SCE, and SDG&E.
Customers	Customer-funded (ongoing)	Customers pay for the installation and operation of PEV charging equipment at their own premises; some costs potentially offset by an electric company, automaker, state, or federal program.
State Governments	NRG Settlement (2012-ongoing)	$100 million settlement agreement, deploying 200 DC fast chargers and infrastructure for 10,000 L1 and L2 stations in public locations, workplaces and multi-unit dwellings.
	VW Settlement, Appendix D (starting 2017)	States may allocate up to 15 percent of their funds for EV charging infrastructure from the $2.7 billion Environmental Mitigation Trust as part of the VW diesel settlement.
	State Funding (ongoing)	30 states have programs (rebates, tax credits, and/or grants) that support EV charging deployment.
Federal Government	ARRA EV Project (2009-2013)	$115 million matching grant, deployed more than 12,500 L2 chargers in residential and public locations, at 110 DC fast chargers.
	ARRA ChargePoint America (2009-2013)	$15 million matching grant, deployed more than 4,600 L2 chargers in residential, private, and public locations.
	Federal Tax Credit (2007-2016)	Alternative Fuel Vehicle Refueling Property Credit applied to 30 percent of the cost of infrastructure, up to $30,000 for businesses and $1,000 for others.

About the Institute for Electric Innovation

The Institute for Electric Innovation focuses on advancing the adoption and application of new technologies that will strengthen and transform the energy grid. IEI's members are the investor-owned electric companies that represent about 70 percent of the U.S. electric power industry. The membership is committed to an affordable, reliable, secure, and clean energy future.

IEI promotes the sharing of information, ideas, and experiences among regulators, policy makers, technology companies, thought leaders, and the electric power industry. IEI also identifies policies that support the business case for the adoption of cost-effective technologies.

IEI is governed by a Management Committee of electric industry Chief Executive Officers. In addition, IEI has a Strategy Committee made up of senior electric industry executives and a select group of technology companies on its Technology Partner Roundtable.

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EEI is the association that represents all U.S. investor-owned electric companies. Our members provide electricity for 220 million Americans, and operate in all 50 states and the District of Columbia. As a whole, the electric power industry supports more than 7 million jobs in communities across the United States. In addition to our U.S. members, EEI has more than 60 international electric companies as International Members, and hundreds of industry suppliers and related organizations as Associate Members.

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1 electric car teardown, 6 pivotal questions, 39 UBS analysts providing answers

We tore down the Chevy Bolt, the world's first mass-market electric vehicle (EV) with a range well above 200 miles. We gained key insights to understanding the content and profitability of EVs, especially Tesla's upcoming Model 3. Our findings expand beyond the autos industry to include technology, capital goods, chemicals and commodities.

$4.6k cheaper than we thought – EVs to be profitable sooner, incl. Model 3

We found that the EV powertrain is $4.6k cheaper to produce than we thought and there is more cost reduction potential left. Consumer cost of ownership (TCO) parity vis-à-vis combustion engine (ICE) cars can be reached from 2018 (first in EU), creating an inflection point for demand. We raise our 2025E EV sales by ~50% to 14.2m, or 14% of global car sales. We estimate GM loses $7.4k (EBIT) with every Bolt sold today, mainly due to the lack of scale. Because of many similarities between the Bolt and Tesla's long-awaited Model 3, we estimate Tesla incurs an EBIT loss of $2.8k per vehicle in its base version, but will break even at an ASP of $41k – a level most likely to be exceeded. We generally expect the profitability of premium EVs to be higher than in the mass segment. Once TCO parity is reached, mass-brand EVs should also turn profitable.

Widespread impact on auto sector, technology, chemicals, cap goods and more

For OEMs, earlier cost parity means earlier and more visible returns on the current high R&D. Furthermore, the contribution of EVs to CO_2 fleet targets, particularly in Europe, will remove a key cost burden. For our tier-1 supplier coverage, the teardown delivered two takeaways: (1) LG, a new entrant in automotive, has ~56% content in the Chevy Bolt, whereas "traditional" tier-1 suppliers only exist outside the electric powertrain. (2) Our detailed analysis of moving and wearing parts has shown that the highly lucrative spare parts business should shrink by ~60% in the end-game of a 100%-EV world, which is decades away. EVs are an opportunity for tech companies because the electronics content in the Bolt is $4k higher than in an ICE car, excluding the battery. Commodities-wise, we detected the highest deviation in weight shares between the Bolt and ICE car in copper, aluminium, battery active materials and rare earths.

Stocks positively and negatively impacted by the theme

A comprehensive list of stocks positively or negatively impacted in autos (OEMs and suppliers), chemicals, batteries, tech, and capital goods can be found on page 59.

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Executive summary

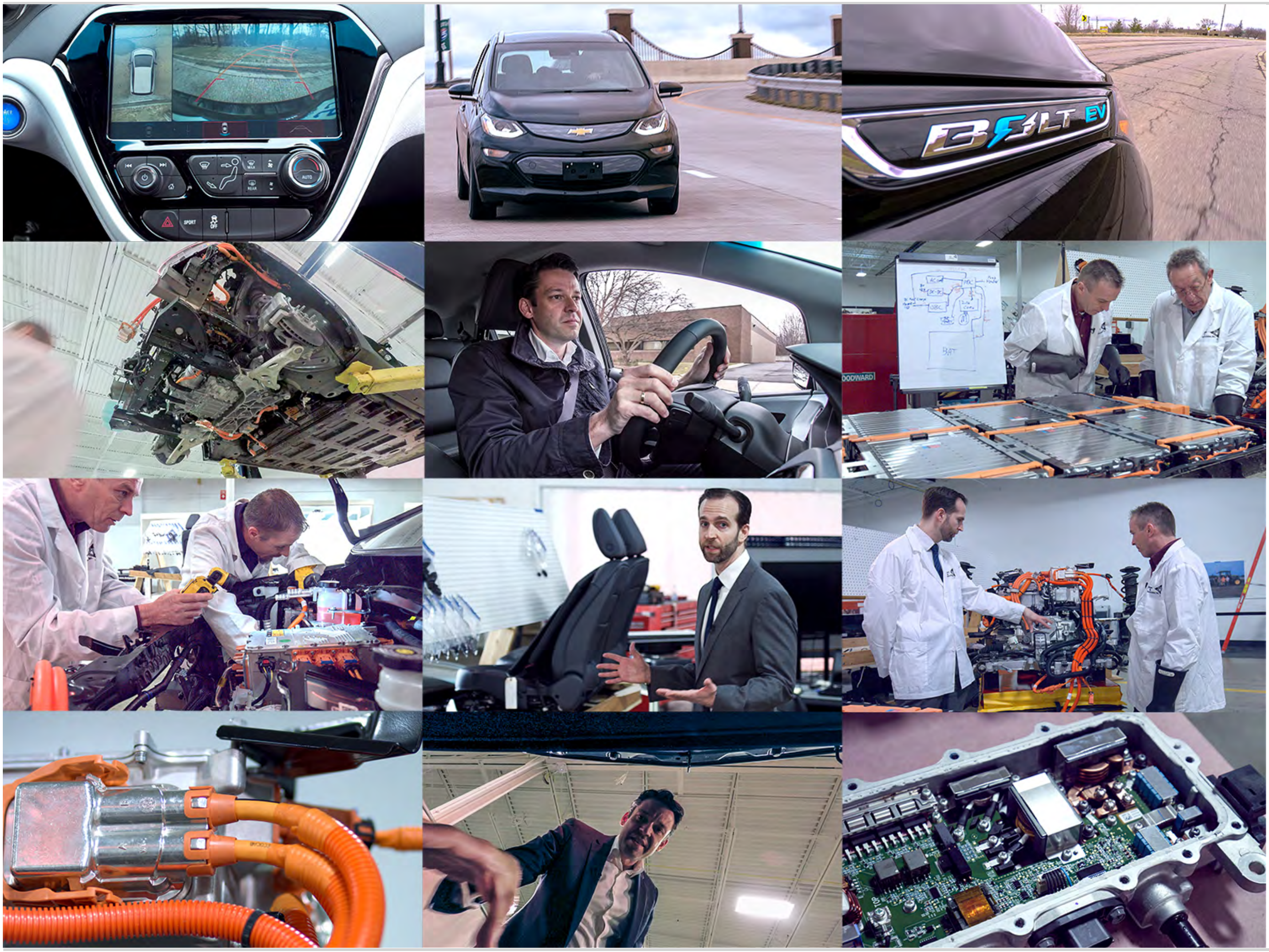
Tearing down the world's first mass-market electric car

We are more convinced than ever that electric cars are about to reach the tipping point in the penetration curve in the next few years. This new generation of electric cars has far-reaching implications for the global autos industry, but also for many other sectors, such as capital goods, chemicals, mining, technology, and energy. The only way to better understand these implications was to tear down the first vehicle of its kind, piece by piece. So, that is what we did. We tore down the Chevrolet Bolt, which we consider the world's first *real* mass-segment electric vehicle (EV). The Bolt combines a $37k price tag ($30k including US government subsidies) with an EPA-estimated range of 238 miles on a single charge, which surpasses competitors by at least 30% in this price segment. Moreover, the Bolt has a price tag and range similar to the upcoming Tesla Model 3, which is Tesla's long-awaited entry into the mass market.

238-mile range

$37k price tag

Figure 1: UBS Research and UBS Evidence Lab have gone the extra mile



Source: UBS

UBS's Q-Series products reflect our effort to aggressively anticipate and answer key investment questions, to help drive better investment recommendations. Q-Series is a trademark of UBS AG.

Figure 2: Pivotal questions we can answer thanks to the teardown

Pivotal questions	Our answers	For details …
Q: When will EVs reach consumer cost parity, and what will be the impact on EV sales?	- Europe is first in 2018E but still at a loss for the OEMs; true cost parity (5% OEM margin) is reached in 2023E. - Raising forecasts by ~50% to 14% global sales penetration (30% in Europe) by 2025E.	*Click here*
Q: What is different in an EV like the Chevy Bolt, compared to an equivalent ICE car?	- Much less mechanical complexity, far fewer moving and wearing parts. - EV powertrain $9k more expensive today, going down to $4k by 2025E.	*Click here*
Q: How profitable are EVs like the Bolt and the upcoming Tesla Model 3?	- Bolt: $7k EBIT loss per car 2017E, going to $6k profit in 2025E, holding price stable. - Tesla Model 3: $2,800 loss per car today on base version, but well-equipped versions should be profitable. We estimate $41k is the break-even point.	*Click here*
Q: What is the impact on the auto industry?	- OEMs: EVs become profitable sooner; more CO_2 benefit, particularly for EU OEMs. Finco risk is the key downside. - LG as a new entrant has ~56% content share in the Bolt. - Mixed picture for "traditional" tier-1 suppliers and long-term threat in aftermarket.	*Click here*
Q: How are global commodities markets influenced by the shift to EVs?	- Highest impact on markets for aluminium, copper, battery active materials, rare earths (all positive) and platinum group metals (negative). - Largely no impact on steel demand.	*Click here*
Q: How much more electronics and semi content is in an EV, and who is set to benefit?	- $3k more electr(on)ic content (ex battery). - EV powertrain contains c$580 of semiconductor content compared to an ICE car at $60-90. - Electronics powerhouses and semi suppliers likely to grab substantial market share. - Shift to EVs is one of the two structural trends driving up semi content (along with autonomous driving). Autos to be one of the fastest-growing markets for semis.	*Click here*

Source: UBS estimates

Note: This Q-Series focuses on the differences between an EV and ICE car. Stay tuned for further teardown research about tech content outside the powertrain.

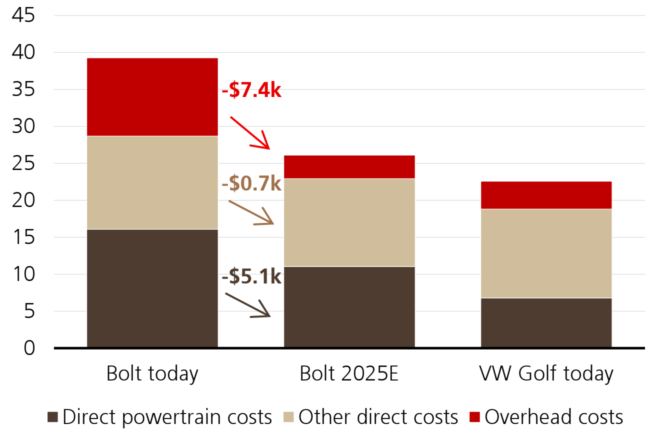
Q: When will EVs reach consumer cost parity, and what will be the impact on EV sales?

- **Surprise finding #1:** In the Bolt's powertrain, costs are $3k lower for the battery and $2k lower for the other modules versus our previous expectations. This means TCO parity between EVs and ICE is reached 2-3 years earlier.
- The battery pack, which is the largest cost item in the Bolt, is likely to become 36% cheaper by 2025E, from ~$12.5k today to ~$8.0k. Therefore, the cost difference (not the retail price difference) between the Bolt and the VW Golf, which we consider an equivalent ICE car, appears set to shrink to $2.3k.
- On a total cost-of-ownership basis (TCO), which also factors in the Bolt's lower energy and maintenance costs (the latter is even lower than we thought), *true* TCO parity (*true* meaning the OEM makes a 5% EBIT margin) should be reached in Europe in 2023E, and in China in 2026E ex subsidies, 2-3 years earlier than previously expected.

$5k cheaper

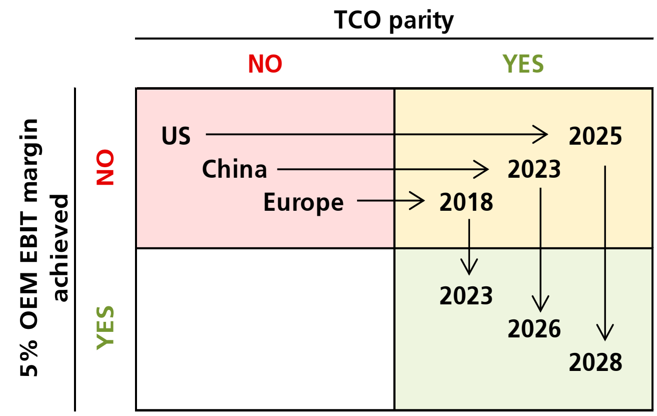
TCO parity 2-3 years earlier

Figure 3: Cost breakdown ($ per car) – Bolt versus Golf



Source: UBS estimates

Figure 4: TCO analysis

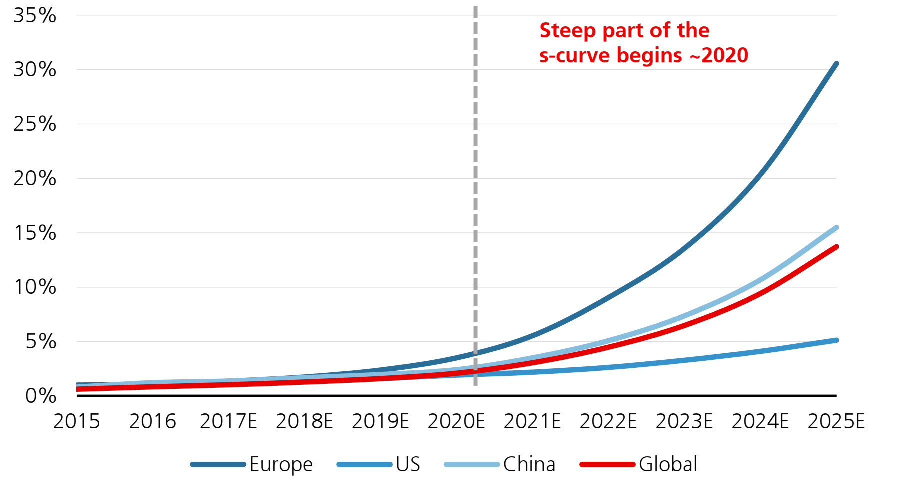


Source: UBS estimates

As a consequence of earlier-than-expected cost parity, we raise our EV sales penetration forecasts. We now forecast 3.1m EVs sold in 2021E (battery-electric cars and plug-in hybrids) and 14.2m sold in 2025E, instead of 2.5m and 9.7m previously. In our updated global market model, the share of EVs in global annual new car sales is now 3% in 2021E and 14% in 2025E. The difference with our old forecast mainly stems from Europe, where we now expect 30% EV sales in the mix in 2025E. While the new numbers appear aggressive at first glance, they are in sync with the findings from our ~10k consumer-strong UBS Evidence Lab survey and are not contradicted by availability of battery raw materials and required investments in electricity infrastructure. We have also raised our forecasts for Japan and the US, albeit from a low base. The US is likely to lag due to worse consumer economics (lower fuel prices). We see upside risk to our US forecasts in the event of a return to a more benign political environment at the federal level or rapidly rising gasoline prices.

Electric car sales: 30% in Europe 14% globally in 2025E

Figure 5: Raising our global EV forecasts – steep part of s-curve getting closer



Source: UBS estimates

Q: What is different in the Chevy Bolt, compared to an equivalent combustion engine car?

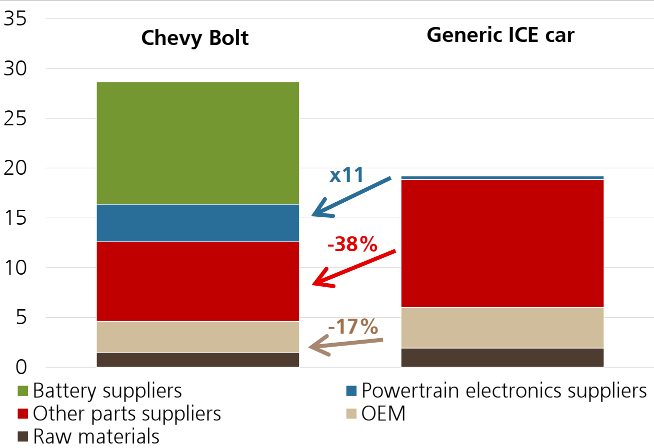
- **Surprise finding #2:** Some 56% of the vehicle content comes from outside the traditional auto supply chain.
- By value created, the share of tier-1 suppliers from outside the traditional auto supply chain reaches a remarkable ~56% (14% excluding the battery). In the case of the Bolt, the entire electric powertrain and infotainment modules are supplied by LG. This comes at the expense of "traditional" tier-1 suppliers.
- Mechanical complexity is much lower, whereas electronic complexity is higher. We counted 24 moving parts in the Bolt's powertrain, versus 149 in the Golf. The powertrain electronics content is $4k higher on the tier-1 level, motor included.

56% LG content

24 versus 149 moving parts

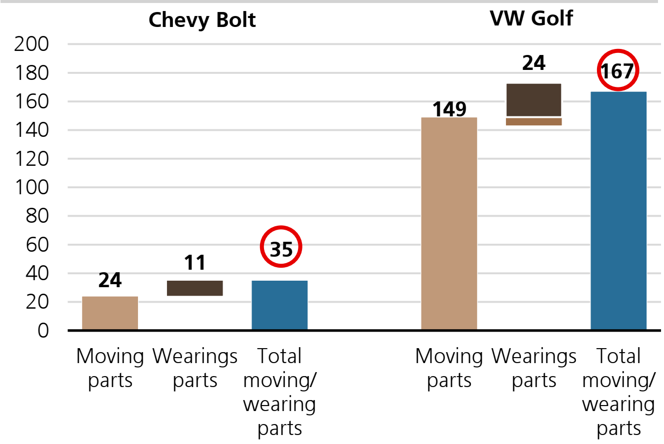
+$4k electronics

Figure 6: Vehicle content on tier-1 level by sub-sector ($k)



Source: UBS estimates

Figure 7: Number of parts in the powertrain



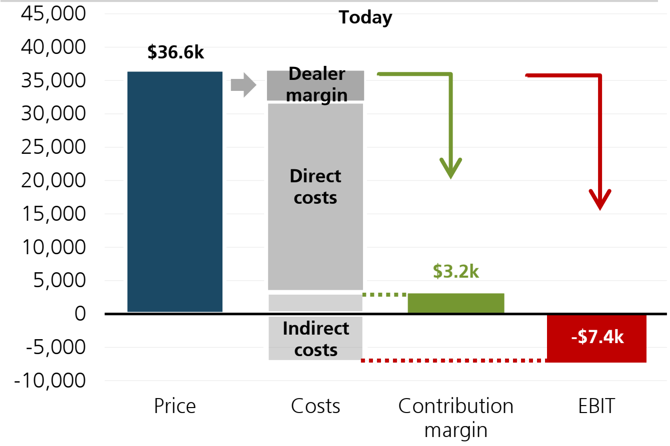
Source: UBS estimates

Q: How profitable are EVs like the Bolt and the upcoming Tesla Model 3?

- **Surprise finding #3:** The Model 3 will require an ASP of ~$41k to break even, on our calculations. This is only ~$6k above the expected base price, and very likely to be exceeded.

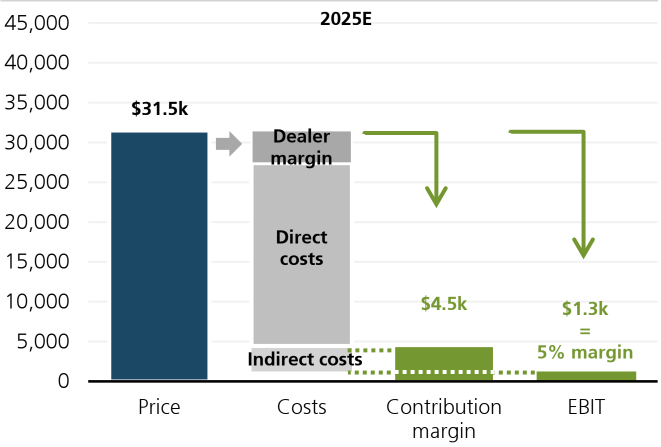
- We estimate that GM loses ~7$k per vehicle at the EBIT level, but the contribution margin (selling price less variable production costs) is in positive territory at ~$3k. Based on our component costs forecasts, the EBIT per vehicle can improve to $1.3k (5% EBIT margin) by 2025E, assuming that the lion's share of the cost savings need to be passed on to the consumer in order to reach TCO parity.

Figure 8: How much money does GM lose with a Bolt today (EBIT/contribution margin in $)...



Source: UBS estimates

Figure 9: ...and how will it evolve until 2025E?

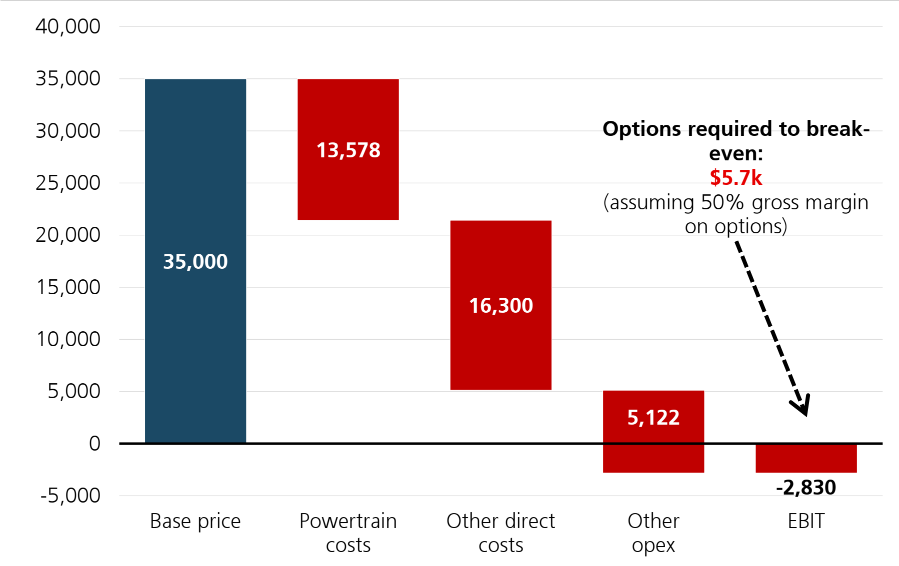


Source: UBS estimates

- The findings on the Bolt enable us to assess the profitability of the long-awaited Model 3, Tesla's entry into the mass segment. We estimate that Tesla will require an achieved selling price of ~$41k for the upcoming Model 3 to break even at the EBIT level. This is ~$6k above the estimated base price of $35k. As Tesla buyers are likely to order well-equipped versions (margins on the options should be ~50%), the required ~$41k threshold is likely to be well exceeded, in our view.

$41k break-even price for Model 3

Figure 10: What will be the break-even selling price ($) for the Tesla Model 3?



Source: UBS estimates

Q: What is the impact on the auto industry?

- **Surprise finding #4:** The transition to EVs could be better than feared for OEMs from a return and CO_2 cost perspective, but there are potentially more risks for "traditional" tier-1 suppliers. This is contrary to the consensual view that suppliers are better positioned to master the transition to EVs.

EVs profitable sooner

- **OEMs:** EV manufacturing costs are likely to be lower than previously expected, which means: (1) profitability for OEMs can be better; and (2) volumes can grow faster, leading to better economies of scale and a faster return on current high investments. The positive contribution of EVs to CO_2 fleet targets, in particular in Europe, is another key positive. The flipside is elevated residual value risk for OEMs with own fincos, as well as lower contribution from the highly profitable aftermarket (10-15% of EBIT today).

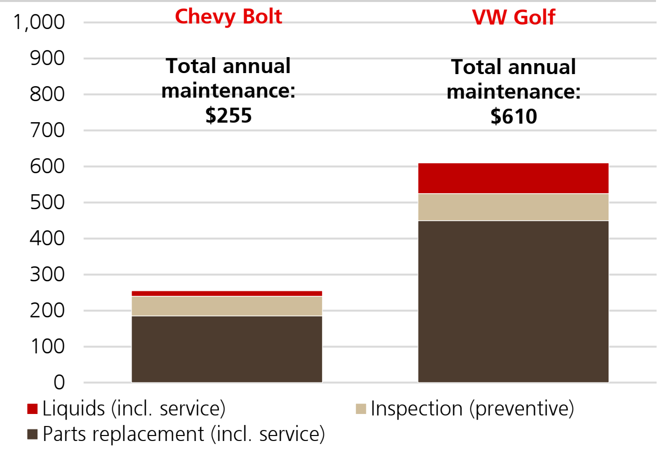
Threat of new entrants

- **"Traditional" tier-1 suppliers:** Better EV economics and higher growth induces better and earlier returns on high current EV-related investments. However, the content per vehicle will likely decline due to the higher content share of non-traditional suppliers (but there will be a large variance among individual players). Some suppliers will have to write down some divisions or product lines, mostly related to emissions. Also, revenues from the lucrative spare parts business, which accounts for ~20% of EBIT, are likely to drop by ~60% in the long term in an EV world. However, this scenario is several decades away. We expect more M&A activity in the supplier space.

~60% decline in aftermarket

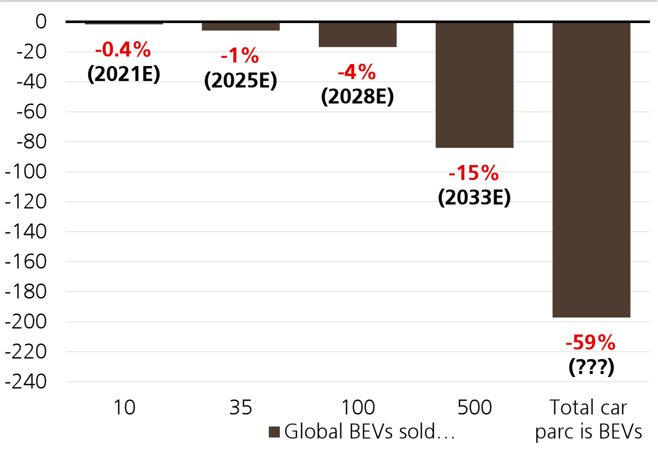
- **Aftermarket:** The Bolt is almost maintenance-free. Not only do fewer parts need to be replaced over the car's life, it also does not require a regular change of fluids, such as engine oil. On our analysis, the after-sales revenue pool could drop by ~60% or >$400 per vehicle per year. This should pose a major challenge for dealerships, which typically generate >40% of their gross profit pool in service and maintenance.

Figure 11: The Bolt has ~60% lower after-sales costs ($)



Source: UBS estimates

Figure 12: Aftermarket revenues ($bn) to drop by ~60%



Source: UBS estimates

Q: How are global commodity markets influenced by the shift to EVs?

- **Surprise finding #5:** The Bolt's body and chassis are fairly conventional in terms of the commodities used. It has, however, a 70% higher aluminium content (we expect an even higher aluminium share in premium EVs). We have not found any carbon fibre-reinforced polymers. The Bolt's total weight is 22%

higher than that of the VW Golf, mainly due to the battery. The key differences between the Bolt and the Golf are the following:

Less steel, more aluminium

- **Steel, aluminium, copper:** There is 7% less steel in the Bolt, but meaningfully more aluminium and copper. If all passenger vehicles sold were electric, the incremental decline in steel demand would be marginal in the context of the global steel market, while aluminium demand would increase by 13% and copper demand by 21%, compared to today's market size (based on the Bolt).

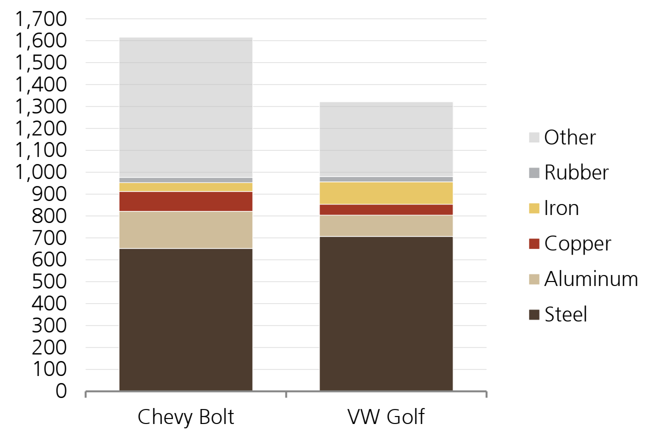
Battery materials boom

- **Battery active materials:** Commodity markets in the lithium battery supply chain would be most disrupted by a rapid increase in EV penetration, in particular lithium, cobalt and graphite. But only cobalt faces the issue of limited reserves, whereas for the other materials, current production capacity is the only bottleneck. New cell generations, however, will use less cobalt.

Neodymium, platinum

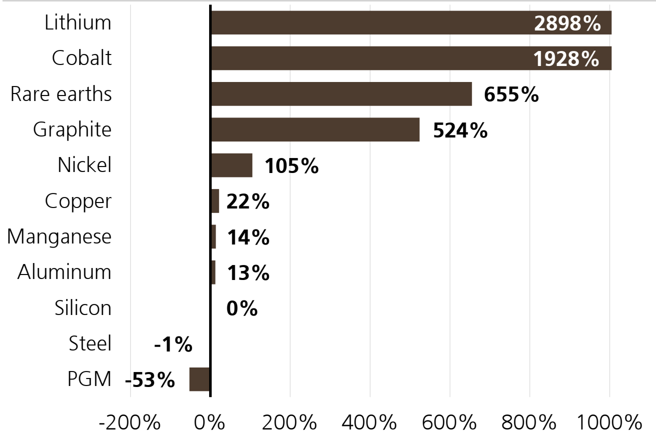
- **Rare earths, other:** The market for rare earths, neodymium in particular, could face demand shocks in case of a rapidly evolving EV market. The material is used in the e-motor magnets. There is only one obvious loser among global commodities in a 100% EV world: platinum group metals, which are used in ICE emission treatment solutions.

Figure 13: Weight of key commodities – Bolt versus Golf



Source: UBS estimates

Figure 14: Incremental commodity demand in a 100% EV world (% of today's global production)



Source: UBS estimates

Q: How much more electronics and semi content is in an EV, and who is set to benefit?

6-10x more semi content

- **Surprise finding #6:** We estimate that the Bolt EV powertrain has $580 semiconductor content, or 6-10x more than an average equivalent ICE car, such as the VW Golf.
- We estimate that, in an ICE, the powertrain electronics can range from as much as $60 to $90, implying a significant step-up, even for a relatively low-end mass-market EV. At this point, we are only focusing on the powertrain; however, we did also tear down the infotainment/connectivity/ADAS components, which will be analysed in separate research.

Summarizing the impact by sector

EVs will have a strong fundamental impact on many sectors. UBS global sector teams have contributed their analysis based on the findings from the teardown. Further, they have highlighted the stocks most positively or negatively exposed.

Figure 15: Sector map – impact from EVs at a glance

EV impact on …	Revenue growth	EBIT margin	ROIC	Valuation	Sector impact & UBS positively/negatively impacted by the theme
Auto OEMs	→	↘	→	→	**Sector impact:** Better EV profitability, CO_2 tailwinds, more Finco risk **Positively impacted:** Daimler, Volkswagen, Renault, GM **Negatively impacted:** FCA, PSA, Subaru
Auto suppliers	→	↘	↘	→	**Sector impact:** Top line impact varies, risk of content loss to new entrants, aftermarket risk **Positively impacted:** Valeo, Delphi, Conti, Hyundai Mobis **Negatively impacted:** Schaeffler, Faurecia, Tenneco
Battery producers	↗	↗	→	→	**Sector impact:** Strong top-line growth to drive EBIT break-even in 2018/19 **Positively impacted:** LG Chem, Samsung SDI **Positively impacted but priced in:** Panasonic
Capital goods	Varies widely by company				**Sector impact:** Mixed. Auto capex winners but some players lose content (bearings) **Positively impacted:** Siemens, Atlas Copco, Hexagon, GKN **Negatively impacted:** SKF, Rheinmetall, Sandvik, Kennametal
Chemicals	→	→	↘	→	**Sector impact:** EV winners in battery value chain; ICE losers (catalyst materials) **Positively impacted:** Umicore, LG Chem, Asahi Kasei, Sumitomo Chem, Albemarle, Sika **Negatively impacted:** Johnson Matthey, BASF, Clariant, EMS Chemie
LG companies	↗	→	→	→	**Sector impact:** 56% content in the Bolt from LG Group as automotive new entrant **Positively impacted:** LG Chem, LG Display **Positively impacted but priced in:** LG Electronics
Commodities	↗	↗	→	↗	**Sector impact:** Positive for most commodities **Positively impacted:** Lithium, cobalt, graphite, nickel, rare earths **Negatively impacted:** Platinum and palladium
Semiconductors	↗	↗	↗	→	**Sector impact:** Electric and autonomous cars as a key growth driver **Positively impacted:** Most autos semis – we favour Infineon, Texas Instruments **Positively impacted but priced in:** Melexis, STMicro

Source: UBS estimates

* *UBS Evidence Lab provides our research analysts with rigorous primary research. The team conducts representative surveys of key sector decision-makers, mines the Internet, systematically collects observable data, and pulls information from other innovative sources. It applies a variety of advanced analytic techniques to derive insights from the data collected. This valuable resource supplies UBS analysts with differentiated information to support their forecasts and recommendations—in turn enhancing our ability to serve the needs of our clients.*

For this report, UBS Evidence Lab entered an exclusive partnership with Munro & Associates. The Auburn Hills, Michigan based firm is specialized in teardown benchmarking and accurate costing in the automotive industry. The project included a teardown of all electric powertrain-related parts and components – in essence, everything that's different compared to a combustion engine car. Furthermore, Munro tore down the modules related to connectivity / HMI and ADAS (advanced driver assistance systems).

The Munro cost estimates reflect the cost an automaker would pay a supplier. Generally, these costs are calculated by estimating the raw material costs, the amortization of parts tooling, and estimating labour costs and applying an industry standard mark-up for supplier overhead and profit. To create its estimates, Munro looks for numerous variables, including materials and material comparisons, process, machinery, tooling, labour (modelled by region of production), geography, competition, and logistics.

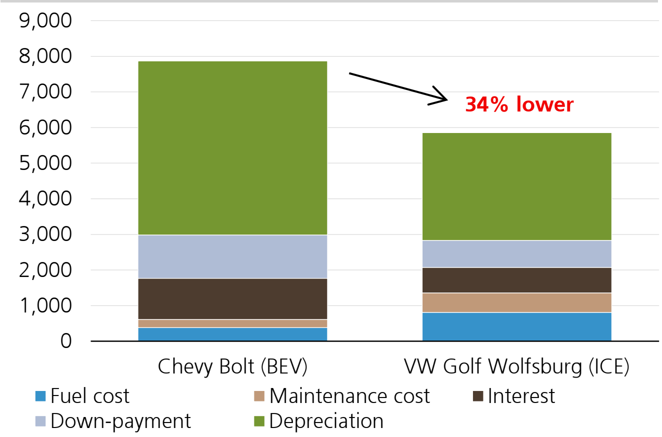
We would like to thank the Munro team for its excellent collaboration and enthusiasm throughout the project.

Q: When will EVs reach consumer cost parity, and what's the impact on sales?

TCO parity already almost reached in Europe today

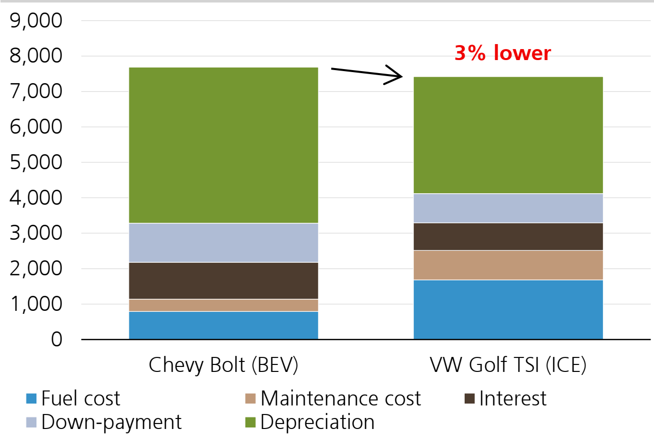
Because of lower vehicle component and also maintenance costs than previously expected, total cost of ownership (TCO) parity to consumers between EVs and ICE cars is reached earlier than modelled in last year's Q-Series *What is the Powertrain of the Future?*. The charts below illustrate cost of ownership today in the US and Europe. It can be seen that thanks to higher fuel prices, TCO parity in Europe has almost been reached already today, whereas the Golf is significantly cheaper in the US. The detailed assumptions and maths are shown in the appendix of this report.

Figure 16: TCO analysis Bolt vs. Golf – US (2017 - $)



Source: UBS estimates

Figure 17: TCO analysis Bolt vs. Golf – Europe (2017 - €)

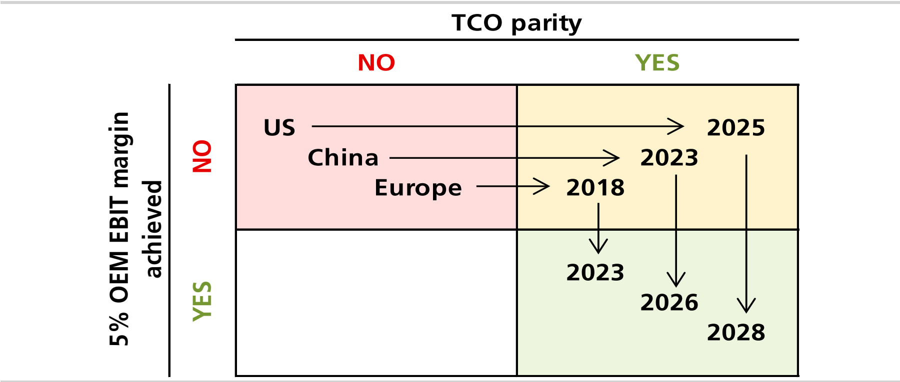


Source: UBS estimates

In the next few years, most if not all cost savings will need to be passed on to consumers until consumer TCO parity is reached. TCO parity occurs first in Europe in 2018E, then in China in 2023E, and in the US in 2025E, excluding any EV purchase incentives or other subsidies. The *true* cost parity, by when the OEM makes money with an EV, is a few more years out. Assuming that TCO parity is achieved, further savings will end up in the OEM's pocket until a 5% EBIT margin level is reached (which we consider a normal over-the-cycle margin for this vehicle type). Such an EBIT margin level should be met in Europe in 2023E and in China in 2026E. However, it would take ~10 years to achieve such a profitability level in the US, unless fuel prices surge or EV subsidies continue to exist for such a long period.

***True* cost parity to be reached by 2023E in Europe and 2026E in China**

Figure 18: TCO parity matrix – Chevy Bolt vs. VW Golf by region



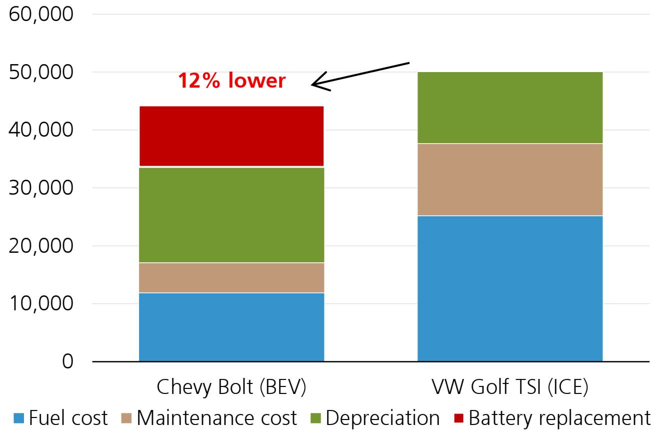
Source: UBS estimates

Note: The TCO analysis is based on a 3-year lease (longer periods lead to better EV economics due to energy/maintenance cost advantage), annual mileage of 9,000 miles and 50% residual value after 3 years. See the detailed maths in the appendix.

What if the battery needs to be replaced during the life of the vehicle? This is not our base case, because user data of latest-generation EVs show limited battery degradation even after 150k miles (240k km). Nonetheless, we alternatively look at the TCO over the life of the vehicle (150k miles driven) assuming one battery replacement. It can be seen that in spite of high costs of the battery replacement (UBSe: $11,700 at 2025 costs – includes ~100% aftermarket surcharge), TCO for the EV vis-à-vis the ICE car become even better. This is because the energy cost advantage of EVs plays out over a longer time period. Residual value risk is removed if the vehicle is owned for 15 years. Also, we would highlight that there is a significant chance of gearbox or engine failure in the ICE car over the vehicle's life, which is *not* included in our analysis.

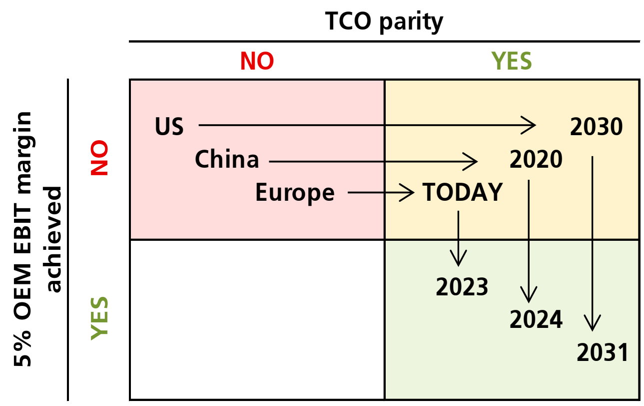
Comparing TCO over vehicle lifetime improves the EV economics, even with battery replacement

Figure 19: Stress test – 15-year lifecycle TCO if battery needs replacement (Europe, €) at 2017 vehicle price and 2025 battery replacement costs



Source: UBS estimates

Figure 20: Stress test – TCO parity matrix (15-year lifecycle, including battery replacement in 2025)



Source: UBS estimates

14% global EV penetration in 2025; 30% in Europe

TCO parity is the main prerequisite for rising EV sales. As TCO parity can be reached earlier than we anticipated previously, we are raising our global EV sales forecasts. We believe that extrapolating near-term trends results in a drastic under-estimation of what will happen to the powertrain mix once the TCO inflection point has been reached. We expect the steep part of the penetration s-curve to begin ~2020, with Europe and China leading. Our forecasts include plug-in hybrids (PHEVs). We assume that in 2017, about 40% of all EVs sold will be PHEVs and 60% battery-electric (BEVs). Over time, as BEVs become more competitive vis-à-vis PHEVs, we expect the PHEV share to drop below 20% by 2025.

We raise our EV penetration forecasts ~50% to 14% globally and 30% in Europe in 2025

In our updated base case scenario, we expect 14.2m EVs to be sold in 2025. This represents 13.7% of global car sales by then. We previously assumed only 9.7m EV sales or 9% of total car sales. The main difference to our old forecast is the higher penetration in Europe, where EV economics appear even more favourable after 2020. In Europe, we now expect an EV share of 30% in 2025, up from 1% today. But we have also raised our estimates for Japan and the US, albeit from a very low base. Estimates for China remain broadly unchanged. With a 2025E view, we remain ~45% below the government target of 8.8m new-energy vehicles (25% BEV and PHEV out of 35m new car sales), mainly due to unclear political support medium-term.

Our raised forecasts for Europe may appear very aggressive at first glance, but:

- EVs are likely to replace **diesel** cars, which currently have ~45% share in Europe. Cost of ownership is a key (yet fading) argument in favour of diesel in Europe – and this is exactly what should play out in favour of EVs after 2020. We expect the European diesel share to drop to ~7% by then. Political action is taken against diesel cars in some major European cities, including driving bans on days with high pollution. This political debate also bodes well for EVs.

- EVs will become the cheapest option for OEMs to meet **post-2020 CO_2 targets in Europe**. Therefore, marketing and consumer education, as well as investments into charging infrastructure, are likely to intensify.

- Findings from our recent **UBS Evidence Lab survey** (~10k participants, 6 largest car markets) about price, cost and range expectations for EVs support our thesis that EVs can become mainstream in the next few years.

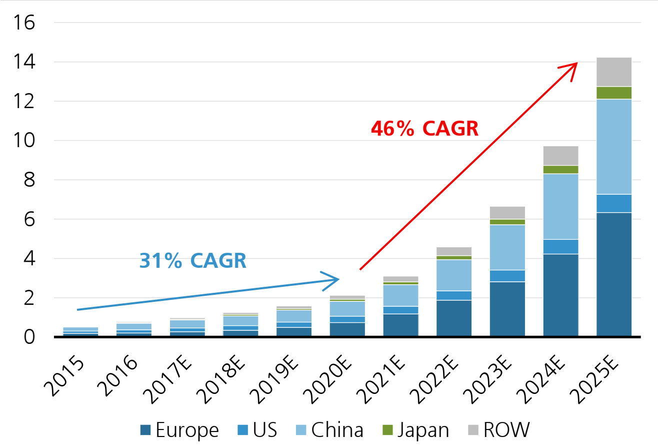
Our near-term estimates between now and 2020 are broadly unchanged on a global basis.

Figure 21: UBS EV forecast by region ('000 units)

EV sales (BEV + PHEV)	2015	2016	2017E	2018E	2019E	2020E	2021E	2022E	2023E	2024E	2025E
Europe	186	207	269	349	489	733	1,173	1,877	2,815	4,223	6,335
growth y/y		*11%*	*30%*	*30%*	*40%*	*55%*	*60%*	*60%*	*50%*	*50%*	*50%*
% of new car sales	*1.0%*	*1.1%*	*1.4%*	*1.7%*	*2.4%*	*3.5%*	*5.5%*	*9.1%*	*13.6%*	*20.4%*	*30.6%*
US	116	159	191	229	275	330	396	475	594	742	928
growth y/y		*37%*	*20%*	*20%*	*20%*	*20%*	*20%*	*20%*	*25%*	*25%*	*25%*
% of new car sales	*0.7%*	*0.9%*	*1.1%*	*1.3%*	*1.6%*	*1.9%*	*2.2%*	*2.6%*	*3.3%*	*4.1%*	*5.1%*
China	206	336	403	504	605	756	1,096	1,589	2,305	3,342	4,846
growth y/y		*63%*	*20%*	*25%*	*20%*	*25%*	*45%*	*45%*	*45%*	*45%*	*45%*
% of new car sales	*0.8%*	*1.2%*	*1.4%*	*1.7%*	*2.0%*	*2.4%*	*3.5%*	*5.1%*	*7.4%*	*10.7%*	*15.5%*
Japan	25	25	47	66	80	103	145	203	284	426	638
growth y/y		*-2%*	*90%*	*40%*	*20%*	*30%*	*40%*	*40%*	*40%*	*50%*	*50%*
% of new car sales	*0.5%*	*0.5%*	*1.0%*	*1.4%*	*1.7%*	*2.2%*	*3.0%*	*4.2%*	*5.9%*	*8.9%*	*13.3%*
ROW	15	51	71	100	140	195	293	440	659	989	1,484
growth y/y		*239%*	*40%*	*40%*	*40%*	*40%*	*50%*	*50%*	*50%*	*50%*	*50%*
% of new car sales	*0.1%*	*0.2%*	*0.3%*	*0.4%*	*0.5%*	*0.7%*	*1.1%*	*1.6%*	*2.4%*	*3.5%*	*5.2%*
Total	549	777	981	1,248	1,588	2,118	3,103	4,584	6,657	9,722	14,230
% of global PV sales	*0.6%*	*0.8%*	*1.0%*	*1.3%*	*1.6%*	*2.1%*	*3.1%*	*4.5%*	*6.5%*	*9.4%*	*13.7%*

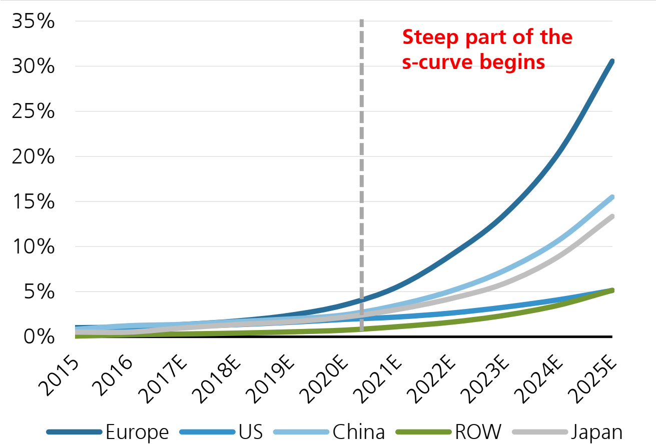
Source: UBS; IHS, ACEA, CAAM, Fourin, EV-Sales, Inside-Evs of historical figures

Figure 22: EV sales by region (m units)



Source: UBS estimates

Figure 23: EV share by region (% of total car sales)



Source: UBS estimates

We also run upside and downside scenarios for EV penetration.

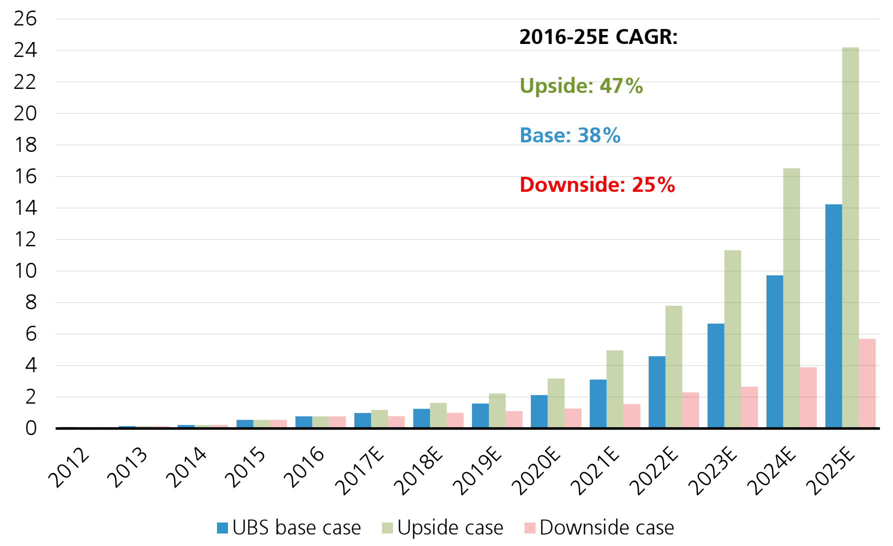
- **Upside scenario:** We forecast 24.2m EVs sold in 2025, or 23% of global car sales. This would imply that EVs become the dominant powertrain in Europe and China by then – a scenario that would most likely only materialize with sustained strong political support and rising fuel prices. Why not even higher? Because cost parity in the US is highly unlikely to be reached before 2025 without subsidies, EV economics in EM are still inferior to ICE cars, and CO_2 regulation is of subordinated importance. Also, battery production capacity and the number of charge points need to grow at the same pace to support such high EV sales growth, which may represent potential bottlenecks in some regions.

Upside: 23% EV penetration by 2025E

- **Downside scenario:** We forecast 5.7m EVs sold in 2025, or 5.5% of global car sales. This scenario discounts a low-to-zero political support level, sustained low gasoline prices and a slower-than-expected consumer response to EVs (TCO concept is not well understood as consumers are focused on vehicle selling prices only).

Downside: 5.5% EV penetration by 2025E

Figure 24: UBS base, upside and downside EV penetration scenarios (m units)



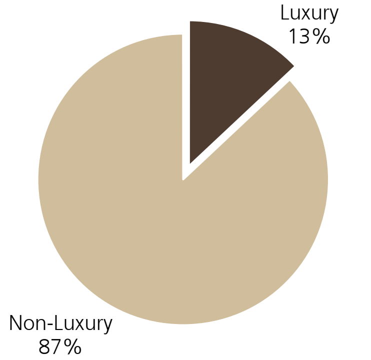
Source: UBS estimates

Why we still remain relatively cautious about EVs in the US

With low gas prices and likely easing fuel economy regulations, the economics of pure EVs remains challenging. There also remain challenges around infrastructure and significant uncertainty around consumer behaviour. However, the economics are more compelling in luxury as the luxury powertrain is more costly and luxury customers are willing to pay a premium for the rapid acceleration, quietness, and avoidance of gas stations as part of their daily routines. That said, the range limitation and longer charging times may imply EVs will be an ideal second car with an ICE available for longer trips. With ~13% of industry sales in luxury, this would imply ~40% of luxury sales will be EVs by 2025E. This is very consistent with expected EV launches from Mercedes, Audi, Porsche, and BMW.

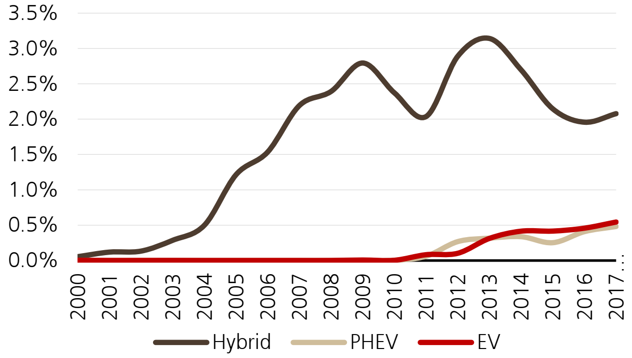
Low gas prices challenge EV economics in the US

Figure 25: US Luxury Mix 2016



Source: Wards

Figure 26: Hybrid, PHEV, and EV Mix



Source: Wards

Stress-testing our forecasts

We have sanity-checked our new forecasts against the following:

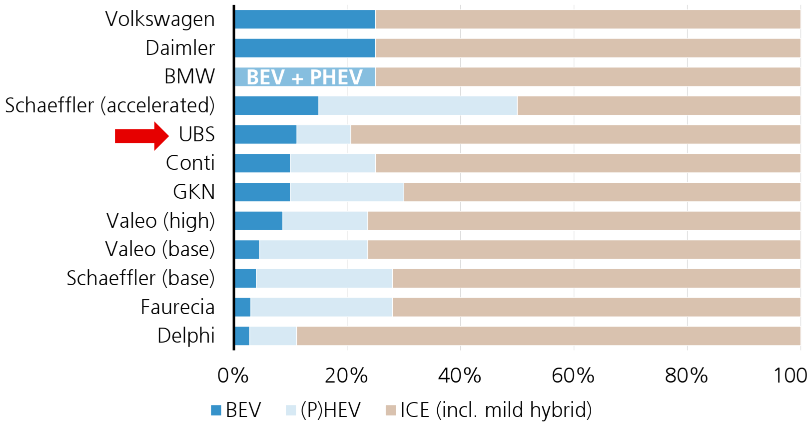
- EV sales and production forecasts of **major OEMs and tier-1 suppliers**
- Availability of **battery raw materials and cell production capacity**
- Availability of charging and power generation infrastructure, particularly in **Europe**
- Findings from our recent **UBS Evidence Lab survey** (~10k participants, 6 largest car markets) about stance towards EVs

What are OEMs and key suppliers saying about the powertrain mix?

OEMs EV targets are already above our forecasts; suppliers are turning more optimistic

OEMs and suppliers have dramatically increased their EV targets over the past 12 months. Volkswagen, the world's largest carmaker, now believes it will have 20-25% battery-electric vehicles in its sales mix in 2025 (excluding plug-in hybrids), and Daimler expects 15-25% BEVs in its mix – both are well above our estimates. Leading suppliers, such as Continental, are also turning more optimistic on EVs. These announcements go hand in hand with rising R&D and capex budgets that facilitate these new targets. We don't believe that powertrain and vehicle assembly capacity will be a bottleneck, because to a large degree, existing capacities will be upgraded or re-tooled to produce EVs in the same plants as today.

Figure 27: 2025 powertrain mix forecasts (suppliers, UBS) and targets (OEMs)

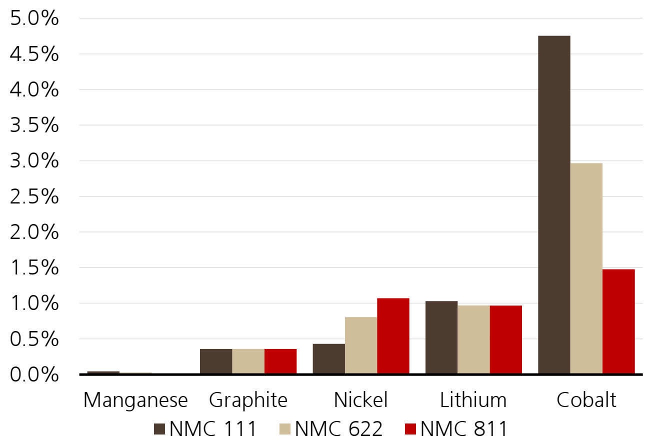


Source: Company disclosures, UBS estimates

Battery raw mats availability and cell production capacity

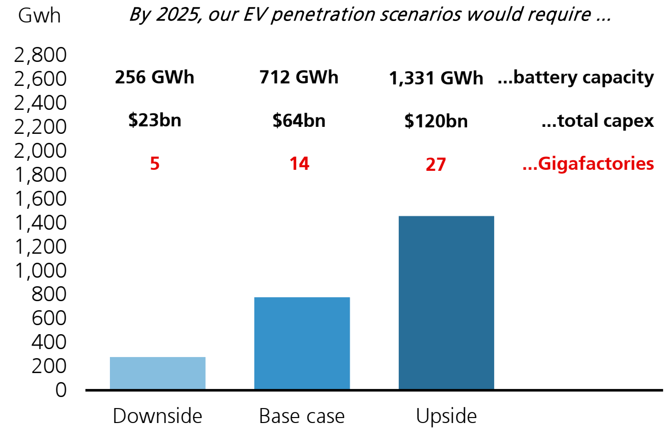
Can battery demand be met from a raw materials and production capacity point of view? The analysis below shows (1) the incremental demand for lithium, nickel, cobalt, graphite and manganese and how the respective commodity markets would be affected and (2) the required investments in cell production capacity.

Figure 28: NMC battery raw mats demand 2025E in % of proven reserves – NMC 811 likely mainstream after 2020



Source: UBS estimates

Figure 29: 16 Tesla Gigafactories required to meet 2025E battery cell demand – ambitious yet possible



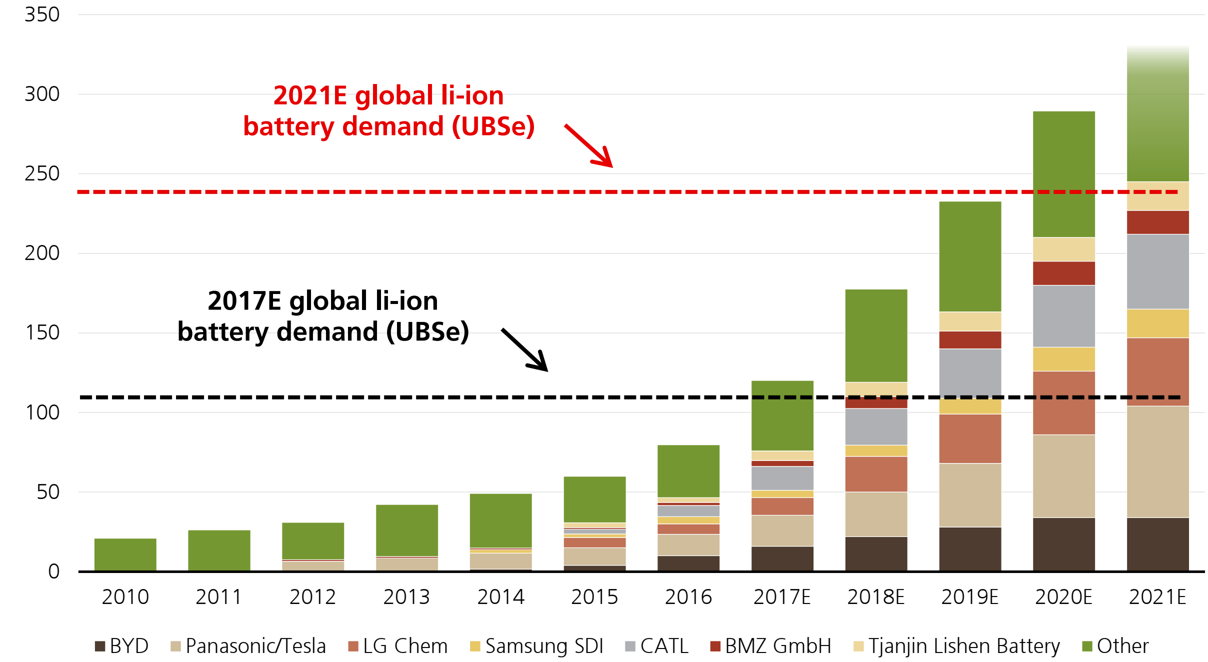
Source: UBS estimates

Our stress-test shows global raw mat reserves are not a bottleneck; the supply chain might be

In a 2025 world with 14.2m EVs sold (our base case), Cobalt would be the material with the highest depletion ratio, of 5% p.a. of proven reserves. In last year's Q-Series, we covered the commodities space in great depth. We believe that raw mats are not a bottleneck as such, but the supply chain needs significant investment to increase the output in the required order of magnitude. However, we would emphasize that (1) the use of cobalt will be significantly lower in future NMC cell generations on a per-kWh basis. In the 8:1:1 NMC battery cell, which is expected to enter mass production around 2021, the use of cobalt declines by 69% per kWh, compared to the 1:1:1 materials mix today. (2) The chance of a break-through in battery chemistry in the long term is significant, ie, the commodity depletion rates cannot be extrapolated beyond 2025.

In terms of battery cell capacity, the equivalent of 14 Gigafactories would be required globally to meet expected 2025 cell demand in our base-case scenario. This equates to $64bn total investments, applying the cost/GWh ratio of the first Gigafactory. Tesla managed to build a green-field (actually, it's located in a desert) Gigafactory within three years. The Korean battery suppliers are investing heavily in new capacity already today, and so are the Chinese suppliers.

Figure 30: Li-ion battery cell production capacity plans in line with EV sales forecast for the next five years – limited visibility on post-2020 plants at this point (GWh)



Source: UBS

Note: Includes non-automotive li-ion demand

Charging and power infrastructure in Europe

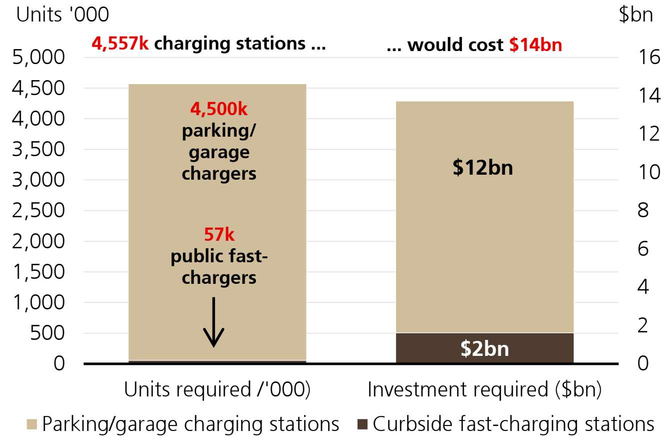
Our EV forecast would require $14bn charging infrastructure capex by 2025…

What's the required investment in charging infrastructure and power generation capacity, with a particular focus on Europe? We estimate that $14bn investments into charging infrastructure will meet requirements for 19m EVs on European roads in 2025. The infrastructure will be a mix of high-performance chargers alongside major motorways and lower-performance curb-side charging facilities, as well as home chargers. We think the need for high-performance chargers is over-estimated by many people, because only a fraction of miles driven during the year requires long-distance charging. In our UBS Evidence Lab survey, 81% of respondents said that they do two or less trips a year with a driving distance of >300 miles.

…and no incremental power generation capacity in Europe

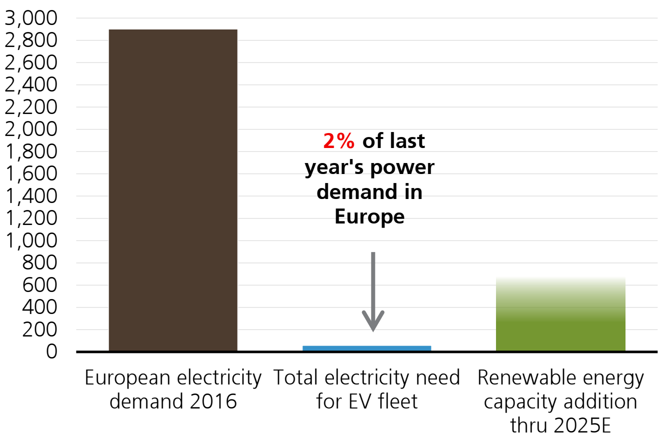
On the power generation side, most European power markets are currently oversupplied and power demand keeps shrinking by ~1% p.a. on energy efficiency measures. In a world of 19m EVs on European roads in 2025E with an average electricity consumption of 20 kWh per 100 km (conservative), the incremental power demand from EVs would be ~67 TWh (terawatt-hours) or 2% of Western European electricity demand. In light of the projected decrease in electricity demand excluding cars, we believe that the entire incremental demand can be met with existing production capacity. Furthermore, Western European countries currently add about ~30 TWh in new renewables capacity every year, which means that incremental supply for electric cars should mainly stem from CO_2-free sources.

Figure 31: Required investment in charging infrastructure in Europe



Source: UBS estimates

Figure 32: EV Impact on European power demand (2025)



Source: UBS estimates

How does our raised EV sales forecast square with our UBS Evidence Lab survey?

In September 2016, we published an in-depth report about likely consumer adoption of EVs. We conducted a survey with 10k consumers in the six largest car markets globally. In our view, some key findings of the survey support our increased forecast, particularly for Europe where TCO parity should be reached first:

UBS Evidence Lab: 55% of Europeans would be ready to pay a premium for an EV…

(1) The survey results show that today's high purchase price is the #1 reason why many people are unlikely to buy an EV today. However, when asked "if two cars had the same features, but one a gas or diesel vehicle, whereas the other was an all-electric vehicle, how much would you expect to pay for the all-electric vehicle?", **about 55% of European respondents would be ready to pay a higher purchase price for an EV vis-à-vis an ICE car, and about 30% are prepared to pay a 20% or even higher premium**. The actual price difference in 2025 will likely shrink to below 20%, and this ignores the running cost advantage the EV has. As the price premium narrows, the key reason for consumers not to buy an EV fades and eventually disappears. Hence, our 30% EV sales penetration forecast for Europe in 2025 is well below the share of survey respondents who, at least theoretically, would be ready to pay a higher price for the EV. Of course, the theoretical nature of this question makes it only one piece in the mosaic that influenced our EV sales forecast.

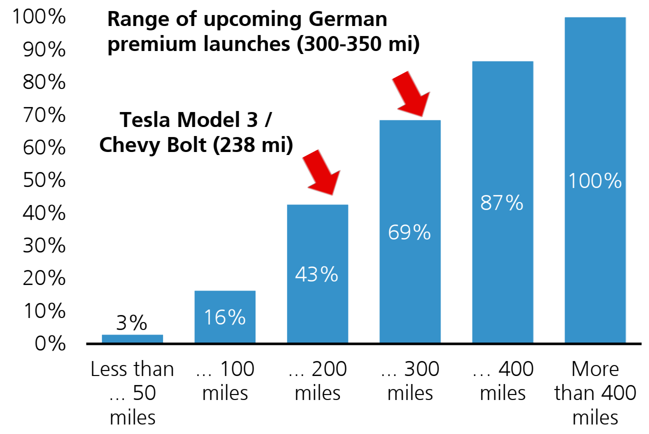
…two-thirds consider 480 km range sufficient…

(2) **Two-thirds of consumers consider 300 miles / 480 km range on a single charge as sufficient**, which will be met by upcoming product launches (in particular in premium);

…and over half of those with >$150k household income are likely to consider buying an EV

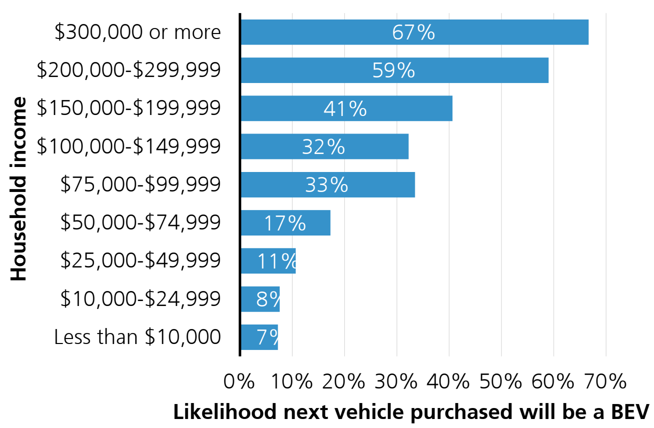
(3) **52% of respondents in the >$150k household income bracket are likely to consider buying an EV, which bodes well for premium brands.** Europe is the market with the highest premium brand share globally, about 22%. Overall, about 33% of European consumers said they are either likely to or uncertain about whether they would consider buying an EV. This result needs to be seen against the background of a very limited awareness / education level about EVs, due to the lack of models in the market at the time of the survey. We expect awareness and interest in EVs to increase on the back of numerous upcoming product launches over the years 2018-20, both in premium and mass (VW, Mercedes, Tesla, Audi…)

Figure 33: Acceptable minimum range for a single charge



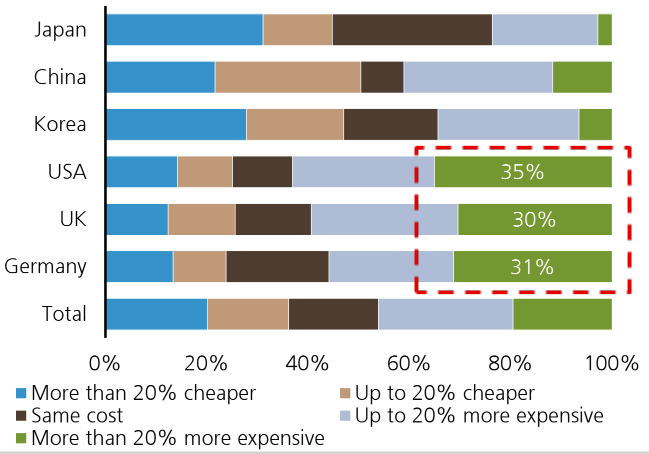
Source: UBS Evidence Lab

Figure 34: Likelihood to purchase BEV by household income ($/year)



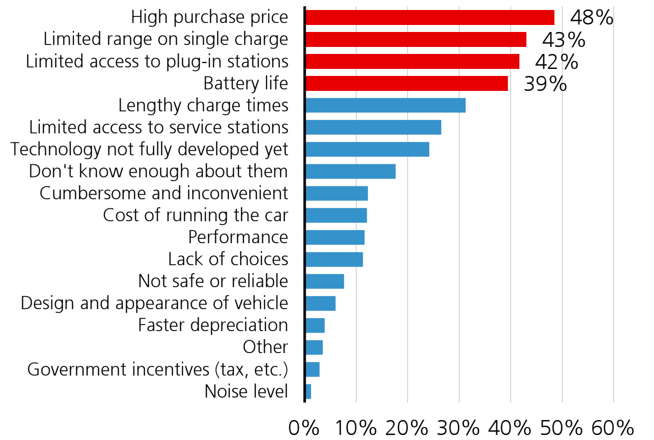
Source: UBS Evidence Lab

Figure 35: Consumers' expectations for price of BEV vs. a similar ICE car



Source: UBS Evidence Lab

Figure 36: Key concerns of consumers about BEVs



Source: UBS Evidence Lab

Q: What is different in the Chevy Bolt, compared to an equivalent ICE car?

Summary of results

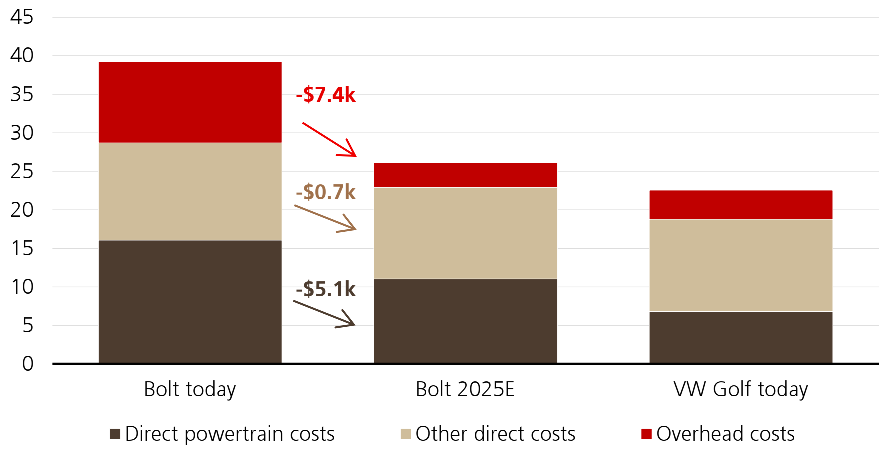
Below, we provide an overview of estimated component costs for the Bolt today and estimated costs in 2025 based on Munro expertise, in comparison to the Volkswagen Golf, Europe's top-selling ICE car with key features comparable to the Bolt. We have factored in our estimates for future battery pack costs based on our own extensive research.

Key conclusions about costs:

Munro's more optimistic cost estimates suggest OEMs and suppliers will be profitable sooner…

- Munro findings are **more optimistic** than our previous assumptions, which means that EVs should (1) be **more profitable for OEMs and suppliers** and (2) **reach the break-even in cost of ownership earlier** than anticipated. **Powertrain-specific costs** according to the teardown experts are $2.8k lower than our hypothesis, excluding the battery. It also turned out that the **battery pack** is $2.5k cheaper than our previous estimate (the battery *cell* costs were announced by GM).
- On our forecasts, the difference in **direct production costs** between the Bolt and the Golf will **shrink from $9.5k today to $2.7k in 2025.** A "second-generation" Bolt in 2025 is likely to be ~20% cheaper to manufacture than the first generation. And thanks to likely higher volumes, there is also better fixed cost absorption (R&D, SG&A etc). **Hence, the all-in cost difference should shrink from $16.5k today to $2.3k in 2025.**
- Battery cell and pack costs are the most important driver, but there is also further savings potential in the other powertrain components, which are ignored by the Street, in our view.

Figure 37: All-in cost comparison between the Bolt and Golf ($k)



Source: UBS

Further, our teardown analysis found that the Bolt has **$3k higher electronics content** than the Golf (measured at tier-1 supplier level including the e-motor), instead of $4.5k ICE powertrain content from "traditional" tier-1 suppliers. In terms of **commodities**, the most remarkable differences between both vehicle types are in the use of aluminium, copper, active battery materials, rare earths (all higher in the Bolt) and platinum group metals (don't exist in the Bolt). The use of steel is fairly similar, and more expensive light-weight materials, such as carbon fiber based materials, are not found in the Bolt.

Differences in vehicle architecture and powertrain

The Bolt has more interior space than the VW Golf with smaller external dimensions

Our focus of the teardown is on the powertrain, which is totally different between these two vehicles. But the vehicle platforms are also quite different. The Bolt, in spite of an overall shorter length, has a longer wheelbase than the Golf. This is for two reasons: (1) The Bolt's battery is underfloor between the axles. In order to fit as much battery capacity as possible, the wheelbase needs to be long. (2) A longer wheelbase maximizes interior space. The Bolt has 1% more passenger volume than the Golf and more legroom for both front and rear passengers, in spite of being 8 cm shorter. The main reason is the shorter front "engine" compartment. The e-motor and electronics require much less space than the combustion engine. The VW Golf is built on the so-called "MQB" platform, a German abbreviation for "modular transverse (engine) toolkit". This is Volkswagen Group's state-of-the-art modular platform for almost all new non-premium cars.

Figure 38: Chevrolet Bolt cutaway

Source: GM

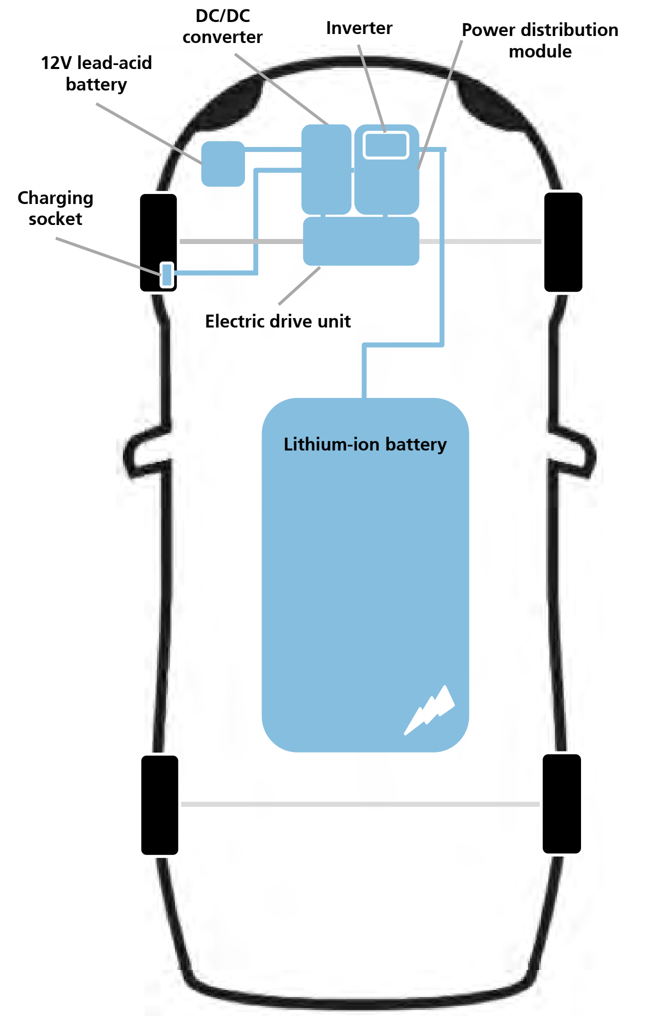
Figure 39: VW Golf cutaway

Source: Volkswagen

Zooming into the powertrain, the following schematic illustrations show the key differences between the Bolt and the Golf.

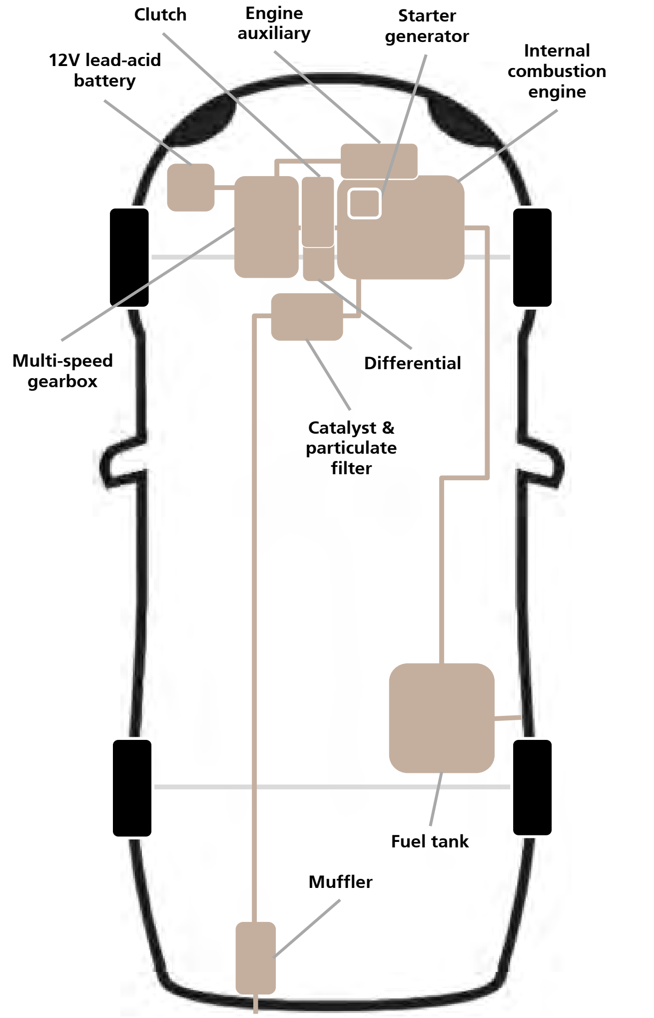
- The **Bolt** carries the e-motor (front-wheel drive), power electronics and charging equipment under the short front hood. The battery resides between the axles. There is a small **single-speed transmission** integrated into the e-motor unit.
- The **Golf** has a transversely mounted 4-cylinder gasoline engine (front-wheel drive). The version we use for this comparison has a **6-speed automatic transmission**.

Figure 40: Chevy Bolt powertrain



Source: UBS

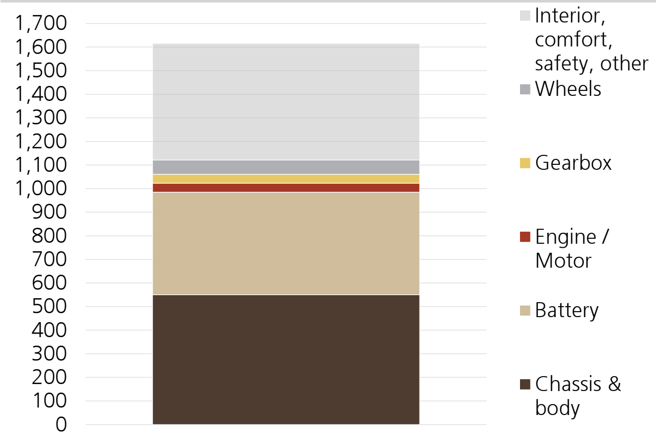
Figure 41: VW Golf powertrain



Source: UBS

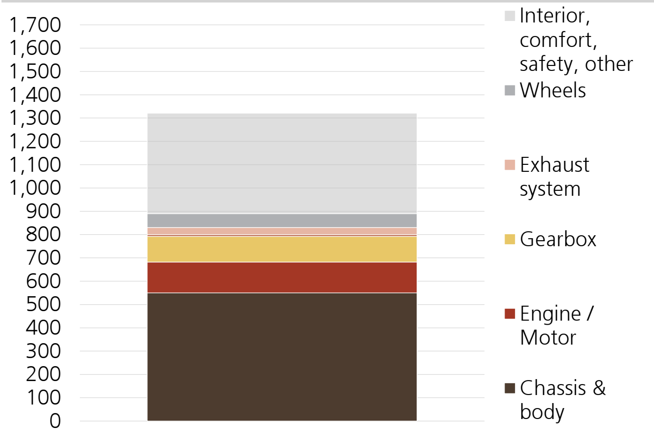
Differences in commodity weights

Figure 42: Chevy Bolt curb weight breakdown



Source: General Motors, UBS estimates

Figure 43: VW Golf curb weight breakdown

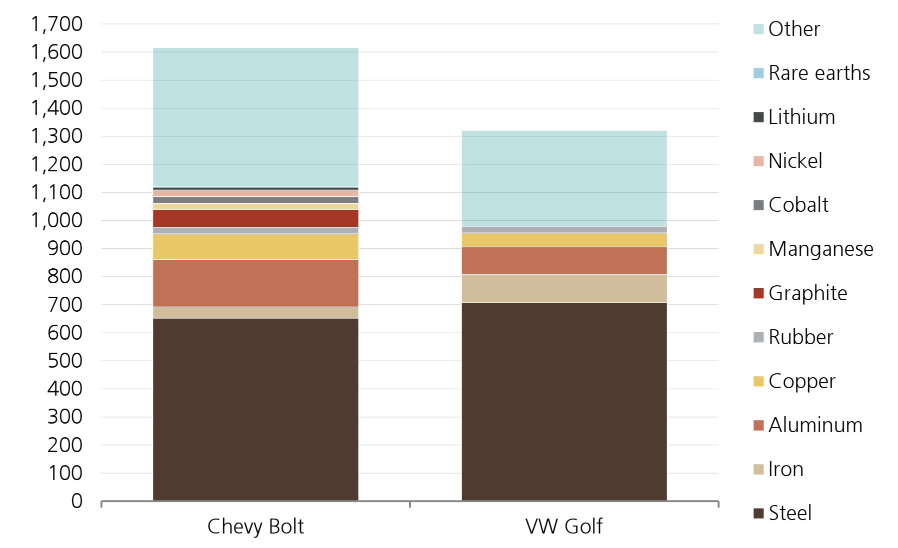


Source: Volkswagen, UBS estimates

The Bolt is 22% heavier than the Golf. The main reason is the battery pack. But what are the main differences in terms of the commodity weight share? In the Bolt, we have found (compared to the Golf):

- ~70% **more** aluminium
- ~80% **more** copper
- ~7% **less** steel
- ~60% **less** iron
- 100% **less** precious metals
- ~140 kg of "active" materials in the battery cells (Nickel, Cobalt, Lithium, Manganese, Graphite)
- ~1 kg of rare earths in the e-motor, in particular neodymium and dysprosium
- the same amount of rubber

Figure 44: Chevy Bolt vs. VW Golf commodity mix (kg)



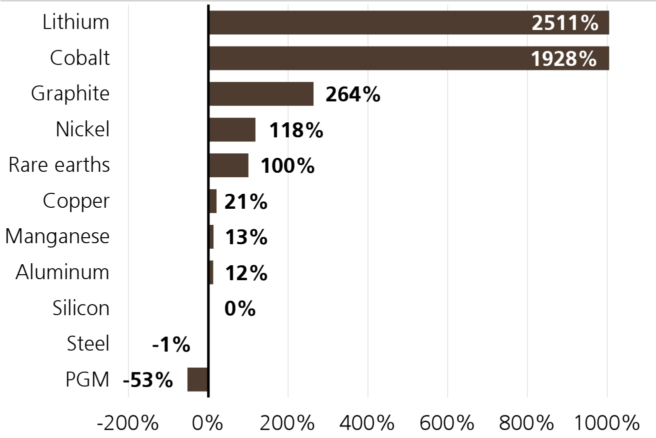
Source: UBS estimates

The shift to EVs should impact aluminium, copper, precious metals, rare earths and active battery materials most

Consequently, the shift to electric cars is likely to have a significant impact on the markets for aluminium, copper, precious metals, rare earths and the active battery materials. As a scenario analysis, the following graph shows how the respective commodity markets would be influenced if 100% of all vehicles sold globally would be Chevrolet Bolts, instead of today's vehicle sales mix. We put the incremental commodity demand (or lack thereof) in a 100% Bolt world in relation to the size of the respective commodity markets today. Lithium, cobalt, rare earths and graphite markets would be most disrupted on the positive side, and platinum group metals, which are used in catalysts, on the negative side. Not shown in the chart below is the use of plastics materials. We expect a moderately higher use of plastics (polymers- or polyester-based), for example for the upper cover of the battery pack.

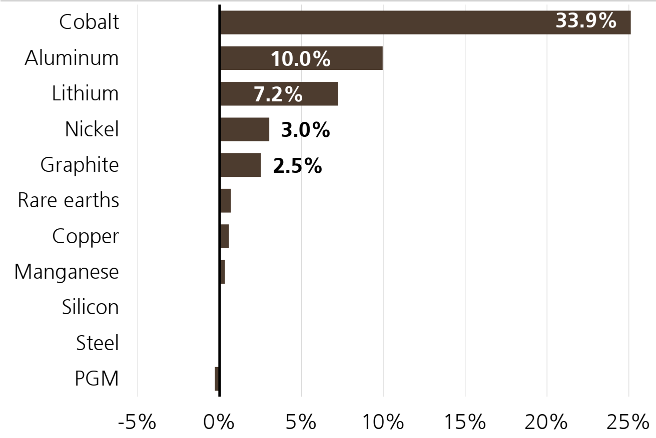
It is also worth highlighting that the battery active materials use is based on the Bolt's battery chemistry today. Future cell generations are likely to use significantly less cobalt and manganese, ie, the charts below would over-estimate the long-term impact. Please refer to the battery section for more details.

Figure 45: In a 100% EV world, demand for commodities would change by… (in % of global market today)



Source: UBS

Figure 46: In a 100% EV world, incremental annual commodity demand would deplete reserves by…



Source: UBS

As EVs become mass-market thanks to decreasing battery costs, we don't expect a higher use of more expensive 'exotic' light-weight materials, such as carbon fibre reinforced plastics. Lower costs and higher energy density (and hereby lower weight) will greatly reduce the need to spend additional money on light-weight materials for body and chassis.

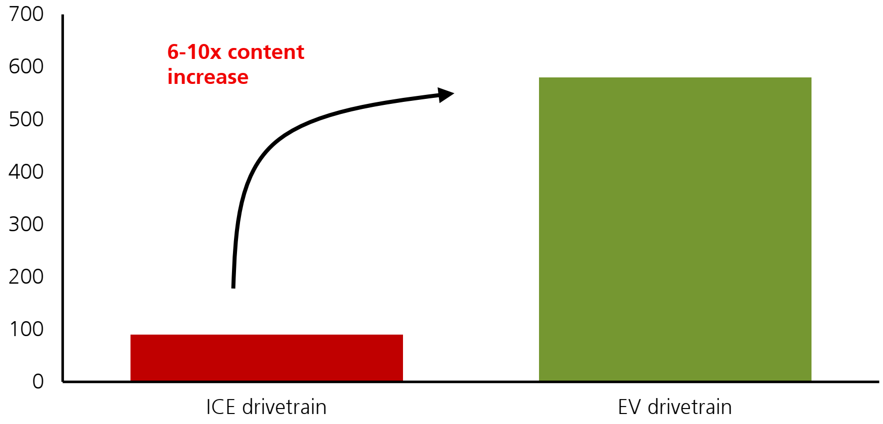
Differences in electronics / semiconductor content

The Bolt has ~$580 of semiconductor content on our estimates, 6-10x more than an ICE

We estimate that the Bolt EV powertrain has ~$580 semiconductor content, or 6-10x more than an average equivalent ICE car such as the Golf. We estimate that in an ICE the powertrain electronics can range from as much as $60 to $90 meaning that at ~$580 for a relatively low-end mass-market car, EV is a significant step up. At this point we are only focusing on the powertrain. We did also tear down the infotainment / connectivity / ADAS components, but these will be analysed in separate research.

Where are the main differences? We plan to carry out further in-depth analysis on the breakdown on the semi content side, but at a high level, in a traditional ICE powertrain, the main semiconductor content is in the engine control unit (ECU) and the sensors that feed it information. In an EV powertrain, there are numerous new components that contain a mix of power electronics (modules used to convert back and forth between AC & DC and between different voltages of DC) along with many 32-bit microcontrollers used to manage different subsystems (e.g. battery, charger module). The most prevalent suppliers in the teardown of the Bolt are Infineon (power electronics including the inverter/converter IGBT), NXP/Freescale for the higher value 32-bit components and STMicro for an ASIC supplied to LG Chem for battery management.

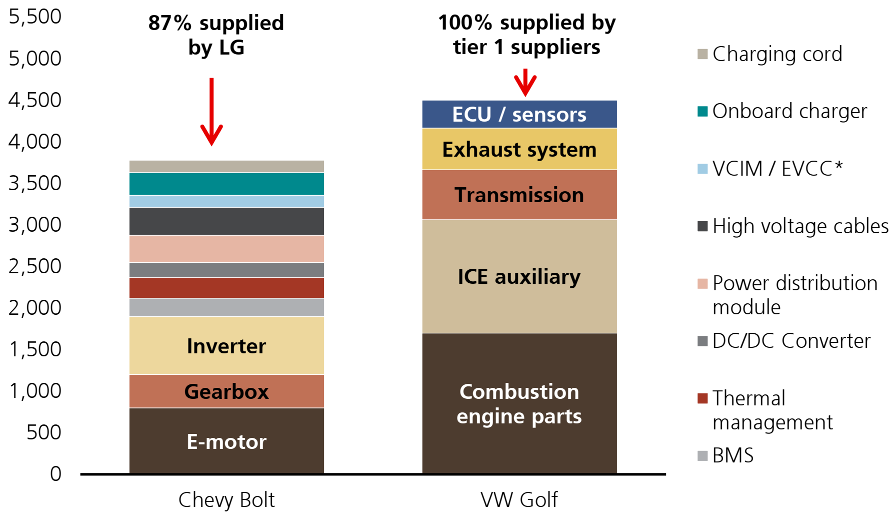
Figure 47: Semiconductor powertrain content increase in an EV



Source: UBS

At ~$3,800, the Bolt's powertrain excluding the battery pack is 16% less expensive than the Golf's full powertrain, on our estimates. In a nutshell, the lion's share of mechanical content gets replaced by electr(on)ical content.

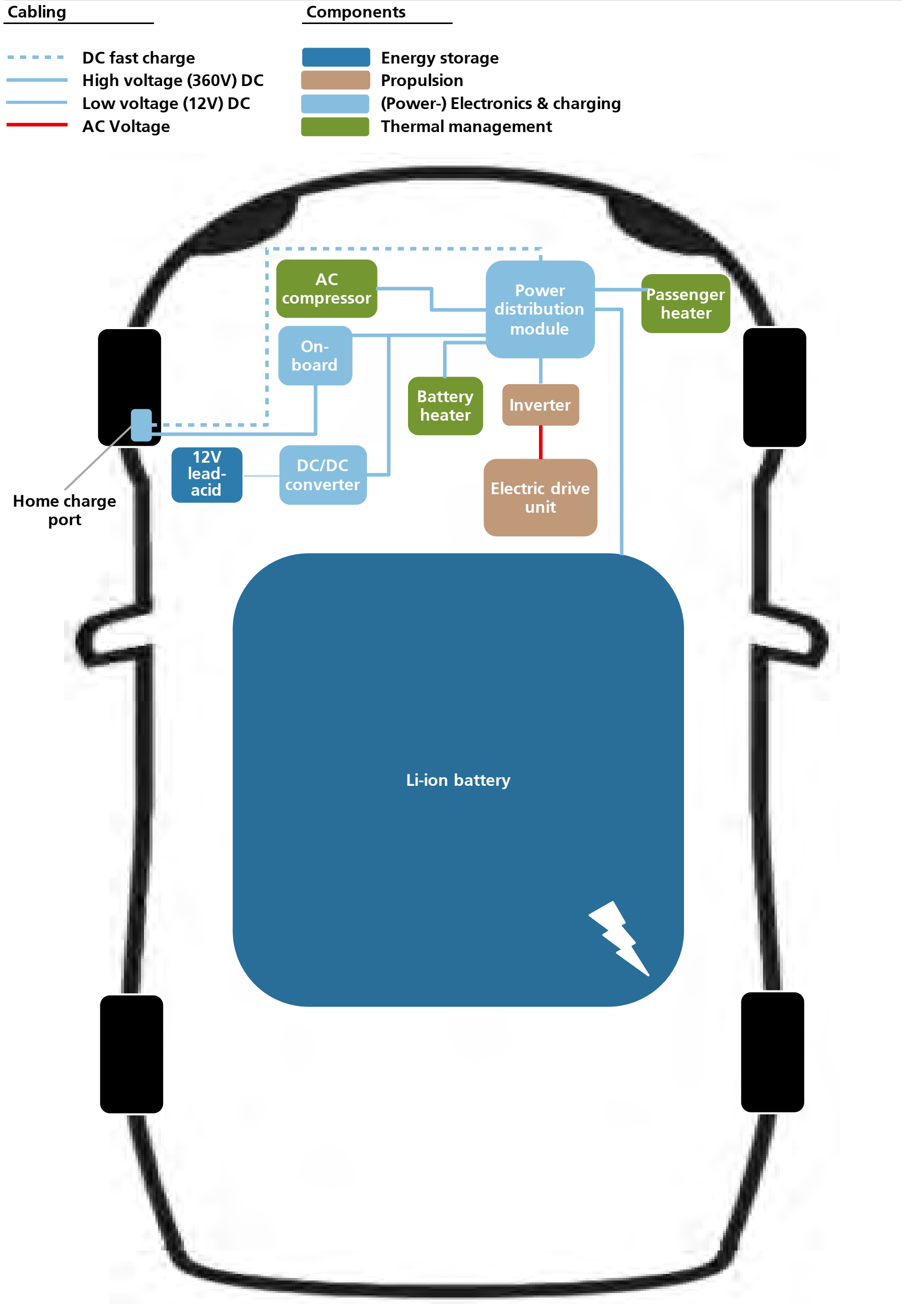
Figure 48: Powertrain components – Bolt vs. Golf ($)



Source: UBS estimates
* VCIM = Vehicle interface control module
** EVCC = Electric vehicle communication controller

Deep-dive into the Bolt's electric powertrain

Figure 49: Chevy Bolt Powertrain overview



Source: UBS

Figure 50: Chevy Bolt powertrain modules

Component	Price today ($)	Price 2025E ($)	Change %	Function
Li-ion battery pack	**11,500-12,522**	**8,000**	**-30-36%**	**Entire battery pack including housing, thermal control, internal wiring, emergency switch and battery management system**
Li-ion battery cell	*8,700*	*5,400*	*-31%*	*Stores up to 60kWh of electric power, $145/kWh*
Battery management system (BMS)	*150-222*	*200*	*up to -10%*	*Monitors the voltage output of each cell group and temperature of the pack*
Battery thermal management	*100*	*90*	*-10%*	*Heats and cools battery in order to keep operating temperature within desired range; glycol/water based*
All other pack content	*2,550-3,500*	*2,310*	*-9-34%*	*Module frames, internal wiring, cooling plates, steel pack case, plastics cover, emergency switch, safety relays, pack assembly*
Thermal management	250	225	-10%	Controls temperature of electronics and cabin via liquid-based cooling/heating loops
Power distribution module (PDM)	250-328	295	*up to -10%*	Takes in DC from battery or charging system and distributes it to the inverter, DC/DC converter and electric heating system
Inverter / converter	697-700	523	-25%	Takes in DC from the PDM and converts it to 3-phase AC for the e-motor
Electric drive module	1,200-1,550	1,080	-10-30%	150kW permanent-magnet e-motor takes in AC from the inverter to turn a drive shaft via magnetic power; a single-speed gearbox is used to translate rotational speed down to final drive ratio
DC/DC converter	150-179	134	-11-25%	Takes in 360V DC from PDM and converts to 12V DC for low-power systems in the vehicle
Electric Vehicle Communication Controller (EVCC)	51	46	-10%	Supports communication between the vehicle and charger for fast charging
Vehicle Interface Control Module (VCIM)	93-100	84	-10%	Functions like a data storage and distribution centre, controlling and monitoring operations between inter-reporting modules; maintains diagnostic information related to the electric propulsion system
High voltage cables	335	302	-10%	Connects the various electronics modules, the e-motor and the battery
On-board charger	273-598	205	-25-66%	Charges the battery pack by converting AC from the charging cord to DC. High end of range represents fast charging (paid option in our Bolt vehicle)
Charging cord	150	135	-10%	Allows the customer to charge the car using a standard 120V AC outlet. Rated to withstand 10,000 mating cycles. With 1 mating cycle per day, the theoretical lifespan is approx. 27.4 years
Total	**14,949-16,763**	**10,416**	**-30-38%**	

Source: UBS estimates. Note: Estimates highlighted in blue are Munro estimates, which we use as basis for further modelling purposes in this report

Number of moving and wearing parts

A combustion engine has many shortcomings vis-à-vis an e-motor, which have to be dealt with through complex technical solutions. The only reason why electric cars have not become mainstream yet, is energy storage, i.e. the battery. The e-motor is superior to the ICE: less mechanical complexity and fewer moving / wearing parts, stronger and linear torque, shorter response time, no local emissions, wider usable rpm range, no "cold start" issues, no energy-consuming idle running and the capability of regenerative braking to recover kinetic energy. Additional components, such as a complex gearbox, a clutch, a starter generator, a start-stop system, and emissions after-treatment are required to address the shortcomings of the combustion engine. The Bolt's powertrain is much simpler than the Golf's from a mechanical point of view:

The e-motor is significantly less complex than the combustion engine

- The e-motor itself is much less complex than the combustion engine. Bearings aside, there are only **three moving parts**. Modern e-motors are brushless, ie, maintenance-free. The Golf's 4-cylinder engine has **113 moving parts**. On top, spark plugs need to be replaced and engine oil needs to be changed regularly.

The e-motor has three moving parts vs. the combustion engine's 113

- The combustion engine has a limited usable rotation range, between c800-6,000 rpm. Also, its torque is not constant over the usable rpm range (unlike the e-motor). Therefore, a complex gearbox and clutch (or torque converter) are needed. The Golf's 6-speed automatic transmission has **27 moving parts.** Gearboxes and clutches also wear. After mileage of 150k kilometres, gearbox replacements begin to rise significantly. In contrast, the Bolt has a very simple single-speed gearbox with only **four gear wheels**. We expect no maintenance or replacement to be required over the life of the car.

The e-motor generates usable torque over the rpm range; the combustion engine needs a complex transmission

- Stating the obvious: A combustion engine produces emissions and more heat than the e-motor due to worse energy conversion efficiency. This requires complex after-treatment with ever-increasing regulatory standards (catalysts, particulate filters, mufflers, etc). Emissions after-treatment components wear down.

The e-motor's energy efficiency is far superior

Figure 51: Comparing the number of moving and wearing parts

Chevrolet Bolt	Parts	VW Golf
24	**(1) Moving parts**	**149**
3	… in engine	113
12	… in gearbox	27
9	… other	9
11	**(2) Wearing parts**	**24**
0	**(3) Moving & wearing parts**	**6**
35	**(1) + (2) - (3) Total moving and wearing parts**	**167**

Source: UBS

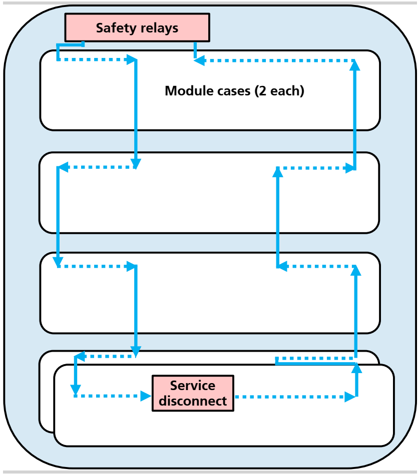
Battery pack

Need-to-knows

The Bolt's battery pack is supplied by **LG Chem**. It is a latest-generation NMC (Nickel Manganese Cobalt) battery with a usable capacity of 60kWh, which provides an EPA-rated range of 238 miles / 384 km. It weighs 436 kg, out of which 300 kg relate to the battery cells. Of the total weight, 26% is contributed by the packaging and cooling (steel, aluminium and iron), and about 68% by the "active" materials in the battery cells. Other key features:

- 288 LG battery cells in pouch format, with 96 cells connected in series (adding up to a voltage of 365V) and three strings of cells in parallel. The cells house in 10 module cases.
- The battery cell frames and the heating/cooling plates are made of aluminium, whereas the battery pack protection case is made of steel.
- The battery management system, which sits on top of the battery modules in the rear, is assembled by LG Innotek and designed by LG Chem.
- The battery pack is equipped with two disconnect methods, one if a system fault occurs, and another manual emergency disconnect under the rear seat.

Figure 52: Bolt battery layout



Source: UBS

Figure 53: Chevrolet Bolt key battery specifications

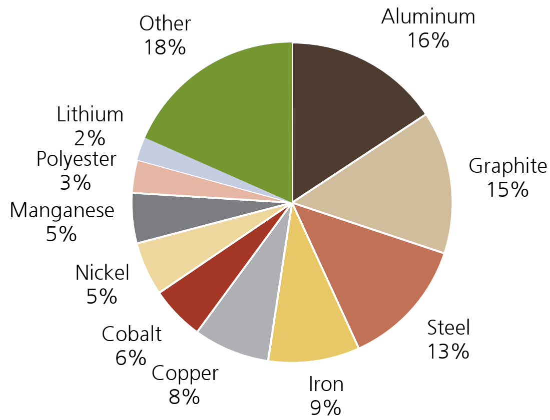
Li-ion cell technology	Nickel-manganese-cobalt (NMC)
Cell format	Pouch
Capacity	60 kWh
EPA-rated range	238 miles
Number of cells	288 cells
Charge times	
Basic (Level 1) - standard 120V residential cord	~60 hours / home
Fast (Level 2) - 240V fast-charging cord	~9.5 hours / home + public
Super-fast (Level 3) - public DC fast-charging	~1.5 hours / public
Cost today	$209 / kWh = $12,522
… cell	$145 / kWh = $8,700
… pack	$64 / kWh = $3,822
Cost 2025 (UBSe)	$133 / kWh = $8,000
--> Cost digression	-36%
Pack weight	436 kg
… cell material	300 kg
… cell frame and cooling plate	54 kg
… protection case	71 kg
… other	10 kg

Source: General Motors, UBS

Figure 54: Chevy Bolt battery pack

Source: UBS

Figure 55: Battery pack commodity breakdown (weight)



Source: UBS

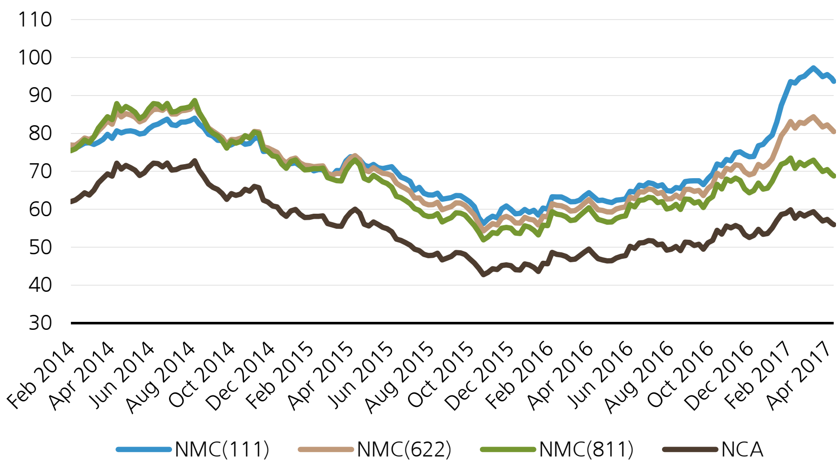
Technology

The chemistry used in the NMC cathodes is the state-of-the-art 1:1:1 ratio between Nickel, Manganese and Cobalt. The same chemistry is also used by Samsung SDI. Panasonic's cylindrical NCA technology (Nickel Cobalt Aluminium) is mainly used by Tesla.

Next gen NMC cells will reduce the share of expensive cobalt and manganese

The upcoming next generation of NMC cells (expected for 2018) will use a different materials mix: The ratio is expected to be 6:2:2, which means the share of cheaper Nickel is set to increase while the share of more expensive cobalt and manganese should drop. With a 2021 view, the cathode materials mix is expected to be optimized further to 8:1:1. At the same time, the energy density is expected to be further improved by ~20% for every new generation. This will lower not just the bill of materials per kWh, but also the costs for the module / pack assembly on a per kWh basis.

Figure 56: Commodity cost by cell generation ($/kWh)



Source: UBS. Note: Calculations are based on today's energy density. Positive impact from higher energy density will reduce BOM further.

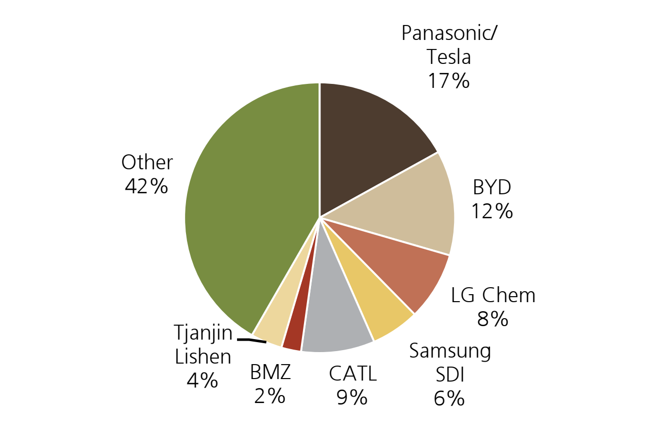
The battery management system is responsible for monitoring the voltage output from each battery module and the temperature of the pack. The module consists of various electronic components from a range of sub-suppliers.

Competitive landscape

EV battery supply to non-Chinese OEMs is quite concentrated: LG Chem, Samsung SDI and Panasonic are the leading players. There are several Chinese battery makers that predominantly supply the domestic carmakers – BYD is the largest player. Most of the Chinese supply is based on the LFP (Lithium Metal Phosphor) technology – a chemistry that industry experts see little further optimisation potential in. We doubt OEMs will commit large sums of money into own battery cell manufacturing due to the high capital intensity and the lack of technological edge, at least for the foreseeable future.

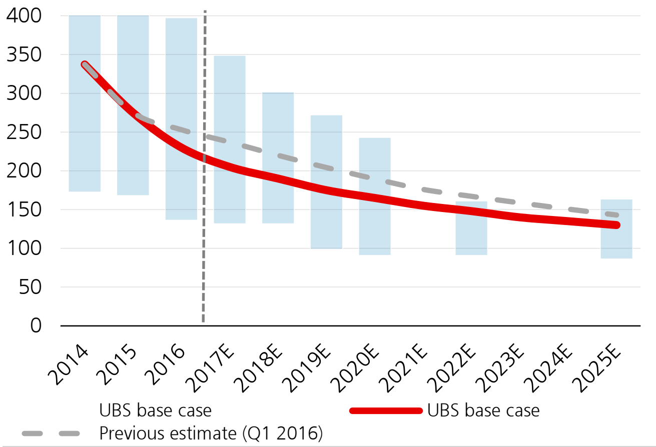
LG Chem, Samsung SDI and Panasonic dominate the non-Chinese market

Figure 57: EV battery cell producer capacity share 2016



Source: Company data, UBS

Figure 58: EV battery pack costs ($/kWh)



Source: UBS, various. Note: See source of external estimates in the appendix.

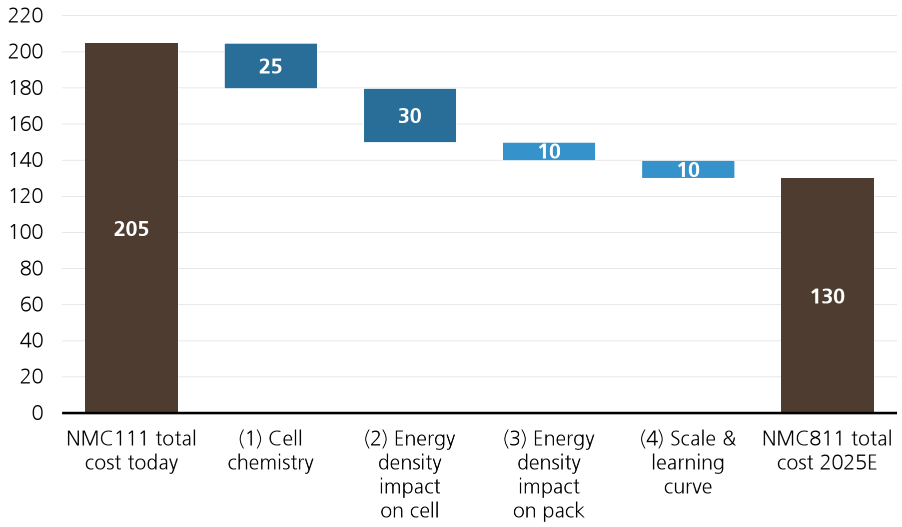
We over-estimated battery pack costs; $130/kWh by 2025E realistic

GM pays $145/kWh for the battery cells, i.e. $8,700 in total, and Munro estimate a $3,600 mark-up for the battery pack. The mark-up includes all materials, wiring/connectors, cooling plate, emergency switch and assembly. The battery management module comes on top of this and is estimated to cost $222 by Munro. Hence, total pack costs are $12,522 or $209/kWh. Our Asian tech team, who cover LG Chem and Samsung SDI, believe that this estimate is at the high end. They estimate that the total pack costs in the Bolt could be as low as $11,500 today.

The Bolt's battery pack is estimated to cost $192-209/kWh

We continue to expect a drop in cell costs to $90/kWh with a 2025 view, resulting in pack costs of $130/kWh (our previous forecast was $145/kWh). The following chart provides a breakdown of estimated costs today and in the future. The reduction of battery pack costs is the key driver of BEV economics. The projected reduction in the pack cost implies a reduction in total vehicle manufacturing costs by $4,500 or ~12% of the Bolt's price tag today.

Figure 59: Battery pack cost bridge 2017-2025E in detail ($/kWh)



Source: UBS estimates

$25/kWh from material weight changes in the cell

(1) The **shift from NMC 111 to NMC 811**, which battery suppliers expect to achieve as early as 2020-21, contributes **$25/kWh**. This is because of the lower weight share of the expensive commodities, Cobalt above all. We have not factored in any further optimisation in the chemistry mix after that, even though in the "normal" cycle of 2-3 years for the next cell generation, another step is quite likely by 2025.

$30/kWh from higher energy density

(2) Every new cell generation has an increase in energy density by ~20%. LG publicly stated that it expects an increase in energy density by 30-40% by 2020. We (highly conservatively) assume an increase in energy density by 25% on a 2025 view, in order to reflect a potential slowdown in the decline rate. As the commodity use per kWh also declines accordingly, the **contribution from higher energy density is $30/kWh**.

$10/kWh from lower pack assembly cost per kWh

(3) The higher energy density of the cells also has a **positive impact on pack assembly cost on a per kWh basis**, because the assembly steps remain the same and the use of materials is not affected (if anything, it goes down because of smaller battery size). This item delivers **savings of $10/kWh**.

$10/kWh from scale and learning curve effects

(4) Finally, **economies of scale and the learning curve in cell and pack assembly** should bring further savings. In today's $3,600 pack mark-up, only ~25% relates to materials used. This points to high fixed costs in a sub-scale production environment. We assume a contribution from economies of scale of $10/kWh.

Our forecasts lie within the range of various industry experts. **Key risks to our forecasts** would include changes in **commodity prices**, **timing of the delivery of new NMC generations** and the **magnitude of economies of scale**, given the risks to EV demand forecasts over such a long period.

Electric motor (drive unit)

Need-to-knows

The Chevy Bolt uses a permanent-magnet synchronous motor supplied by **LG Electronics** and engineered by GM. The one-speed transmission (7.05:1 final drive ratio) houses in the same module, also known as drive unit. The regenerative braking function is accomplished via the e-motor being utilized as a generator and the inverter/converter converting the generated AC in to DC for the battery, i.e. no additional mechanical equipment is required.

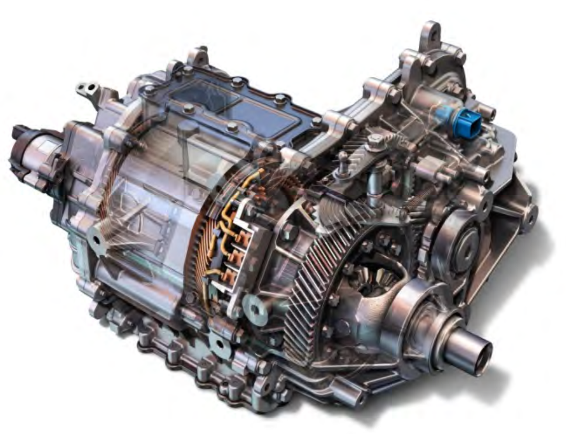
The Bolt's e-motor is designed by GM and manufactured by LG Electronics

Figure 60: Chevrolet Bolt key drive unit specifications

Type	Permanent magnet synchronous motor (PMSM)
Peak power	150 kW / 204 HP
Peak torque	360 Nm
Max rpm	8,810
Acceleration	0-60 mph in 6.9 seconds
Top speed (capped)	145 km/h
Cost today	$1,200
… E-motor	$800
… Gearbox, housing, rest	$400
Cost 2025 (UBSe)	$1,080
--> Cost digression	10%
Weight	76 kg
… E-motor	35 kg
… Gearbox, housing, rest	41 kg
Size / volume	~25 x 25 x 40 cm = 25,000 ccm
Gearbox final drive ratio	7.05:1

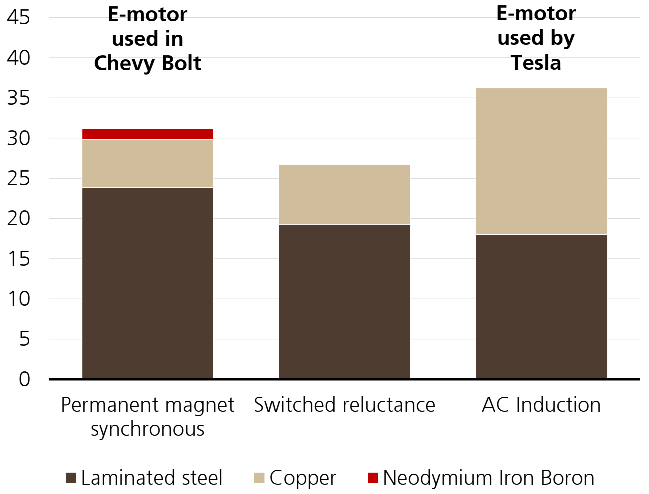
Source: General Motors, UBS

Figure 61: Chevy Bolt electric motor / gearbox unit



Source: GM

Figure 62: Electric motor commodity breakdown (kg)



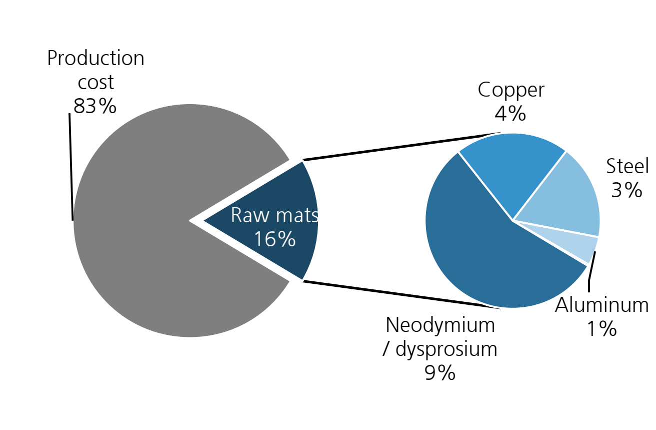
Source: UBS

Technology

There are different e-motor designs in the market, and each one has pros and cons. The electric rotor design in the Bolt optimizes magnet placement between the adjacent poles asymmetrically to lower torque ripple and radial force. It offers 204hp (150kW) of power, 360Nm of torque (almost 2x the ICE) and is maintenance free. This motor type requires the highest amount of neodymium and dysprosium for the magnets – rare earth materials that have experienced a volatile price curve over the past few years. We estimate a neodymium and dysprosium content in the Bolt's motor of ~1kg, which represents ~$100 unit cost or ~8% of the total e-motor cost. In a world of 14m EVs sold every year (our 2025E base case), the incremental demand would represent 54% of global neodymium production in 2016. While the rare earths, the raw material for magnets, are abundant (14.2m annual EV production would deplete reserves only by 0.04% p.a.), there could be risks of temporary bottlenecks in extraction. A well-known fact is that rare earths supply is highly concentrated in China.

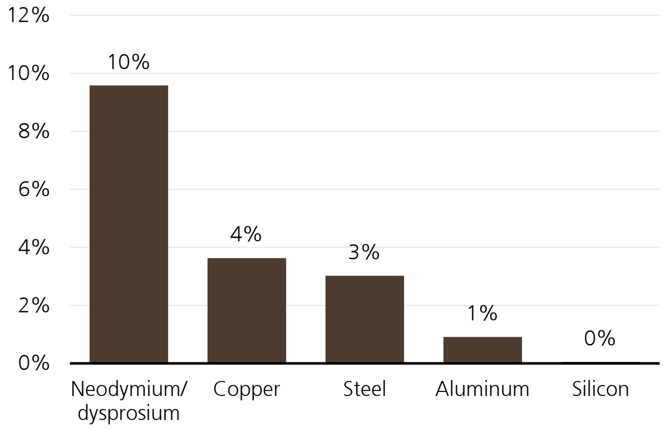
The one-speed transmission is directly attached to the e-motor and sits in the same housing. We counted only four gear wheels. A fixed transmission ratio (to reduce the rpm of the engine while increasing the torque) is sufficient due to the constant torque across the entire usable rpm range of the motor.

Figure 63: Bolt e-motor cost breakdown (total = $1,200-1,550)



Source: UBS estimates

Figure 64: Stress test – impact of doubling commodity prices on total e-motor module costs



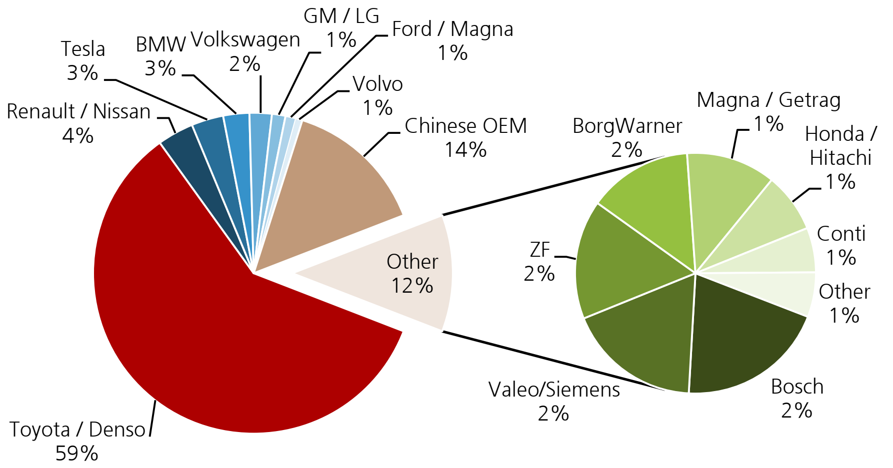
Source: UBS estimates

Competitive landscape

Make or buy decision is not clear-cut for e-motors

E-motors are either manufactured by the automakers or by suppliers, the latter of which can be split into "traditional" tier-1 suppliers and new players from the electronics industry, including LG Electronics. As OEMs need to focus their investments in a rapidly changing industry, there is a case for outsourcing to prevail longer-term. For the next five years, however, some OEMs (including Tesla, Toyota, Nissan and BMW) will likely hold on to in-house manufacturing in order to better understand the technology and also the levers of cost reduction. In-house manufacturing at some OEMs (such as Volkswagen) is also likely driven by job considerations. Finally, as there is still potential for innovation in e-motor technology, some OEMs might be able to create a competitive advantage with in-house produced motors. However, as the mechanical complexity of e-motors is much lower compared to combustion engines, the number of plant workers should be dramatically lower in any case.

Figure 65: E-motor production split by OEMs and traditional suppliers (2016)



Source: Company data, UBS
Note: Includes only high-power e-motors for BEV and hybrid cars; "Other" includes smaller suppliers including Torque Trends (USA), Buehler Motor (Germany), Electric Motorsport (USA), EVDrive (USA) and others

Costs today and future reduction potential

We conservatively forecast a ~10% cost reduction by 2025

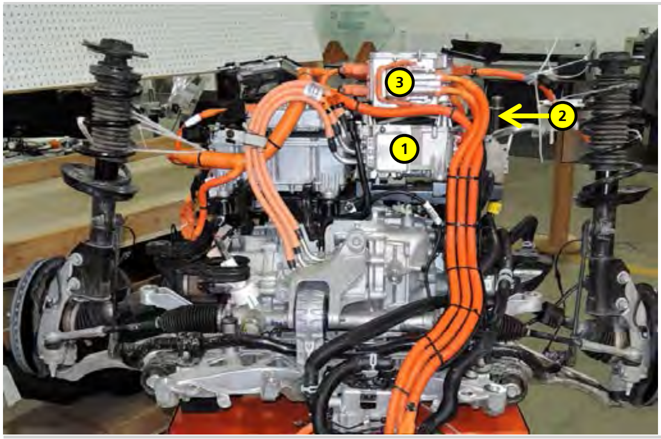
Munro estimates the costs of the Chevy Bolt e-motor and transmission at $800. Motor housing, gear train, resolvers etc. add another $400, resulting in $1,200 total e-drive module cost. Upside risks to e-motor costs are the rare earths, which represent ~8% of the total module cost today. In the future, economies of scale are likely a key cost driver. Furthermore, active cooling of the rotor could reduce rare earth content, as manufactured by Toyota. Daido Steel and Honda have created Hot Deformation Magnets. These are Neodymium magnets that do not contain Dysprosium or Terbium, yet have not lost any of the strength of Neodymium and maintain heat resistance. No cost data is available currently but Daido Steel plans to invest heavily in a US-based production facility in 2019. Generally speaking, reducing rare earth use and improving efficiency of motors (increasing range) will be key areas of product optimisation. Possibly, new e-motor variants including switched reluctance (SR) or variable magnetic motors could become more relevant, but are currently not used in mass production. This would eliminate the need for rare earths. We therefore consider our ~10% cost reduction potential assumption for 2025 as conservative. There could also be potential for in-wheel motors, which would improve drivability drastically, but this requires a much more sophisticated motor and control system.

Power electronics

Need-to-knows

Power electronics include: (1) the e-motor controller / inverter; (2) the DC/DC converter; and (3) the high power distribution module. All modules are assembled by **LG Electronics and LG Innotek**.

Figure 66: Positions of the inverter (1), DC/DC converter (2) and power distribution module (3)



Source: UBS

Figure 67: Cutaway of a DC/DC converter (left) and inverter (right)

Source: UBS

Technology

The DC/DC converter converts high-voltage DC from the battery management system to low voltage for the non-propulsion electricity users. Before "arriving" in the DC/DC converter, the current is routed through the power distribution module (PDM) from the battery management module. An inverter takes DC supplied from the PDM and converts it to 3-phase AC for synchronous motor control. The inverter assembly also houses all e-motor control hardware. The modules share the same cooling loop as the e-motor.

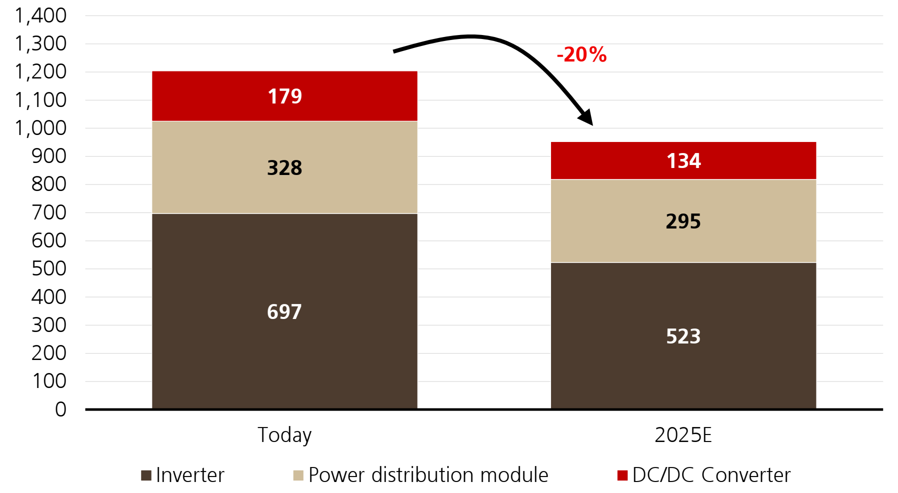
Competitive landscape

Chip content is from TDK (Epcos), Shizuki, Texas Instruments, Freescale, Infineon, among others. Other suppliers for the semi content include Würth Electronics, Schaffner EMC, STMicroelectronics, Atmel, Fairchild Semiconductor and others.

Costs today and future reduction potential

All the aforementioned components in this sub-group cost $1.2k according to Munro, as the following overview shows. The inverter/converter assembly is the most expensive module at an estimated $697 (Munro). The DC-DC converter costs $179 (Munro). The cost reduction potential for both modules is estimated at ~25% on a 2025 view, mainly on new semiconductor materials that reduce cost and size. The high-power distribution module costs $328 (Munro) and cost reduction potential is mainly seen through economies of scale.

Figure 68: Power electronics cost reduction potential of ~20% by 2025E



Source: UBS estimates

Thermal management

Need-to-knows

The Bolt has three separate thermal management circuits:

(1) for the battery (heating and cooling);

(2) for e-motor/power electronics (cooling only);

(3) for the cabin (heating and cooling).

Technology

All heating is performed by liquid heating circuits; AC functionality is similar to ICE cars

As there isn't enough heat produced by the e-motor in an EV for heating up the cabin and the battery, separate electric heaters are required for both the battery module as well as the cabin. Battery heating/cooling as well as cooling of power electronics is performed by liquid circuits, in the battery pack through aluminium plates and in the e-motor and electronics through built-in passages in the module housing. This avoids the need for a dedicated e-motor oil cooling loop, reducing cost, mass and design complexity. AC functionality is similar to an ICE car.

Competitive landscape

Electric heaters and coolant pumps are supplied by "traditional" tier-1 suppliers, as shown in the list below:

Figure 69: Thermal management supplier overview

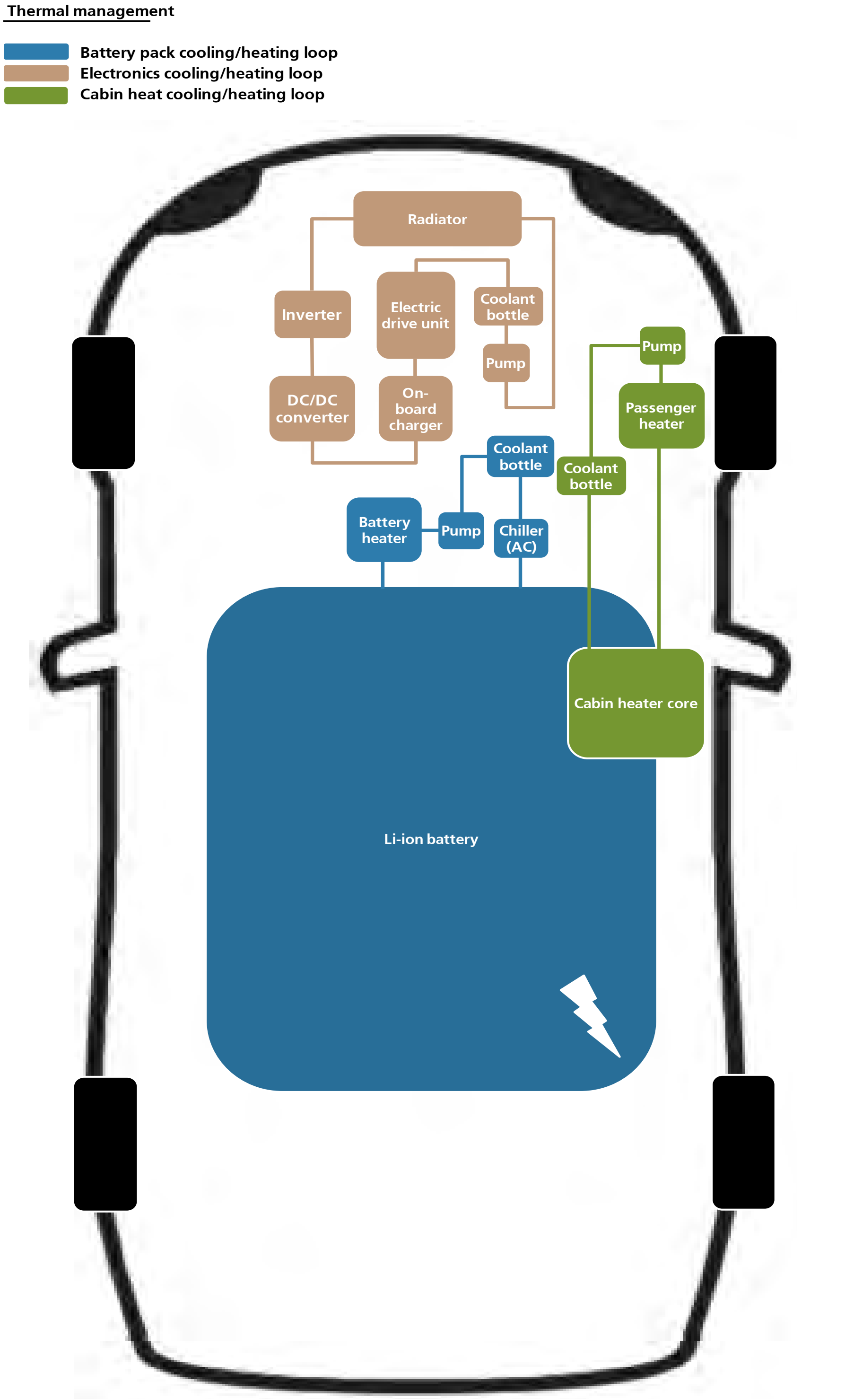
Electric heater	Electric coolant pump
Beru	Bosch
BorgWarner	Buhler
Denso	**Continental**
Eberspächer	Nidec GPM
Valeo	**Valeo**
Infineon	**Pierburg (Rheinmetall)**
Mahle	**Schaeffler**

Source: UBS; UBS-covered companies in **bold**.

Costs today and future reduction potential

The incremental costs of electric heaters and pumps compared to an ICE are seen at $298 by Munro. A potential future technology is to use the AC also as a heat pump for cabin heating. The VW e-Golf has such a technology. Munro believes it is ~40% more expensive than a traditional heater, but consumes less electricity.

Figure 70: The Bolt has three thermal management circuits



Source: UBS

Charger, charging cord and high-voltage cables

Need-to-knows

Charging requires an on-board charger module, a communication controller and a charging cord. The charger module is responsible for charging the battery pack by converting AC to DC with high efficiency. Various high-voltage cables are required to connect the modules with each other and with the battery.

Technology

The charger module is responsible for charging the battery pack by converting AC to DC with high efficiency. The EV communication controller is a core device that supports communication between the vehicle and charger for fast charging.

Competitive landscape

The charging cord is supplied by ClipperCreek. For cables, the suppliers for harness include Delphi, Yazaki, Sumitomo, Lear, Leoni and Nexans. Harness components are supplied by Huber + Suhner, Judd Wire, Leoni, Acome, Rosenberger (HVConnectors) and Coroplast.

Costs today and future reduction potential

The on-board charger cost is estimated at $698 by Munro (high-performance optional charger included in our Bolt – not a standard feature). Our vendor sees ~25% cost-cutting potential for the module on a 2025 view. The EV communication controller costs $51, and the charging cord is estimated at $150 by Munro. All other high-voltage cabling costs $335 according to Munro. The cost-cutting potential is largely limited to economies of scale in manufacturing.

Figure 71: On-board charger

Source: UBS

Figure 72: Charging cord incl. electronics module

Source: UBS

Differences in production processes

Figure 73: BEV production process schematic

	Power Train Assembly	Stamping	Body Shop	Paint Shop	General Assembly	Quality Assurance
Summary	The EV powertrain production contains three main components (inverters, motors, battery). The electric motor is often manufactured in-house, e.g. at Tesla. The process is largely manual with some help of robots.	In the stamping plant, the metal for the frame is unrolled, cut, and stamped into panels by hydraulic presses.	Robots assemble the stamped metal panels, joining them through welding, riveting, or using adhesives. The final output is the body-in-white , the unpainted metal shell of the car.	The body-in-white is primed and top coats are applied by robots in an environment that is carefully controlled to prevent contamination and defects in the paint. Baking and drying completes the process. Whilst the paint shop is highly automated, human input is required to inspect work and repair defects.	The shell is transformed into a fully functioning vehicle as the battery, pony pack, trim, and seats are attached. General assembly would typically be divided into three lines: trim, chassis, and final. The complexity of the process means that general assembly is labour intensive, with manual stations rather than robots.	The BEV is given alignment, and gets a water test, a drive test and a BSR (bumps, squeaks, rattles test).
Companies affected	SKF GKN Sandvik	Sandvik Andritz GKN	Atlas Copco Kuka	Dürr	Dürr Siemens ABB Kuka	
Number of robots, sample ICE plant (capacity > 350,000 p.a.)			700	150		
Number of robots, sample BEV plant (capacity c.120,000 p.a.)			350	70		

Source: UBS

In the following we will describe the elementary differences in the production process between Internal Combustion Engine (ICE) cars and Battery Electric Vehicles (BEVs). We look at the key process steps: 1) Powertrain assembly, 2) Stamping, 3) Body Shop, 4) General Assembly and 5) Quality Assurance.

Powertrain Assembly

Companies impacted from …

Fewer bearings: *Schaeffler, SKF*

Less machining: *Sandvik, Kennametal*

Need for battery capacity: *Automation players in cap goods*

The motor in a BEV replaces the engine and transmission in an ICE vehicle and will contain a significantly lower number of moving parts. For instance, we expect that electric vehicles will have 6-7 bearings in the drive module (e-motor and mini gearbox) compared to 40-50 bearings in a traditional ICE. This clearly changes the market-place for companies such as Schaeffler and SKF in this end market. Although the process is largely manual, e-motors are significantly easier and less costly to manufacture compared to engines and transmissions, with lower cost and less labour input required. We also expect significantly less machining will be required for the e-powertrain vs. conventional ICEs. Our channel checks indicate up to 80% of the cutting tool work needed to manufacture a car happens in the combustion engine. Significantly less machining is required for the e-motor. In our European and US coverage, we believe Sandvik and Kennametal will be impacted the most here. Depending on the platform, BEVs may also contain a higher ratio of lighter materials (predominantly aluminium), such as the current Tesla models. Lighter materials such as aluminium are also softer in comparison to steel. This means that tooling intensity will come down as well, leading to less usage of tools. That being said, we believe that in the long run it is likely that range benefits come from better battery cell technology rather than from dramatically changing the material mix in the car body. We will elaborate on this in the "stamping section" below. In addition to the motor, key componentry are inverters, converters and power management systems, as well as obviously the battery. Battery manufacturing will lead to new suppliers entering the auto supply chain and is an incremental opportunity for the automation players in our coverage given that these manufacturers build factory capacity.

Stamping

The stamping process depends on the type of metal used. When manufacturing with aluminium, it is not possible to stamp out or extrude large panels, because these panels would be comparatively weak. This is critical for capital goods as more panels mean more robots in the body shop, as we will explain later. However, before we get there, let's think about what the typical mass-market BEV will be made of?

While manufacturing with aluminium would be more complex, the Bolt's frame has roughly as much steel as a conventional ICE mass-market car

The EV frame is typically majority aluminium in most high-end EVs available today (a lower-density material, to compensate for the weight of the battery), whereas the typical ICE vehicle has a steel frame. However, also BEVs can still be majority steel (e.g. the Chevy Bolt, as our teardown has shown). Ultimately this will be a weight (range!) vs. cost trade-off. We expect that most of the advances to range come from better battery technology in the near term and that the material mix in a typical mass-market BEV will not be materially different from today's ICE. This is due to the fact that applicable aluminium alloys are 5-10x more expensive vs. steel. This buys the OEM a weight advantage of 40%. In an EV manufactured from aluminium, you might have four or five different parts, while in a steel ICE vehicle you would stamp a single panel. In the case of the Chevy Bolt, with a 95% steel frame, the stamping process would be more in line with a conventional ICE car.

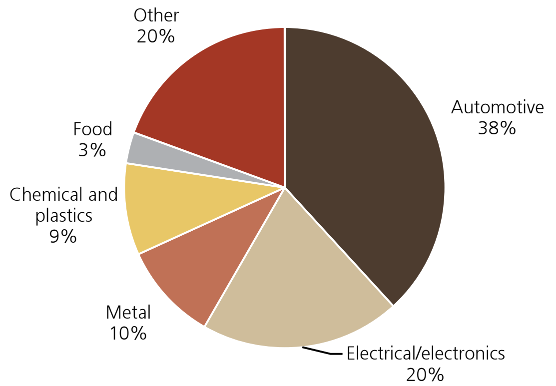
Body Shop

If the BEV is manufactured from aluminium, then more capital equipment may be required compared to a regular steel frame car because of the higher number of panels (as discussed in the stamping section). Equally, different end-effectors may be required on the robots for joining aluminium vs. steel, making it difficult to set up a flexible body shop able to produce both BEVs and ICE vehicles. Hence, incremental body shop capacity may have to be created depending on the material of choice for the vehicle. Whether manufacturing a BEV or an ICE, the process is highly automated; as many as 80% of a final assembly plant's robots would be located in the Body Shop. Considering that ca. 38% of the operational stock of industrial robots is in the automotive industry, the material choice for a car's frame could be an important growth lever for robotics / motion control players in the capital goods universe (Kuka, ABB, Siemens most notably) if, e.g., existing ICE OEMs add platforms where aluminium is the material of choice. However, given our base case assumption that material composition will not move heavily towards aluminium, we do not foresee a step change in demand for robots from this.

Aluminium bodies require different capital equipment – though we do not expect a material move away from steel

Companies potentially affected include Kuka, ABB and Siemens

Figure 74: The Automotive sector accounts for 38% of the worldwide operational stock of industrial robots (year end 2015)



Source: International Federation of Robotics

ICE vehicle manufacturers typically work with a strategic or owned body shop vendor. There are fewer high-volume aluminium body shops, meaning that the cost is significantly (perhaps 2-3x) higher.

Paint Shop

The differences between BEV and ICE vehicle production are minimal in the paint shop. Manufacturers would use the same equipment, although the paint might be chemically different for a BEV manufactured from aluminium.

General Assembly

General assembly is a similar process for BEVs and ICE vehicles. Given the assembly is modular, and stations can be shifted around, it would be possible to set up a general assembly manufacturing line for both BEVs and ICE vehicles. There may be differences in terms of software, given that BEVs tend to rely more heavily on software than mechanical processes. The need to upload new software as updates are made can slow the production process, and require more engineers to fix issues. Also final assembly for BEVs will require new risk management procedures once the battery is installed (and hence the vehicle is 'powered up').

Quality Assurance

The testing process is less lengthy for a BEV than an ICE vehicle, largely because there is no need for emissions testing.

Q: How profitable are EVs like the Bolt and the upcoming Tesla Model 3?

How profitable is the Bolt for GM?

Figure 75: Previous UBS EV powertrain cost estimate versus teardown findings

Powertrain	Previous UBS estimate	Teardown cost analysis
Battery cell	8,700	8,700
Battery pack (including BMS & thermal mgmt)	6,300	3,822
BMS	*500*	*222*
Thermal management	-	*100*
Other	*5,800*	*3,500*
Electric drive module	1,200	1,200
Inverter	850	697
DC/DC Converter	500	179
On-board charger (excl. fast-charge option)	700	273
Power distribution module		328
Thermal management		250
Vehicle interface control module (VCIM)		93
Electric Vehicle communication controller (EVCC)		51
High-voltage powertrain cabling		335
Charging cord		150
Other power electronics	2,400	
Total	**20,650**	**16,078**

Source: UBS

The powertrain turned out to be $4.6k cheaper than we thought

The components of the Bolt we tore down (everything that relates to powertrain and battery) have turned out to be $4.6k cheaper than previously anticipated, based on Munro findings. It has to be noted that our Bolt had various options, including the "Premier" trim with various additional ADAS and comfort functions, as well as the fast-charging capability. That's why we have done the maths for both "our" Bolt and a "naked" Bolt without any options. For the parts and components out of the scope of the teardown, we believe we have a fairly solid understanding of costs because the Bolt does not differ from a standard ICE car.

On our analysis, the total **direct production costs** of the "naked" Bolt add up to $28.7k, as the following analysis shows. This implies a positive contribution (selling price less cash manufacturing costs) of $3.2k per vehicle sold. The contribution represents 10% of the vehicle price (excl. dealer mark-up). Hence, GM has an incentive to sell more vehicles. At **EBIT level**, however, including proportionate overhead costs and D&A, GM likely incurs a loss of $7.4k per vehicle sold. We have assumed an initial annual production of 30k Bolts, in line with LG Chem's guidance for the Bolt's battery production. As it stands, GM/Opel currently have difficulties in meeting European demand for the car – therefore, 2018 production could increase (leading to better fixed cost coverage).

On a 2025 view, the "next-gen" Bolt's **total costs** (down to EBIT level) should decrease by $13.2k, in our view, driven by:

- **Innovation and economies of scale at supplier level:** Lower costs for the battery and for other EV powertrain components ($5.5k);
- **Economies of scale at OEM level:** Lower unit costs through mass production and better R&D and overhead coverage ($7.7k).

Figure 76: Detailed Chevrolet Bolt profitability analysis ($)

	Today		2025E		Commentary
Battery cost ($, total)	**12,300**	**12,300**	**7,800**	**7,800**	
Battery cost ($ / kWh)	**205**	**205**	**130**	**130**	
Cell	145	145	90	90	Based on GM disclosure and UBS cost forecast
Pack*	60	60	40	40	Previous UBS estimate for 2016: ~$100/kWh
	w/ options	**Base**	**w/ options**	**Base**	
MSRP	**42,635**	**36,620**	**42,635**	**36,620**	Future Bolt MSRP likely lower; kept stable only for this exercise
Dealer/incentive (15%)	5,561	4,777	5,561	4,777	
Price charged by OEM	**37,074**	**31,843**	**37,074**	**31,843**	
Direct powertrain costs	**16,403**	**16,078**	**11,272**	**10,028**	$4.6k or 26% below our previous estimate
Battery cell	8,700	8,700	5,400	5,400	
Battery pack*	3,600	3,600	2,400	2,400	Pack cost based on teardown analysis
BMS	222	222	200	200	
Thermal management	250	250	225	225	
Inverter	697	697	523	523	
DC/DC Converter	179	179	134	134	
Power distribution module	328	328	295	295	Cost reduction of 10-25% per component on a 2025 view driven by scale, technology improvements and competition
High-voltage cables	335	335	302	302	
Electric drive module	1,200	1,200	1,080	1,080	
VCIM & EVCC**	144	144	130	130	
Onboard charger	598	273	449	205	
Charging cord	150	150	135	135	
Other direct costs	**15,608**	**12,600**	**14,908**	**11,900**	
Warranty provision	700	700	500	500	
Direct assembly staff cost	2,400	2,400	2,400	2,400	Based on average OEM factory assembly staff costs
Direct materials (assembly)	1,500	1,500	1,500	1,500	Primarily body and chassis
Supplier components	8,000	8,000	7,500	7,500	Includes interior, safety, ADAS & other electronics, etc.
Costs of optional features	3,008	0	3,008	0	Assume OEM generates 50% gross margin on options
Contribution margin	**5,063**	**3,165**	**11,895**	**8,916**	
% margin	14%	10%	29%	28%	
D&A	1,929	1,929	952	952	D&A cost degression driven by higher unit sales
R&D	7,143	7,143	714	714	R&D cost degression driven by higher unit sales
SG&A	1,512	1,512	1,512	1,512	Assume company-wide average SG&A / car for GM
D&A % of sales	5%	6%	3%	3%	
R&D % of sales	19%	22%	2%	2%	
SG&A % of sales	4%	5%	4%	5%	
EBIT	**-5,520**	**-7,418**	**7,716**	**5,737**	
EBIT margin	-15%	-23%	21%	18%	Assumed Bolt sticker price stays constant

Source: UBS
* ex BMS (Battery management system) ** VCIM = Vehicle interface control module; EVCC = Electric vehicle communication controller

We note that the estimated loss of $7.4k on the base model is lower than GM's guidance. The company talked about an initial EBIT loss of ~$9k per vehicle. Hence, there is a difference of $1.6k or 4% of the total costs of the Bolt between our analysis and GM guidance. As we don't have a detailed breakdown from GM, we cannot reconcile this number, but we believe the difference stems from differences in allocation of overhead costs.

TCO parity to be reached starting in 2018E in Europe; true parity in 2023E

Naturally, competitive forces and the need to improve consumer economics for EV mass adoption should drive down the selling price. Below, we look at the years of consumer TCO parity under the condition of GM: (1) making an EBIT loss like it does today; (2) breaking even; (3) making a 5% EBIT margin. The TCO parity would be reached one year later using the $9k loss indicated by GM as a starting point.

Figure 77: Projected years of TCO parity, breakeven margin and 5% margin for OEM

Projected year of ...	US	Germany	China	Japan
TCO parity	2025	2018	2023	2023
TCO parity & breakeven OEM margin	2027	2022	2025	2025
TCO parity & 5% OEM margin	2028	2023	2026	2026

Source: UBS estimates

Implications for the Tesla Model 3

Many similarities between Chevy Bolt and Tesla Model 3

We believe the profitability analysis of the Bolt can to a large extent be applied also to the upcoming Tesla Model 3, the company's long-awaited EV with a mass-market base price of $35,000. We summarize below what's similar and what's different between the two EVs.

- **What is similar:** Base version pricing, range / battery capacity, single e-motor with two-wheel drive, about the same interior space.
- **What is different:** Higher premium appeal of the brand (more pricing power and longer list of profitable options), different battery chemistry and more scale in battery manufacturing (Gigafactory), rear-wheel drive instead of front-wheel drive (all-wheel drive version at a later stage), more connectivity functionality (eg, over-the-air-upgrades) and autonomy-relevant hardware as standard (cameras, sensors), and better likely fixed cost absorption thanks to more ambitious production targets (>10x vs. the Bolt).

Further to that, there are differences in the distribution model and marketing. While Tesla receives the entire MSRP thanks to its fully-owned distribution operations and lack of discounting, GM's MSRP includes a ~15% mark-up for the independent dealerships and incentives. This also implies Tesla has higher distribution costs in SG&A.

The biggest uncertainty in the read-across from the Bolt to the Tesla is the battery costs. However, there are some data points that help us to narrow the range. For the Model S, the Tesla gives total battery pack costs of $190/kWh. Cell costs are $140-150/kWh today, similar to the price of the cells in the Bolt. Assuming that the next generation of cells produced in the Gigafactory have 20% higher energy density, ie, less use of active battery commodities and lower packaging volume, we think the pack costs for the Model 3 will initially be in a range of $160-180/kWh. The table below summarizes the expected profitability of the Model 3. We assume that the 55kWh battery pack is $9,075, or 26% cheaper than the Bolt's, mainly due to economies of scale in the Gigafactory.

Below, we use the estimated cost for the Chevy Bolt and BMW 3-Series to estimate the profitability of the Tesla Model 3. We looked at stripped-down and optioned-up versions of each model. We assume the Model 3 will be $7k higher with options (~20% of base). We estimate the Model 3 battery pack will be 26% cheaper than the Bolt and that EV powertrain components will be about $400 higher as the Model 3 will likely have stronger luxury performance. We also assume the assembly body will be $700 more costly due to the use of more aluminium. Our estimated warranty is about half the initial Model S accrual (given relative price). Lastly, we assume the non-powertrain components would be about $400 lower than the BMW 3-Series as the interior content will likely be more limited.

Figure 78: Detailed Model 3 profitability analysis ($) and comparison to Bolt (today)

	Chevy Bolt		BMW 330i		Tesla Model 3		
	Base	w/ options	Base	w/ options	Base	w/ options	Comments
MSRP	**36,620**	**42,635**	**38,750**	**45,000**	**35,000**	**42,000**	*Model 3 assumed +20% of base*
Dealer/incentives (15%)	4,777	5,561	5,054	5,870	-	-	
Price charged by OEM	**31,843**	**37,074**	**33,696**	**39,130**	**35,000**	**42,000**	
Battery cost ($ / kWh)	**205**	**205**			**165**	**165**	*Assumes ~20% lower cost due to Gigafactory*
kWh	60	60			55	55	*TSLA guided to <60*
Battery cost ($, total)	**12,300**	**12,300**			**9,075**	**9,075**	
Powertrain cost	**3,778**	**4,103**	**8,500**	**8,500**	**4,503**	**4,503**	*$400 higher vs. Bolt (performance related)*
Warranty provision	700	700	674	783	1,700	1,700	*Half of Model S initial accrual*
Direct assembly staff cost	2,400	2,400	2,800	2,800	2,400	2,400	
Direct materials	1,500	1,500	1,800	1,800	2,200	2,200	*$700 higher vs. Bolt due to aluminium*
Supplier components	8,000	8,000	10,400	10,400	10,000	10,000	*Less luxury content but more ADAS tech than BMW 3-Series*
Optional features	0	3,008	0	3,125	0	3,500	*est. 50% contribution on options*
Contribution margin	**3,165**	**5,063**	**9,522**	**11,723**	**5,122**	**8,622**	
% margin	10%	14%	28%	30%	15%	21%	
D&A	1,929	1,929	1,685	1,685	3,000	3,000	*Higher due to Gigafactory*
D&A % of sales	6%	5%	5%	4%	9%	7%	
R&D	7,143	7,143	1,685	1,685	952	952	*Lower vs. Bolt given higher units*
R&D % of sales	22%	19%	5%	4%	3%	2%	
SG&A	1,512	1,512	2,965	2,965	4,000	4,000	*BMW's base; +$2k for dealer SG&A; -$1k for advertising*
SG&A % of sales	5%	4%	9%	8%	11%	10%	
EBIT	**-7,418**	**-5,520**	**3,187**	**5,388**	**-2,830**	**670**	
EBIT margin	-23%	-15%	9%	14%	-8%	2%	

Source: UBS

In terms of vertical integration, the Model 3 has much more OEM content than the Bolt. While we consider the cell manufacturing as external purchasing from

Panasonic, the packaging is done by Tesla. Also, Tesla produces the e-motor unit in-house. Consequently, Tesla will have more capital employed.

$2.8k loss on base model; break-even at $41k likely exceeded on take rate of profitable options

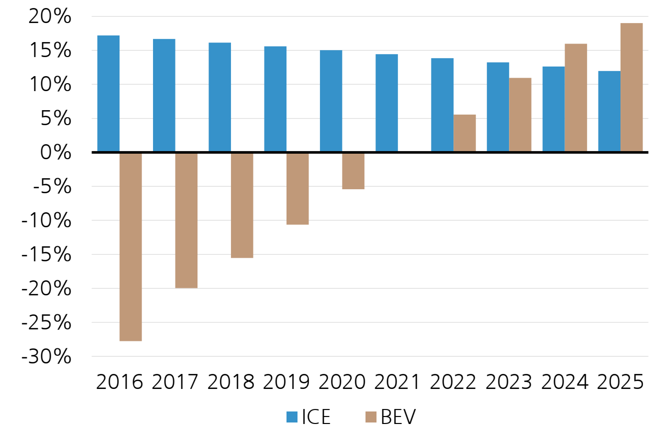
Our analysis shows that Tesla is likely to incur a loss of $2.8k on the base model. However, we expect Tesla to break even at a selling price of $41k, which requires $6k of options. On average, the break-even $41k selling price is likely to be exceeded on a high take rate of options. As the Model 3 is expected to feature all sensor hardware for autonomy functionality already in its base version, the optional software activation should deliver (almost) 100% gross margin for Tesla.

Q: What is the impact on the auto industry?

Shift to EVs could deliver faster returns and major CO_2 benefits, particularly for European OEMs

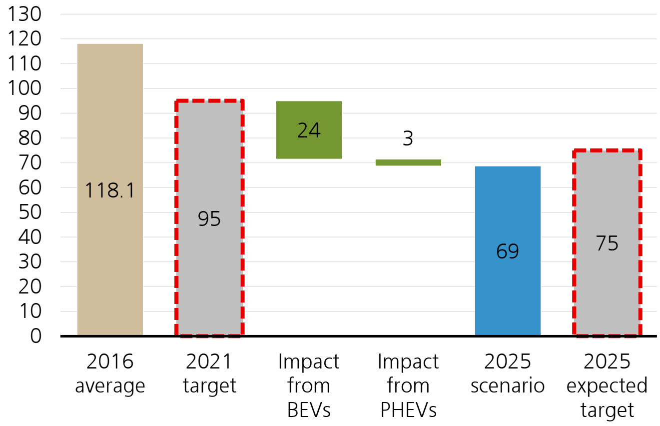
EVs should be cheaper to build, and there is likely more demand than we thought previously. Hence, the profitability of EVs is likely to improve faster (first in the premium segment), and current R&D should have a better and quicker return than anticipated by consensus. Higher EV penetration means a higher contribution of zero-emission vehicles to fleet-wide CO_2 targets, easing the structural cost headwinds for the OEMs, in particular in Europe. On our new EV sales forecasts, the CO_2 relief would be a big deal for European OEMs.

Figure 79: OEM ROIC trend



Source: UBS estimates

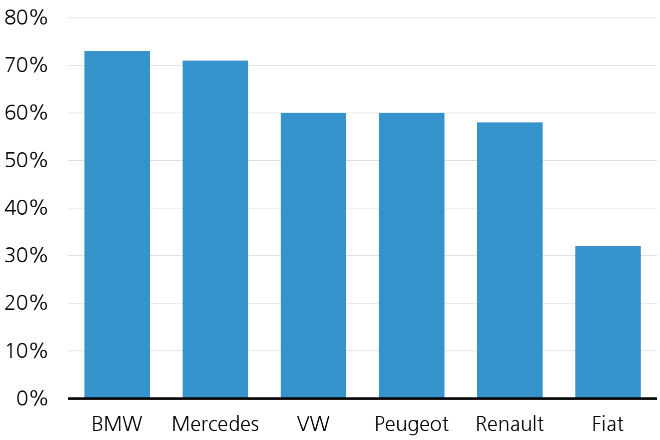
Figure 80: Impact on European fleet CO_2 emissions



Source: ICCT, UBS estimates

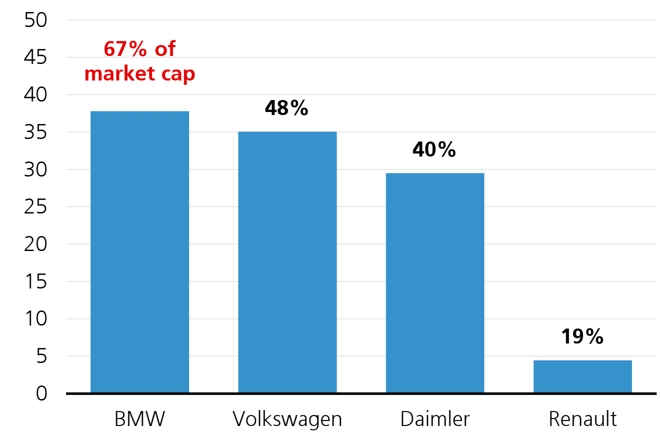
The flipside of an accelerated shift to EVs would be that ICE cars lose value more quickly, with less time for the OEMs to (1) adjust production capacity and workforce and (2) manage residual value risk through their fincos. European OEMs would be most exposed to this risk, in particular as EVs are likely to fuel the demise of the diesel.

Figure 81: EU diesel shares today – EVs could replace the diesel to a large degree



Source: UBS estimates

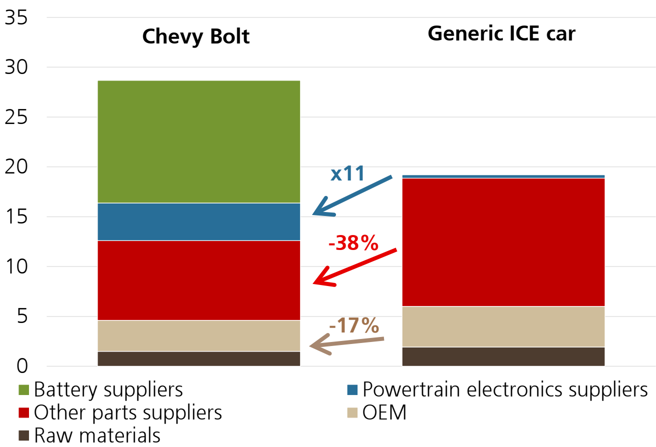
Figure 82: Lease book size by OEM – an accelerated shift to EVs implies residual value risk (€bn)



Source: UBS estimates

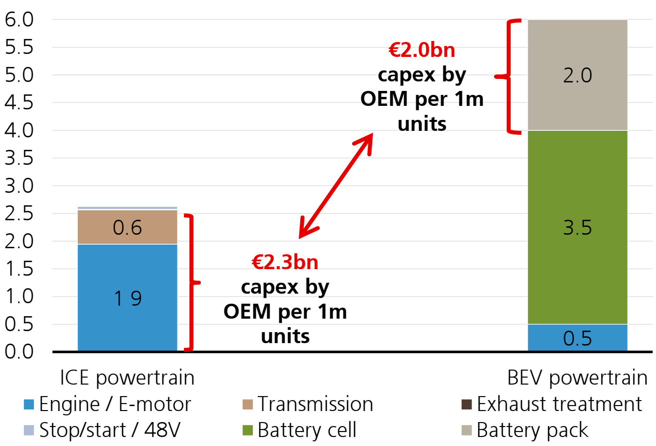
Also, the Bolt teardown has delivered evidence about a shrinking OEM content in an EV, which should lead to lower value-add. GM has outsourced almost the entire electric powertrain including the battery. Out of the total estimated **direct production costs**, we estimate $3.9k or 14% is GM's own content. OEMs will need to find other areas of differentiation to preserve brand value and pricing power. However, as capital intensity is also going to drop sharply, industry ROIC is unlikely to be materially different after the shift to EVs, all else being equal (new mobility models are a bigger threat). Once all major carmakers have EVs in their portfolio, we expect entry barriers to remain high from a financial standpoint (building/maintaining a brand and (after) sales network) – less so from a technological perspective.

Figure 83: Vehicle content level by sub-sector ($k)



Source: UBS

Figure 84: Powertrain capex EV vs. ICE



Source: UBS

A separate point not to be ignored: Because EVs have much fewer moving and wearing parts, the attractive spare parts business, which represents ~10-15% of an OEM's EBIT, is likely to shrink considerably long-term. However, this should take another 15-20 years longer, due to the replacement cycle of the existing car parc.

OEMs positively and negatively impacted by the theme

Daimler, Volkswagen, Renault best positioned

- **Europe:** Based on our findings in this report, we are confident that premium OEMs will have a sooner-than-expected return on current EV investments. More so, the OEMs without competitive EV product are at risk of forgoing revenue that is more profitable than feared. EV winners in the premium segment are also likely to enjoy the biggest CO_2 relief from EVs. But also in the mass segment, it will be essential after 2020 to offer a comprehensive line-up of EVs. Against this backdrop, we prefer **Daimler, Volkswagen and Renault. BMW** should invest more in EVs based on our market forecasts in order to protect its market share medium-term. The company faces the biggest revenue risk from Tesla's Model 3 (the 3-series is the closest peer). In a European context, **FCA** and **PSA** appear to be laggards on the theme.

GM leading mass maker, Tesla too expensive

- **US:** For US-centric OEMs Ford, GM and FCA that are underweight in premium, EVs are of lower relevance near-term. **GM** has clearly been ahead of the curve on electrification with seven years of development experience from the Chevy Volt PHEV that launched in 2010, and with the Bolt, GM is the first to market with a mass-market pure electric with a +200-mile range. However, the Chevy Bolt won't move the needle for GM's overall result given its low volume. Long term, with the sale of Opel in Europe, GM is leaving the potentially fastest-growing EV market. **Ford** has more modest EV experience with the C-Max and Focus EVs launching in 2012 and Fusion HEV in 2013; however, they will be quickly catching up as they spend $4.5bn over the next five years on 13 'electrified' vehicles (hybrid/PHEV/EV). **FCA** tends to lag GM and Ford on EV development. **Tesla** remains too expensive for the projected profitability and volumes level of the upcoming Model 3. Moreover, we see rising competition from the luxury automakers over the next few years as they roll out EVs.

Toyota leads thanks to hybrids

- **Asia: Toyota** is well positioned thanks to its brand image (UBS Evidence Lab survey confirmed the high credibility of the brand for EVs) and technological expertise in hybrid cars. It self-produces core components used in HEVs and BEVs, including batteries, motors, PCUs, etc., and already has a cost advantage from producing over 1.4 million HEVs/year. The additional R&D burden for BEV-related technologies is therefore relatively small. For a long-term response to environmental regulations, Toyota takes a portfolio approach of pursuing all products. Proactive in developing technology for BEVs, Toyota categorizes them as short/medium-range commuter cars and plans to progressively move from HEVs to PHEVs to BEVs. **Honda**, like Toyota, takes a portfolio approach to next-generation zero-emission cars. The company aims for PHEV/BEV/FCVs to comprise two-thirds of total sales by 2030. **Nissan** places BEVs at the core of its next-generation zero-emission cars and leads global BEV sales with the "Leaf", for which a model update is planned for 2017. We expect an expansion in the number of models Nissan launches to maintain a leading position in the space.

Figure 85: OEM EV heat map – who are the best and worst positioned players?

OEM	EV sales potential	Investment focus on EV	Potential CO_2 benefit	Residual value risk
Tesla	Very high	Very high	n.m.	Low
Daimler	Very high	High	High	High
JLR	Very high	Medium	High	Low
Volvo	Very high	Medium	High	Low
BMW	Very high	Medium	High	High
VW	High	High	High	High
Renault	High	Medium	High	Medium
Nissan	High	High	Low	Low
Toyota	High	Medium	Medium	Medium
PSA	High	Low	High	Low
Hyundai	Medium	Medium	Medium	Low
Ford	Medium	Medium	Medium	Medium
GM	Medium	Medium	Medium	Medium
Kia	Medium	Low	Low	Low
Mazda	Medium	Low	Medium	Low
Honda	Low	Medium	Low	Medium
FCA	Low	Low	Low	Low
Subaru	Low	Low	Low	Low
Suzuki	Low	Low	Low	Low

Source: UBS

Figure 86: EV targets and strategies by OEM (where available)

	Volumes	Models	Other
Volkswagen Group	20-30% of sales	>30 BEV	Investing in dedicated EV platform, €9bn investment for program over next five years
VW brand	1m unit sales		€1bn p.a. investment for 'ID' family in next few years, including R&D and plant re-tooling
Audi	25-30% of sales	3 BEV by 2020	
BMW	15-25% of sales		Investing in flexible EV architecture
Honda	67% of sales by 2030		
Mercedes	15-25% of sales	10 BEV by 2022	Dedicated EV platform, €10bn investment for total program
GM	~30k Bolts in 2017		Bolt architecture to underpin future BEVs
Ford	40% of line-up incl. hybrids	13 BEV + PHEV	$4.5bn by 2020E, including $700m to expand a Michigan plant to produce EVs
Volvo	1m cumulative by 2025		Using flexible EV architecture
Hyundai		4 PHEV, 4 BEV	Investing in dedicated EV platform
Kia		4 PHEV, 4 BEV	Investing in dedicated EV platform
Tesla	0.5m by '18, 1m by '20		35GWh cell capacity @ Gigafactory by 2018E, 50GWh by 2020E
PSA		7 PHEV, 4 BEV	Investing in dedicated EV platform
Toyota	1.5m HEV + 30k FCV		90% reduction in average CO_2 emissions of new vehicle sales by 2050E (vs. 2010 levels)
Nissan	20% of European sales		Dedicated EV platform with Renault
BYD	240k units	16 BEV, 5 PHEV	34 GWh battery capacity by 2020E; Rmb10bn capex each year
Changan	400k units cumulative	27 BEV, 7 PHEV	Rmb 2-3.3bn in next 3 years
SAIC	600k units (200k domestic brand)	13 BEV, 17 PHEV	Rmb 20bn through 2020E (including JVs)

Key

2017/18
2020/21
2025

Source: Company information, UBS

Financial implications for auto suppliers

OE business: >50% of the Bolt from outside the traditional supply chain

The supply chain looks very different for electric cars in general and for the Bolt specifically:

- **The content of "traditional" tier-1 suppliers is materially lower in the Bolt.** Based on Munro estimates for the powertrain, ADAS, connectivity / HMI modules, the content from "traditional" tier-1 suppliers in the Bolt is nearly zero. The other parts and components outside the scope of this teardown (interior, lighting, etc) are similar to an ICE car and therefore represent content from established suppliers.

- **The Bolt has a very high share of content supplied by the LG group of companies.** LG companies supply not only the battery, but almost the entire powertrain, including all electronic modules. On top, they supply connectivity / infotainment modules. Our teardown analysis based on Munro estimates suggests a total LG content of **$16.0k or 56%** of the total vehicle direct production costs (14% excluding the battery). Of course, an LG-assembled electronics module has substantial third-party semiconductor content, which is not subtracted from the aforementioned number. LG is a **new entrant** in the automotive space, but we expect more electronics or chemicals conglomerates to enter the space. For example, Samsung acquired infotainment specialist Harman in 2016. We believe that the LG-GM deal for the Bolt is very specific: We think it is possible GM committed to buy the non-battery components from LG in exchange for a very competitive battery cell price of $145/kWh. Therefore, the average content of "new entrant" suppliers in future EVs might be lower than in the Bolt.

Figure 87: Who supplies what into electric cars?

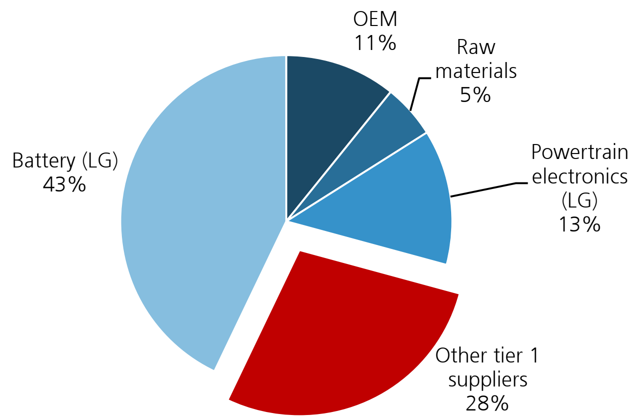
	Battery cell	BMS	Battery pack	Battery charger	Charge cord	Electric motor	Gear-box	Power distr. module	Inverter	DC/DC conv.	Thermal mgmt	Connec tions / wiring
Cell suppliers	■		■									
Aisin Seiki						□	■		□			
BWA						■	■				■	
Bosch						■		■	■	■	■	
Conti		■		□		■		■	■	■	■	
Delphi		■		■				■	■	■	■	■
Dana											■	
Denso		■		■		■		■	■	■	■	
Faurecia											□	
GKN							■					
Hella		■								■	■	
Hitachi	■		■			■			■			
Lear				■								■
Leoni												■
LG Electronics		■	■	■		■		■	■	■	■	
Magna							■				■	
Mahle						■					■	
Nidec						■						
Schaeffler							■					
SKF							Bearings					
Valeo/Siemens				■		■	■		■	■	■	
ZF						■	■		■	■		

Source: UBS

Note: Light blue cells indicate product is currently being developed

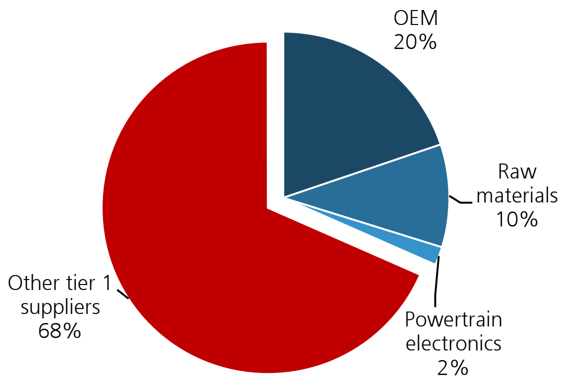
Aggregating the Chevy Bolt's content by sub-group gives the following picture. It can be seen that while the OEM content in the Bolt is slightly lower than in a generic comparable ICE car, the content from "traditional" tier-1 suppliers in the Bolt is meaningfully lower. LG has the biggest content share in the Bolt.

Figure 88: Chevy Bolt content breakdown



Source: UBS estimates

Figure 89: Generic comparable ICE car content breakdown



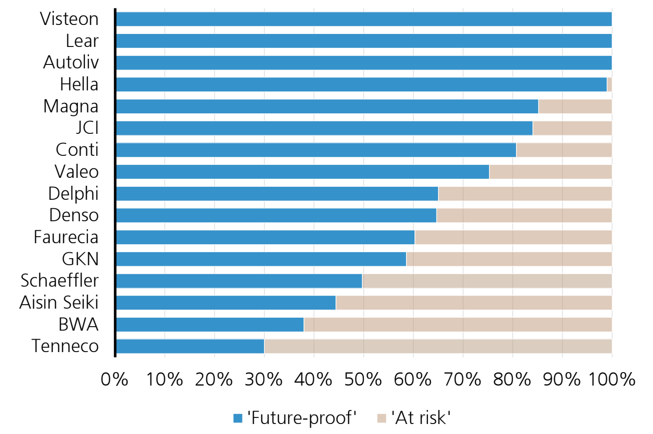
Source: UBS estimates

'Traditional' tier-1 suppliers could have less EV content growth than many investors think

The level of preparedness of our global auto supplier coverage varies greatly, and high R&D is required to develop EV products. Also, the level of vertical integration (ie, the value-add) of tier-1 players is also likely to shrink due to higher content of electronics from semiconductor suppliers. In light of the valuation premium of suppliers vs. OEMs, we see potential for disappointment in some names.

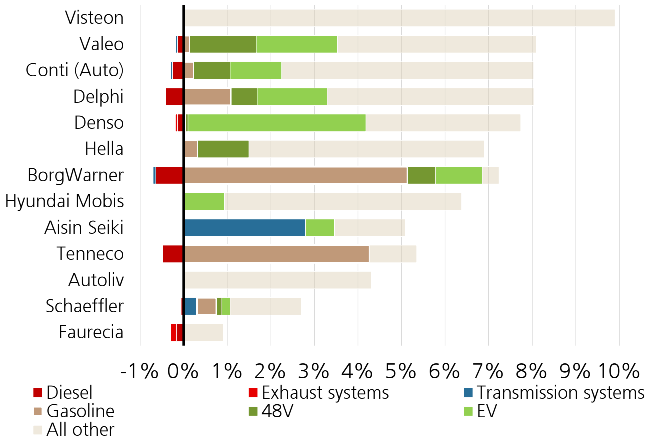
The Bolt example underscores the threat of new entrants. LG has >50% content share in the Bolt, higher than the "traditional" tier-1 suppliers altogether. This adds to competitive pressure in the industry and might imply lower market shares of the "traditional" tier-1 players than many people think. The headline content numbers that suppliers refer to in their investor presentations might overstate the opportunity, not least because today's costs are used. Even if a specific firm has, for example, potentially 3x the content in an EV compared to an ICE car, its actual value-add and its market share might be much lower than in ICE cars today.

Figure 90: UBS global supplier revenue mix – 'future proof' vs. at-risk business in EV world



Source: UBS estimates

Figure 91: Secular revenue CAGR impact of powertrain mix shift, 2016-25E



Source: UBS estimates

Threat in aftermarket business becomes relevant only in the very long-term

Aftermarket revenue pool to drop by ~60% in a 100% EV world

The difference in the number of moving and wearing parts has widespread implications for various players:

- The Bolt requires much **less maintenance** (negative for dealerships and repair shops).
- Over the life of the car, the Bolt will require much **fewer spare parts** than the Golf. This should undermine the spare parts business, which has been very lucrative for suppliers, OEMs and dealerships/repair shops alike.
- The amount of **liquids that require regular replacement is dramatically lower** in the Bolt. For example, there is no regular engine oil change.

Figure 92: Annual maintenance costs of the Bolt and Golf compared ($)

Chevrolet Bolt		VW Golf
790	**Retail value of wearing parts**	**3,950**
	Annual costs ($)	
	Common maintenance only (annualised)	
185	Parts replacement (incl. service)	450
55	Inspection (preventive)	75
15	Liquids (incl. service)	85
255	**Total maintenance**	**610**
	'Worst-case' maintenance (annualised)	
520	Battery/engine/transmission replacement	485

Source: JD Power, Edmunds, General Motors, Volkswagen, UBS

First Bolt inspection after five years

The dramatic differences can be seen at a glance in the respective owner manuals. Except for rotating the tyres and replacing the cabin air filter, the Bolt does not require any maintenance for the first **150k miles / 240k kilometres or five years**, whatever comes first. The Golf, however, requires servicing every **10k miles**.

Figure 93: Comparing the Bolt's vs. the Golf's service and maintenance schedule

VW Golf

Miles	**10k**	**20k**	**30k**	**40k**	**50k**	**60k**	**70k**	**80k**	**90k**	**100k**	**110k**	**120k**
Tyre rotation	X	X	X	X	X	X	X	X	X	X	X	X
Oil change	X	X	X	X	X	X	X	X	X	X	X	X
Oil filter change	X	X	X	X	X	X	X	X	X	X	X	X
Cabin filter change		X		X		X		X		X		X
Transmission fluid change				X				X				X
Spark plug change						X						X
Engine air filter change						X						X
Brake fluid change	**Every two years**											

Chevy Bolt

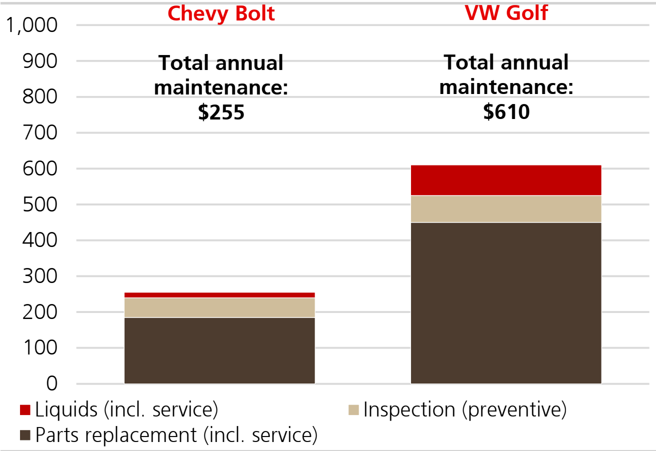
Miles	**7.5k**	**15k**	**22.5k**	**30k**	**37.5k**	**45k**	**52.5k**	**60k**	**67.5k**	**75k**	**82.5k**	**90k**
Tyre rotation	X	X	X	X	X	X	X	X	X	X	X	X
Cabin filter change			X			X			X			X
Vehicle coolant change	**Every five years**											
Brake fluid change												

Source: General Motors, Volkswagen

In the following, we model the after-sales revenue pool for the first 150k miles for both the Bolt and the Golf. On an annual basis, the maintenance costs for the Bolt are about $355 lower than for the Golf. The differences result from (1) no liquids replacement for the first five years; (2) fewer pre-emptive inspections; (3) less wearing on mechanical parts that require replacement.

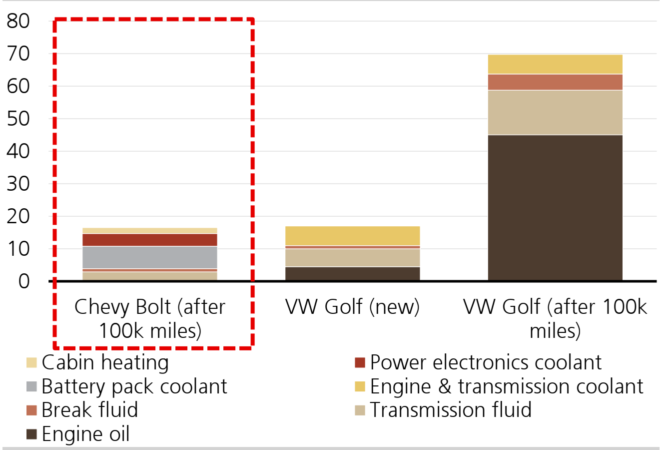
The only thing wearing faster in an EV are the tyres, due to the higher curb weight and higher torque of the vehicle. In our example, we assume that tyres wear 22% faster due to the 22% difference in the curb weight between the Bolt and the Golf. This represents an opportunity for tyre makers. However, as energy density in batteries keeps going up (and battery weight per kWh keeps coming down), the difference in curb weight might gradually disappear in the long run.

Figure 94: After-sales revenue pool shrinks up to 60% ($)



Source: UBS estimates

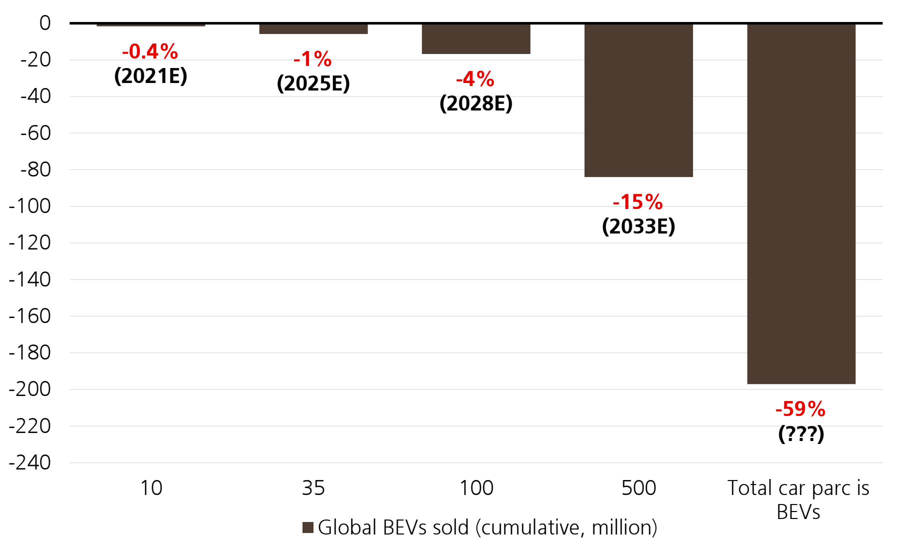
Figure 95: Fluids and coolants required ($)



Source: UBS estimates

Over the coming decades, the aftermarket revenue pool should shrink as ICE cars get scrapped and replaced by EVs. However, as the average life of a car is 15 years or even higher, the speed of change in the car park should be much lower than the shift that will be observed in the OE business. Therefore, we think the decline in the aftermarket revenue pool should be limited to ~1% on a 2025 view. We expect the impact to become much more meaningful only after 2030.

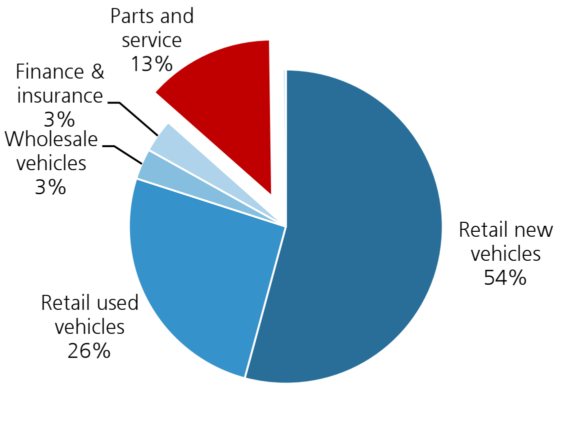
Figure 96: The global automotive aftermarket should ultimately shrink by 60%, although a material impact should not be felt before ~2030



Source: UBS estimates

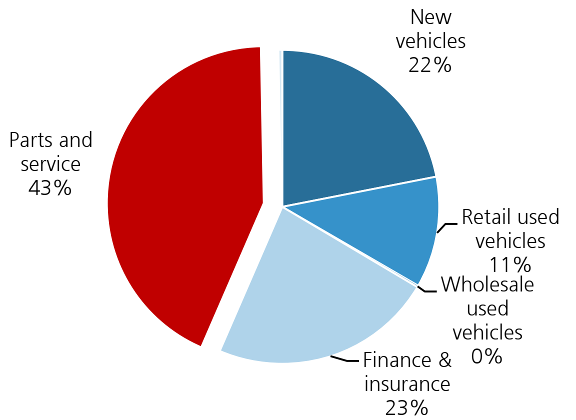
The almost maintenance-free electric car is also a big deal for dealerships. Their business model heavily relies on selling high-margin spare parts and providing regular service and maintenance to vehicles. Almost half of the gross profit of dealerships stems from parts and service.

Figure 97: Dealership revenue mix



Source: UBS (based on average numbers for AutoNation, Penske, SonicAutomotive, Group1, Asbury and Lithia)

Figure 98: Dealership gross profit mix



Source: UBS (based on average numbers for AutoNation, Penske, SonicAutomotive, Group1, Asbury and Lithia)

More supplier M&A ahead

Tier-1 suppliers need to adapt their portfolios to the car of the future, and at the same time, electronics giants as new entrants in automotive need to expand their portfolios, potentially including M&A. There have been several deals recently we would see in the context of a rapidly changing industry:

- **Samsung** buying infotainment specialist **Harman** (2016);
- **Delphi** announced it would spin its conventional powertrain business, but retain the EV powertrain activities;
- **Bosch** announced the disposal of its starter-generator business to a Chinese mining company.

We expect elevated M&A activity in the supplier space in the coming years, driven by the need to (1) adjust product portfolios to the automotive megatrends, (2) create balance sheet headroom for necessary investments and (3) crystallize hidden SOTP value. Spinning off or selling cash-generative (potentially under-valued) legacy businesses in the combustion engine space could prove an attractive way to create value for shareholders, in our view.

Suppliers positively and negatively impacted by the theme

Valeo and Conti to benefit most; Faurecia and Schaeffler at risk

- **Europe: Valeo** and **Conti** appear set to benefit most from the switch to EVs. On top, both companies have very small exposure to the "legacy" combustion engine business. Based on our expectation of a rapidly shrinking diesel share, mild hybrid gasoline engines should represent an important bridge technology that Valeo in particular should benefit from. The tyres business should also benefit from EVs (higher weight, better acceleration) as replacement demand should be positively impacted. **Michelin** is amongst our Buy-rated stocks. At the other end of the spectrum, **Faurecia** and **Schaeffler** have the largest exposure to combustion engines.

- **US:** We see **DLPH** as being best positioned for the shift to EVs given its exposure to wiring content in E/EA and power electronics in its Powertrain division. We see incremental opportunities for **LEA**'s E-System segment and **DAN**'s thermal business (within Power Technologies). We believe both **BWA** and **MGA** are relative hedged for the EV segment shift risk. On the other hand, we think **TEN** is the most at risk given its emissions exposure.

Delphi leads

Figure 99: Summary of US Supplier EV vs. ICE Exposure

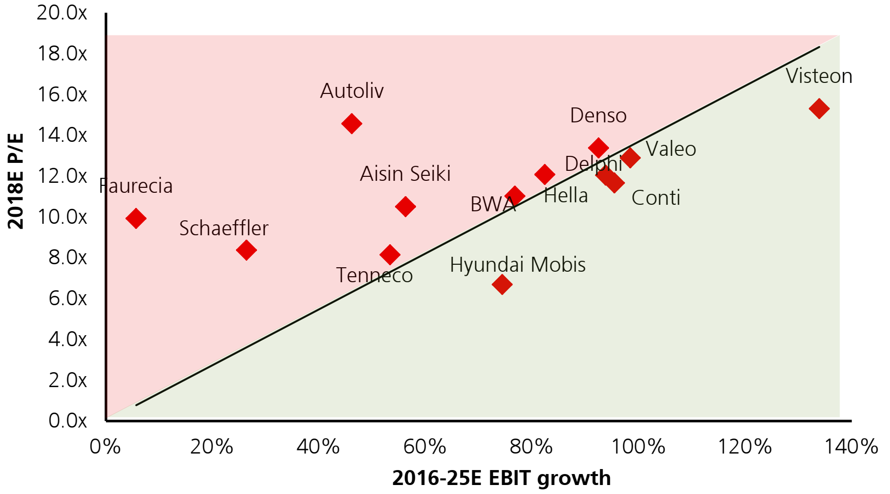
Company	% of EBIT from ICEs	At Risk ICE Content	Added EV Content	Commentary
DLPH	16%	Direct Injection ($300-500) Variable Value Train	High voltage cables ($335) On-board charger ($598) Inverter ($697) DC/DC Converter ($179) Battery Mang Sys ($222)	DLPH appears the best positioned of the US suppliers for EVs. Its core E/EA business should benefit from high-voltage cables and the on-board charger. On the Powertrain side, about 60% of this segment is at risk from the end of the ICE with content associated with direct injection and variable value train. However, this is more than offset by high content components like the inverter, DC/DC converter, the battery management system, and the supervisory controller/software.
LEA	N/A	N/A	High voltage cables ($335) On-board charger ($598)	35% of LEA's EBIT is from its E-System division, which benefits from high-voltage cables and the on-board charger.
DAN	N/A	N/A	Thermal Mang. ($250)	DAN is a leading supplier for light- and heavy-vehicle drivelines. The company sees incremental content opportunities in EVs from thermal management, e-axles, and electronic transmissions.
BWA	72%	Turbochargers ($250) Variable Value Timing Exhaust Gas Recirculation	E-Motor ($1,200) EV Transmission Thermal Mang. ($250)	BWA is a global leader in engine technology with Engine sales representing 72% of its profits; however, the recent Remy acquisition significantly hedges its exposure to EVs. Key BWA engine products include turbochargers, variable cam timing, and exhaust gas recirculation; today BWA's average content per ICE is ~$185/car. With the recent Remy acquisition, BWA now has exposure to e-motors ($1,200/car) and electric drivetrains, and it estimates it will have a content per EV of $285/car by 2023. With a similar number of competitors relative to its ICE business, BWA expects to maintain similar margins on its EV content as its ICE content.
MGA	21%*	ICE Transmissions 4WD/AWD Pumps	EV Transmission Thermal Mang. ($250)	21% of MGA's production sales are in Powertrain; however, most of the key products are largely driveline. MGA is the #1 supplier of transmissions, 4WD/AWD systems, and mechanical pumps. The company has hedged this exposure with its EV transmission and thermal management products, and sees an overall increase in addressable content of $500/vehicle.
TEN	65%	Exhaust ($300-500)	None	We believe TEN is the worst positioned of the US suppliers given ~65% of EBIT comes from Clean Air (emission), which has no content on an EV; fortunately only 14% of EBIT is Clean Air Europe, the region with the fastest EV growth.

* Reflects % of Production Sales as MGA does not disclose EBIT by division
Source: Company reports, UBS

Denso best positioned

- **Japan**: We see **Denso** as best positioned given its experience in manufacturing a wide range of core EV components, including electric motors, semiconductors and ECU. As a main supplier for Toyota HEVs, which makes more than 1.4m units annually, Denso has a competitive edge as it is able to benefit from economies of scale for many of these components. HEVs are complex from a technological perspective, requiring control of both electric and ICE components. Applying its HEV technology to BEVs should be relatively easy for Denso, as BEVs do not have ICE components. The additional R&D burden for BEV-related technologies is therefore relatively small.

Figure 100: Valuation vs. secular EBIT growth – identifying under- and overvalued auto suppliers



Source: UBS estimates (PE based on Bloomberg consensus EPS)

Figure 101: UBS cross-sector coverage impacted by the theme

Stock	Positively/ negatively impacted?	Price (lc)	P/E (2018E)	UBS Analyst
Analog Devices	Positively	81	20.3x	Stephen Chin
Albemarle	Positively	112	22.0x	John Roberts
Asahi Kasei	Positively	1,082	12.4x	Go Miyamoto
Atlas Copco	Positively	328	21.7x	Guillermo Peigneux Lojo
Continental	Positively	206	11.4x	David Lesne
Daimler	Positively	69	7.6x	Patrick Hummel
Delphi	Positively	87	11.4x	Colin Langan
GKN	Positively	352	9.5x	Cristian Nedelcu
GM	Positively	33	4 9x	Colin Langan
Hella	Positively	46	12.5x	Chervine Golbaz
Hexagon	Positively	392	18.6x	Guillermo Peigneux Lojo
Hyundai Mobis	Positively	249,500	7.4x	Young Chang
Infineon	Positively	20	18.1x	Gareth Jenkins
Lear	Positively	146	8.8x	Colin Langan
LG Chem	Positively	285,500	10.7x	Tim Bush
LG Display	Positively	28,800	6.0x	Nicolas Gaudois
Maxim	Positively	47	19.2x	Stephen Chin
Melexis	Positively	81	26.5x	Francois-Xavier Bouvignies
Nissan	Positively	1,103	6.8x	Kohei Takahashi
Renault	Positively	88	5.4x	David Lesne
Renesas	Positively	1,023	20.2x	Kenji Yasui
Samsung SDI	Positively	153,000	11.0x	Bonil Koo
Siemens	Positively	131	15.4x	Markus Mittermaier
Sika	Positively	6,300	22.2x	Patrick Rafaisz
STMicro	Positively	15	16.3x	Gareth Jenkins
Sumitomo Chem	Positively	604	8.7x	Go Miyamoto
Tesla	Positively	317	-86.8x	Colin Langan
Texas Instruments	Positively	82	19.3x	Stephen Chin
Toyota	Positively	6,093	9.6x	Kohei Takahashi
Umicore	Positively	59	23.3x	Geoff Haire
Valeo	Positively	64	13.0x	David Lesne
Volkswagen	Positively	143	5.4x	Patrick Hummel
ABB	Neutrally	25	17.6x	Guillermo Peigneux Lojo
Aisin Seiki	Neutrally	5,620	11 9x	Kohei Takahashi
Autoliv	Neutrally	103	15.8x	David Lesne
BMW	Neutrally	86	8.7x	Patrick Hummel
Dana	Neutrally	20	9.0x	Colin Langan
Denso	Neutrally	4,915	15.6x	Kohei Takahashi
Ford	Neutrally	11	5.6x	Colin Langan
Honda	Neutrally	3,167	8.3x	Kohei Takahashi
Hyundai	Neutrally	157,500	5.7x	Young Chang
Kia	Neutrally	36,900	5.5x	Young Chang
Kuka	Neutrally	109	31.8x	Sven Weier
Magna	Neutrally	46	7.2x	Colin Langan
Mazda	Neutrally	1,555	6.0x	Kohei Takahashi
Subaru	Neutrally	3,922	7.0x	Kohei Takahashi
Suzuki	Neutrally	5,235	17.5x	Kohei Takahashi
Visteon	Neutrally	103	14 9x	Colin Langan
BASF	Negatively	87	14.2x	Andrew Stott
Clariant	Negatively	21	13.2x	Patrick Rafaisz
EMS-Chemie	Negatively	668	33.6x	Patrick Rafaisz
Faurecia	Negatively	46	15.8x	David Lesne
FCA	Negatively	10	3 9x	Patrick Hummel
Johnson Matthey	Negatively	3,143	14.5x	Andrew Stott
LG Electronics	Negatively	79,000	12.2x	Nicolas Gaudois
Panasonic	Negatively	1,373	14.4x	Kenji Yasui
PSA	Negatively	19	9.1x	David Lesne
Rheinmetall	Negatively	87	13.2x	Sven Weier
Sandvik	Negatively	140	20.5x	Guillermo Peigneux Lojo
Schaeffler	Negatively	15	8.7x	Julian Radlinger
SKF	Negatively	183	15.7x	Markus Mittermaier
Tenneco	Negatively	58	7.4x	Colin Langan
W.R. Grace	Negatively	70	17 9x	John Roberts

Source: UBS estimates

Impact on various industries at a glance

Auto OEMs

EV impact on sector … **Growth:** → **Margins:** ↘ **ROIC:** → **Valuation:** →

KEY FINDINGS

Q: What did we learn from the teardown?

EVs are cheaper to build than we thought. Cost parity to consumers should be reached starting 2018, which is why we raise our 2025 EV sales forecast by ~50% to 14.2m. We expect 30% EV penetration in Europe by then.

Q: What was the most non-consensual finding?

The detailed P&L for the Chevy Bolt and the upcoming Tesla Model 3. We demonstrate that at a transaction price of $41k ($6k above the base price), Tesla should break even on the Model 3. This is likely to be exceeded.

FINANCIAL IMPACT

Q: What will be the impact on the industry?

Earlier cost parity implies sooner and higher returns on EVs, in particular in the premium segment and, regionally speaking, in Europe. European OEMs can also benefit from a strong tailwind to CO_2 fleet targets post 2020. The flipside of the accelerated shift is the residual value risk to fincos and lower contribution from highly profitable aftermarket long-term.

SECTOR HEALTH CHECK

Q: Is the industry prepared for disruption from EVs?

Mixed picture. Tesla aside, Daimler and Volkswagen are showing the biggest effort. Overall, investments in EVs (R&D and capex) have risen sharply over the past 12 months.

SECTOR VALUATION

Q: Could the trend to EVs lead to a change in sector valuation multiples?

There is a negative impact, which is likely to stay through the transition period. After 2020, however, returns should become visible and there could be major CO_2 tailwinds, in particular in Europe and China. OEM shares also trade at a discount today due to expected earnings headwinds from CO_2 targets.

STOCK IMPACT

Q: What stocks should be impacted most positively and negatively?

We believe stocks with skew to (1) premium and (2) Europe and China are set to enjoy fastest EV sales growth.

MOST FAVOURED on the theme

Stock	2018E PE	EPS impact 2025	Comment
Daimler	7.6x	10-25%	Highest R&D in EV, likely premium leader
Volkswagen	5.5x	10-25%	Can become global #1 EV producer
Renault	5.5x	10-25%	EV investments already done
GM	4.5x	10-25%	EV investments already done, launched the Bolt

LEAST FAVOURED on the theme

Stock	2018E PE	EPS impact 2025	Comment
FCA	3.8x	<10%	No EV platform; exposure to US non-luxury
PSA	10.4x	<10%	Low investment focus on EV so far
SUBARU	7.1x	<10%	Low investment focus on EV; exposure to US mass

Patrick Hummel, Analyst patrick.hummel@ubs.com +41-44-239-7923
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Auto suppliers

EV impact on sector … **Growth:** **Margins:** **ROIC:** **Valuation:**

KEY FINDINGS

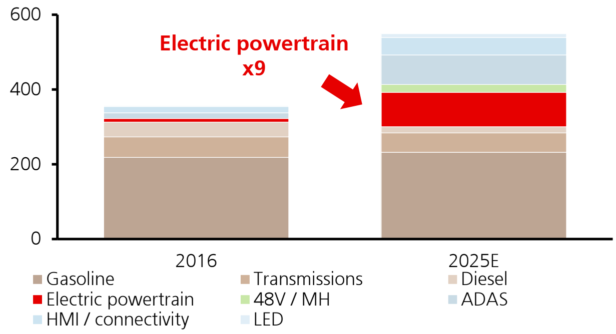
Q: What did we learn from the teardown?
Mixed. More supplier content in an EV, but the Chevy Bolt has >50% content from LG, a new entrant in automotive. The aftermarket revenue pool for the Bolt is ~60% smaller than for a comparable ICE car.

Q: What was the most non-consensual finding?
No "traditional" tier-1 supplier content in the Bolt's powertrain. About $4k electr(on)ics content in the Bolt, all of which assembled by LG. Only 35 moving + wearing parts in the Bolt, vs. 167 in the VW Golf.

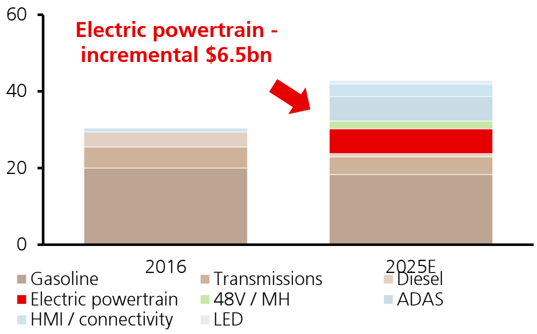
FINANCIAL IMPACT

Q: What will be the impact on the industry …
Mixed. Supplier with strong exposure to EV/hybrid and other megatrends (autonomous driving, connectivity, LED, etc) likely to sharply outperform industry growth; those with big combustion engine legacy business likely to underperform. Electronics giants likely to put margins and market shares of traditional suppliers under pressure.

Revenue pool (€bn) – source UBS



EBIT pool (€bn) – source UBS



SECTOR HEALTH CHECK

Q: Is the industry prepared for disruption from EVs?
Some players like Valeo, Conti, Delphi and others yes; companies like Faurecia and Schaeffler need much more transformation, we believe.

SECTOR VALUATION

Q: Could the trend to EVs lead to a change in sector valuation multiples?
We should continue to see a wide range of multiples depending on the exposure to secular trends. But overall there is a risk the relative valuation premium of suppliers shrinks as the threat of new entrants in EVs is likely under-estimated.

STOCK IMPACT

Q: What stocks should be impacted most positively and negatively?
Our preferences reflect our view on who's going to be a winner / loser on secular trends in automotive.

MOST FAVOURED on the theme

Stock	2018E PE	EPS impact 2025	Comment
Valeo	13.3x	15-20%	JV with Siemens to supply EV powertrain parts
Conti	11.5x	10-15%	Developing EV powertrain solutions in-house
Delphi	11.3x	10-15%	Spinning off ICE powertrain to focus on EV
Hyundai Mobis	7.5x	5-10%	Sole supplier of EV powertrain parts to Hyundai

LEAST FAVOURED on the theme

Stock	2018E PE	EPS impact 2025	Comment
Schaeffler	8.6x	<5%	Highly skewed to ICE powertrain
Faurecia	15.8x	0%	Leading PV ICE exhaust systems player
Tenneco	7.5x	0%	Exposure to PV exhaust systems but strong in CV

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EV battery tech (battery cell suppliers)

EV impact on sector … **Growth:** **Margins:** **ROIC:** **Valuation:**

KEY FINDINGS

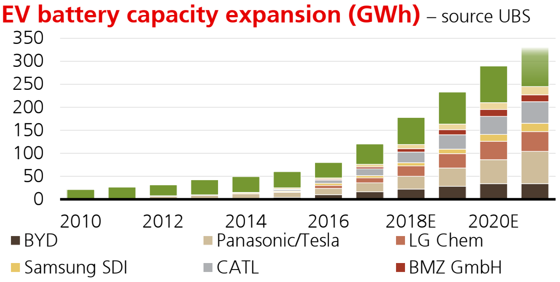
Q: What did we learn from the teardown?
Our teardown analysis validated our view that a mass-market EV passenger vehicle is viable from a costs perspective. This is leading our Autos Team to raise its EV penetration forecasts longer term. In turn, this will likely support further capacity build-up by the key battery cell suppliers, which will eventually lead to lower costs and improved profitability. In addition, the teardown gave us more details on the technology used by known suppliers LGE (battery packs) and LG Chem (battery cells).

Q: What was the most non-consensual finding?
We forecast that EV makers can reach the break-even point sooner than market expectations, which would help the overall profitability of its supply chain. We expect the largest EV battery makers to turn profitable by 2018-19.

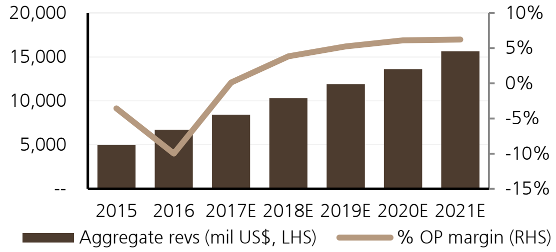
FINANCIAL IMPACT

Q: What will be the impact on the industry?
We forecast that both revenues and operating profits should grow significantly. EV battery cell makers have been loss-making so far, but we expect a turnaround in profits thanks to growing industry demand, increasing production capacity and improving battery technologies.

EV battery capacity expansion (GWh) – source UBS



EV battery maker revenues and OP – source UBS



SECTOR HEALTH CHECK

Q: Is the industry prepared for disruption from EVs?
Yes, the battery packs/cells are core components and the most expensive part of EVs. All major EV battery makers are expanding their production capacity and developing battery technologies at the same time. The battery makers are closely working with auto OEMs from an R&D phase to mass production.

SECTOR VALUATION

Q: Could the trend to EVs lead to a change in sector valuation multiples?
Yes, we think so. Currently, most of the battery makers are losing money in their EV battery business. However, we expect that multiples could be re-rated when investors see the evidence of EV makers making profits.

STOCK IMPACT

Q: What stocks should be impacted most positively and negatively?
This should overall be very positive for EV battery makers.

MOST FAVOURED on the theme

Stock	2018E PE	EPS impact 2025	Comment
LG Chem	10x	>30%	UBS APAC Key call Buy
Samsung SDI	7.5x	>30%	

LEAST FAVOURED on the theme

Stock	2018E PE	EPS impact 2025	Comment
Panasonic	13x	<30%	

Q: What else should investors know? / the sector impact in more detail
The battery has been segmented by type (NMC, NCA, LFP, etc) and auto brands. We think this will continue for a while due to the natural stickiness between auto OEMs and battery makers. We expect China to remain closed to foreign battery makers; Chinese battery makers would be the only beneficiaries from domestic EV growth.

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Capital Goods

EV impact on sector: Varies considerably by company (details in the following pages for each company)

KEY FINDINGS

Q: What did we learn from the teardown?

Given the breadth of our coverage, the impact analysis has to be done at company by company level. We see an impact from changing material usage (more lightweight materials leading to impacts on machining as well as joining technologies: Atlas Copco, Sandvik), incremental auto-related capex from battery manufacturing to upgrades on manufacturing lines (all being else equal, a benefit to Siemens, ABB, Kuka), and finally direct component supplies into electric vehicles where we see different demand patterns (e.g. 50-75% fewer bearings a negative for SKF and Rheinmetall, needing to shift away from their core strengths which are in ICE components).

Q: What was the most non-consensual finding?

Timing. We believe this topic is seen as important, but still rather far away in terms of having a material impact on our companies. We have heard comments, e.g. at SKF, that there is still quite some time to get ready for this transition. However, it appears from the teardown that the value proposition to the end user could be interesting earlier than people thought, and as a result EV adoption (at least in Europe) might be faster and higher than previously thought. This means the 'time to get ready' and win in the space shrinks.

FINANCIAL IMPACT

Q: What will be the impact on the industry …

Not material in the near and medium term (up to a three-year view) in aggregate, given the diluted impact for most companies in the coverage. However, given we see a steeper-than-anticipated adoption rate in Europe in the first half of the 2020s, we believe this will become selectively material (e.g. Siemens/Valeo JV).

SECTOR HEALTH CHECK

Q: Is the industry prepared for disruption from EVs?

We see automation players prepared to serve incremental demand from any platform switches or incremental capex in the space (the product is there). For instance, German car OEMs are planning to upgrade existing lines and we estimate BMW and VW will spend an incremental €10bn and €9bn, respectively, over the next c. five years on their BEV platform rollouts. It has not been disclosed how much of this will go towards tooling, but we expect upgrades to existing lines. We believe the industry is ready for this transition and will give companies such as Siemens, ABB, Hexagon and Kuka the opportunity for holistic discussions around production set-up. We see Siemens as particularly well positioned given its front-to-back offering from design software to motion control and factory automation. Component suppliers (Rheinmetall, SKF, etc) will need to adapt their products, but we believe this is a core topic for management teams at the moment.

SECTOR VALUATION

Q: Could the trend to EVs lead to a change in sector valuation multiples?

Not material in the near term at a sector level, but certainly for individual companies, as we see adoption rates pick up. We provide a detailed company by company view below.

STOCK IMPACT

Q: What stocks should be impacted most positively and negatively?

This list is grouped specifically on EV impact, not our aggregate view on the companies.

MOST FAVOURED on the theme

Stock	2018E PE	Comment
Siemens	15.3x	Incremental auto capex good for Digital Factory business (PLM, factory automation, motion control, etc, estimate ca. 30% of sales driven by autos). Charging infrastructure positive for Energy Management ePowertrain pick-up positive for 50/50 JV with Valeo
Atlas Copco	22.1x	Incremental Auto/Electronics capex a positive for Industrial Technique (critical joint assembly platforms) and, to a lesser extent, Vacuum Technique (Vacuum pumps used for electronics manufacturing)
Hexagon	18.8x	Incremental Auto capex a positive for the Industrial Ent. Solutions (3D modelling CAD/CAM, sensors and simulation)
GKN	9.6x	Higher content to offset lower market share and lower margins

LEAST FAVOURED on the theme

Stock	2018E PE	Comment
SKF	16.3x	~ 20% of SKF's automotive sales relates to drive-train components for cars and light trucks (largely cars). At 100% EV adoption, about 5% of SKF's top line today would disappear.
Rheinmetall	13.1x	Theoretical content per car could be equal, but we note that Rheinmetall has a leading position in the traditional product range today. It will remain to be seen how this plays out for future product.
Kennametal	21.4x	Legacy ICE component business at risk
Sandvik	20.4x	Decreased steel and parts content combined with the transition to the electric motor from the combustion engine should impact Sandvik Machining Solutions

Company level analysis

ABB

ABB's principal exposure to the Automotive industry is found in the Robotics and Motion Business unit, which has an 18% revenue exposure, or 4.1% of group, and has seen growth coming particularly from Asia over the past years as China has ramped up its light vehicle production capacity. Within the exposure, the key product is industrial robots and systems, which, across all end-markets, made up 7% of group revenue in 2016, and likely a considerable part of the revenue exposure to the Automotive sector as well. We believe the gradual adoption of BEVs will alter the type of robot heads used in the production process, notably in the robots associated with the power train and the joining of vehicle body parts, but that the total number of robots and the automation levels in the plant will remain stable or increase slightly, meaning the overall impact could be considered as limited.

Atlas Copco

We estimate that >50% of Atlas Copco's Industrial Technique revenues and profits today (or c.>7% of group sales) could benefit from the increased penetration of hybrid/electric vehicles. In this segment, Atlas Copco provides the motor vehicle industry with accurate fastening tools that minimize errors in production and allow full traceability of operations, as well as adhesives and sealants, and self-pierce riveting and rivets equipment. An increased number of new models and platforms emerging from the rising penetration of EVs in the market should inevitably lead to increased spending in these areas, in our view. We also estimate a very limited but positive impact for the automotive exposures in Atlas Copco's Vacuum Technique (vacuum products, exhaust management systems, valves and related products) and Compressor Technique division, which we estimate at <5% of group sales.

GKN

We estimate that 15%-20% of GKN's group profits today could be at risk in an all-hybrid/electric world. Yet, we take comfort in: a) GKN's leadership incumbent position in eAxles and eTransmissions with more than 300k units on the road; b) our expectations for higher content for hybrid/electric vehicles to offset potential lower market share in a more competitive market. The main findings of our teardown exercise support our view: i) we concluded that the e-drive module is a simple product – and we expect relatively low entry barriers will lead to an intensification of competition in this space; ii) the teardown offered us explicit cost estimates of the electric drive module – which are aligned with UBS estimates – supporting the view that for GKN the higher content per vehicle has the potential to offset the lower market share/lower margins on EVs. Concerns that Driveline profits could decline long-term, as hybrid/EVs gain market share, are overdone – and we expect GKN's Driveline profits to structurally grow long term.

Hexagon

Around 25% of Hexagon's Industrial Enterprise Solutions revenues and profits today (or c.10% of group sales) could be benefiting from the increased penetration of hybrid/electric vehicles in the car market. In this segment, Hexagon offers mainly metrology sensors and software products for statistical process control, CAD/CAM, industrial engineering and schematics design, 3D modelling and visualization, stress analysis, procurement, fabrication, construction and information management for various industries. An increased number of new models and platforms emerging from the increased penetration of EVs in the market should inevitably lead to rising spending in these areas, in our view. With the introduction of EVs into the market, the industry faces ever-reducing design-to-production times, which will need extra spending in industrial metrology and 3D measurement as enablers of productivity (including a move from off-line quality inspection to near-line or in-line measurement techniques, enabling higher sampling rates and faster inspection times, even into automating inspection and integrating metrology data with product lifecycle management systems, statistical process control and supply-chain management software, optimizing ramp-up times and minimizing rework and scrap.

Kennametal

Around 20% of Kennametal's revenues come from the automotive/transportation sector. Kennametal provides a variety of products and solutions that address metal cutting/machining, surface finishing and protection, and advanced materials. Kennametal provides cutting tools for a variety of engine-related products, including shafts and turbines, exhaust manifolds, transmission housings, cylinder blocks and heads, and crankshafts. In turbochargers, Kennametal provides metal shaping, surface finishing and technology, and advanced materials. The Bolt analysis shows that several legacy components are at risk (traditional transmissions, exhausts, turbos, blocks, etc.), and that e-motors do not require the same degree of metal cutting that ICE require. Heat impact and corrosion would also be less relevant. Accordingly, we think Kennametal would face headwinds in these products over time.

Rheinmetall

Rheinmetall's product portfolio is heavily geared into combustion engines (pistons, air supply, emission control and pump products, such as EGR (exhaust gas recirculation) systems, solenoid valves and electric coolant pumps). Rheinmetall has several products for hybrid and electric vehicles, too. It does expect that its theoretical content by car in the next few years will be on a par with today's value for combustion engines. However, we take a slightly different focus on that end, as we believe this number needs to be seen in the context of market share. Rheinmetall has leading positions in its traditional product range, whereas we assume a less favourable position in products for hybrid and electric vehicles. Therefore, we think that, from today's point of view, rapid adoption of electric vehicles would be negative for Rheinmetall, while a more steady evolution would allow it to position itself more meaningfully in electric, too.

SANDVIK

We believe the penetration of EVs in the light vehicle market will have a negative impact on Sandvik's revenues and profits, as it will have clear implications for Sandvik Machining Solutions' (SMS) revenues and profits (accounting to 40% of group revenues and >50% of profits). With c.30% of SMS revenues going to the Automotive segment (or over 10% of total group sales), the penetration of EVs in the market should negatively impact the demand for cutting tools in three different ways, in our view: 1) As our UBS Evidence Lab research indicates, EVs could have up to 75% fewer moving parts, which should result in significantly lower need for tooling work. 2) Even though related to the previous point, it is worth to mention that, as our expert channel checks indicate (click here), up to 80% of the cutting tool work needed in a car happens in the manufacturing of the combustion engine. 3) Finally, although it will depend on models and platforms (e.g. Tesla >80% aluminum content, Chevrolet Bolt >60% steel content and the average combustion engine car 80% steel content), the steel content in an EV should decrease materially in favour of lighter materials such as aluminum, which will require lower tooling intensity.

SIEMENS

We see several divisions benefit from the EV adoption (link to our recent note on Siemens).

1) **Digital Factory**: We expect incremental auto capex from factory upgrades related to BEVs and estimate that ca. 30% of Digital Factory is driven by automotive demand. For instance, German car OEMs are planning to upgrade existing lines and we estimate BMW and VW will spend an incremental €10bn and €9bn, respectively, over the next c. five years on their BEV platform rollouts. It has not been disclosed how much of this will go towards tooling, but we think Siemens stands to benefit with its front-to-back offering in the space from design software to factory automation, motion control, etc. Potentially, major upgrades may trigger changes in PLM software providers, as we saw at Daimler a few years ago, when it switched from Dassault Systems to Siemens. We believe these decisions are nowadays being made at the C-level and occur at times of strategic changes in global production / design requirements in an effort to optimize global product development.
2) **Energy Management:** Siemens produces both high-power charging stations (power ratings up to 350kW), as well as charging units for the home or semi-public areas (WB140A). We estimate that the total investment required to put this infrastructure in place between now and 2025 in Europe alone is $14bn, thereof $12bn for slow chargers and $2bn for high-power charging / fast chargers. Globally we estimate an investment requirement of $39bn, thereof $10bn for public fast charging (e.g. on highways) to fulfill our EV production forecast.
3) **Siemens/Valeo JV (reported as part of CMPA, below the line):** This JV was established in 2016 (50/50) and it was reported that they have already obtained an order backlog of €1.6bn. Siemens largely provides full drivetrain integration, electric motors, inverters and converters to this effort, whereas Valeo contributes generators and on-board chargers.

SKF

We expect that an electric vehicle will have 50-75% fewer bearings compared to today's combustion engine cars (link to our publication on this). We expect bearing content in the drive-train content to drop by at least 80%. We estimate that currently ca. 7-8% of SKF's sales are drive-train related, which would suggest that at 100% EV adoption, more than 6% of the top line would be at risk.

Capital Goods

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Chemicals

EV impact on sector … **Growth:** **Margins:** **ROIC:** **Valuation:**

KEY FINDINGS

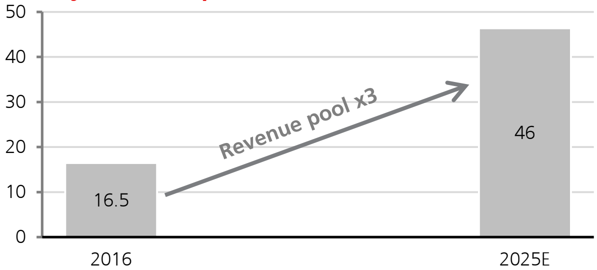
Q: What did we learn from the teardown?
We learnt that the falling cost of battery materials should facilitate a major shift in EV penetration, especially in Europe (where diesel has a high share, CO_2 emission targets are stringent and fuel costs are significantly higher than, say, the US). A faster-than-expected migration to EVs would pose a number of challenges for chemicals companies exposed to the combustion engine, as well presenting clear opportunities for chemical EV 'pioneers'.

Q: What was the most non-consensual finding?
A material risk to demand for polymers in EVs. At least in the example of the Chevy Bolt 'Teardown' for the engine, wheels and exhaust system, the content value of polymers is significantly lower (9kg vs 24kg for a VW Golf) than a combustion engine. Unless this is compensated by much heavier polymer usage in interior trims and seating, then this is currently a risk to several companies' current upbeat guidance and commentary around EVs.

FINANCIAL IMPACT

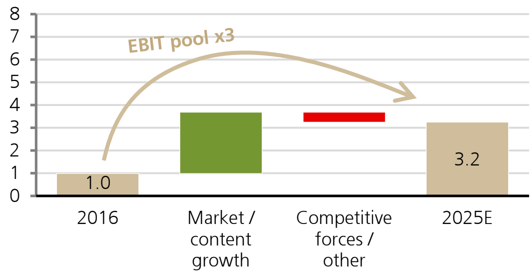
Q: What will be the impact on the industry?
A wide range of impacts, but hard to argue it's positive for the sector overall. The most negative impact from this technology disruption should be among the autocatalysts producers (BASF, Johnson Matthey and Umicore). The UBS view, if correct, would lead to such material revenue loss that it would materially outweigh the positive impact of ongoing legislation tightening for gasoline and diesel engine emission standards. It is still plausible, however, especially in the premium end of the auto market, that content growth for polymer and adhesives companies is positive (aiding companies such as Sika). Finally, we have to consider the long-term risk to future hydrogen growth in the industrial gas industry, as well as the process catalyst companies (Clariant, W.R. Grace, Johnson Matthey), given a likely negative impact on refining demand.

Revenue pool for EV (€bn): beneficial for chemicals battery materials producers



Source: UBS

EBIT pool (€bn): Opportunity at the cost of diesel & gasoline exposure



Source: UBS

SECTOR HEALTH CHECK

Q: Is the industry prepared for disruption from EVs?
Yes, but not likely at the pace we suggest. Management teams have been looking to deepen exposure to the fast-growing EV segment in recent years. Similarly management, no doubt, will be planning strategies around various powertrain scenarios. Perhaps, though, none of them see a '1 in 3 world' for European EV penetration by 2025.

SECTOR VALUATION

Q: Could the trend to EVs lead to a change in sector valuation multiples?
Unlikely to be highly influential beyond a few names. Whilst certainly a game changer for the autocatalysts' companies, we think the sector as a whole is too diversified to be able to claim a major imprint on multiples that investors are willing to pay. Supply dynamics (especially in China), energy costs curves and construction and consumer end-markets should remain highly influential in the debates.

STOCK IMPACT

Q: What stocks should be impacted most positively and negatively?
The significant migration to EV powertrains could significantly impact a number of key stocks in our sector, both positively (Albermarle, Sika, Umicore) as well as negatively (BASF, Clariant, Johnson Matthey).

MOST FAVOURED on the theme

Stock	2018E PE	EPS impact 2025	Comment
Umicore	23x	+30%	Net beneficiary from leading position in cathode materials, outweighing diesel exposure in catalysts and risk to PGM pricing in recycling operations
LG Chemicals	10x	+15%	LG Chemicals has between 10% and 14% of global battery capacity. We expect the business to break even by 2018 and to grow by almost 3x 2017e-2021e
Asahi Kasei	12x	10-20%	We assume an EBIT increase of ¥15-30bn for LIB separators by 2025 (2017 base)
Sumitomo Chem	9x	5-15%	We assume an EBIT increase of ¥8-25bn for LIB separators by 2025 (2017 base)
Albemarle	22x	0-10%	We estimate c30% of 2018e EBITDA is battery-grade lithium, and we model that growing to c.60% by 2025, with batteries for EVs being the largest market by then
Sika	18x	3-5%	c.8% of group exposed to high growth adhesives and sealants in EV market

LEAST FAVOURED on the theme

Stock	2018E PE	EPS impact 2025	Comment
Johnson Matthey	15x	(15-20%)	The biggest net negative impact due to size of light-duty diesel (16% of EBIT) and currently modest position in battery materials
BASF	15x	(3-4%)	We assume a loss of c€150m of EBIT in autocatalysts and PGMs by 2025 as compared with 2017e
Clariant	14x	(1-2%)	Refinery is c15-20% of Catalysis and c10% of Natural Resources, i.e., c.5% of group
EMS Chemie	33x	-	Over 60% of sales exposed to transport end-markets, largely specialty polymers

Q: What else should investors know?

The Autos sector is one of the key end-markets for the Chemicals industry (we estimate around 13% of the sector's revenues directly, but up to 20% of revenues indirectly, i.e. to products that ultimately end up in a vehicle). As a consequence, this should be a major theme for the industry, but we will most likely see positives and negatives counterbalancing each other. Higher content growth for polymers may well continue in both OEM production and EV infrastructure. Conversely, lower demand for components for the combustion engine, such as auto-catalysts and certain engineering plastics, should ensue. The less straightforward analysis is on the energy supply chain overall, considering that there may well be bottlenecks in the pace of EV infrastructure build-out. We capture these risks in our downside scenarios.

Figure 102: End-market splits by stock: we estimate around 20% directly and indirectly are auto-related

	Transport (incl Aerospace)	Agriculture	Chemicals Plastics	Housing /Glass/ Construction	Consumer Goods	Electronics Solar	Oil&Energy	Food Feed	Health Care	Paper & Packaging	Steel & Metal	Textiles	Other
Air Liquide	9%		11%		9%	3%	20%	5%	5%		10%		28%
Akzo Nobel	17%			43%	18%								22%
Arkema	10%		34%	8%	11%	4%	14%	3%					16%
BASF	13%	8%	15%			5%							60%
Covestro	20%		8%	17%	27%	12%							16%
Clariant	5%	5%	27%	14%	10%	5%	12%			10%	3%		9%
Croda	7%	5%	12%	13%	35%		7%		15%			6%	0%
DSM	7%			6%		5%		59%	7%	7%		1%	8%
Elementis	18%			37%	8%		12%				9%	3%	13%
EMS Chemie	64%			7%		5%							24%
Evonik	17%	1%	12%	15%	17%	6%	3%	15%	4%	2%			8%
Frutarom								90%	10%				0%
Givaudan					48%			52%					0%
Johnson Matthey	61%		13%				12%		11%		3%		0%
K S		45%	14%		8%			6%					27%
Lanxess	35%	15%	15%	10%	10%	5%							10%
Linde			17%		5%	5%		5%	20%		11%		37%
Novozymes		15%			33%		18%	27%	7%				0%
Sika	15%			79%									5%
Solvay	26%	5%		11%	21%	6%	8%	5%					18%
Symrise					40%					60%			0%
Syngenta		85%			10%			5%					0%
Synthomer			27%	17%					2%	34%		19%	1%
Umicore	35%					23%			11%				31%
Victrex	22%					25%	12%		6%				35%
Wacker Chemie	4%		14%	22%		41%						4%	15%
Yara	5%	85%	5%					5%					0%
AVERAGE	**13%**	**9%**	**8%**	**10%**	**11%**	**5%**	**4%**	**10%**	**3%**	**4%**	**1%**	**1%**	**13%**

Source: Company data, UBS estimates

Polymers – teardown reveals lower polymer content in EV powertrain

Probably one of the most surprising outcomes of the teardown was the lack of polymer content in the Chevy Bolt. The below shows the kg weight of polymers on the Bolt versus a TSI VW Golf and we can clearly see that for the Engine, gearbox, battery cell, fuel tank, exhaust system, wiring, wheels and chassis, there was actually less weight than for the combustion engine. *That said, the caveat that we would provide is that the analysis did not include the interior trim or seating or roofing.* Many of our companies have already stated that here they expect increased content, eg, for polyamides, polycarbonates and, in some cases, higher-spec grades of MDI.

Figure 103: Polymer content Bolt versus Golf (kg) – on major % of vehicle (engine, gears, battery, etc)

	Materials	
Chevy Bolt	**Total (kg)**	**VW Golf**
652	Steel	707
169	Aluminum	97
91	Copper	50
40	Iron	102
24	Rubber	24
640	Other	342
9	**Polymer**	**24**

Source: UBS estimates

Figure 104: Battery cell materials (kg)

Weight distribution by material	
Aluminum	68
Graphite	63
Steel	57
Iron	40
Copper	33
Cobalt	24
Nickel	24
Manganese	22
Polyester	15
Lithium	10
Other	80
Total	**436**

Source: UBS estimates

Autocatalysts: expect a significant loss of revenue from diesel and gasoline

Whilst electrification seems to offer some significant opportunities, the risk remains that the current technology JMAT has in battery materials (LFP) is less impactful for medium- and long-range battery EVs (albeit it has a role to play in plug-ins, busses, delivery vans). Consequently as we explore in our separate company reports, we see JMAT as a net loser of this UBS base case for powertrains and Umicore a net winner. We assume around $1,200/vehicle for JMAT's battery materials and a 3% global share. We have a similar value per vehicle for Umicore, but an initial 30% market share, fading to a 20% share by 2025E.

Figure 105: Value potential in each powertrain

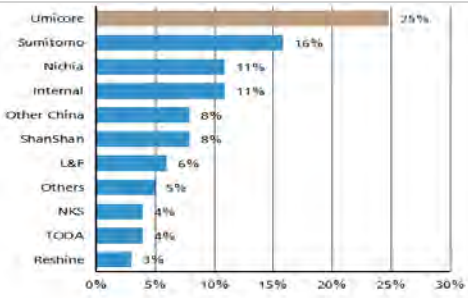
	12v Starter	Micro HEV	HEV	PHEV	BEV medium	BEV long	Delivery van	E-bus
LFP	Major	Major	Major	Major	Minor		Major	Major
NMC		Minor	Major	Major	Major	Major	Minor	
NCA			Minor	Minor	Minor	Major	Minor	
LMO			Minor	Major	Major			

Major Minor

Source: Johnson Matthey

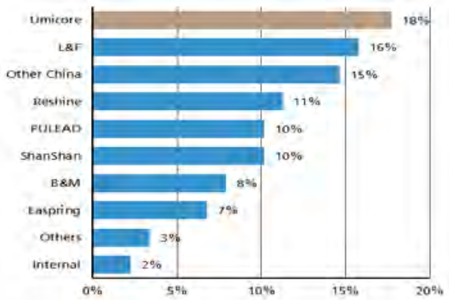
Market shares for the key battery materials producers can be seen below, for each key category. We see Umicore as better able to compensate for its future loss of combustion engine technologies.

Figure 106: 2016E NMC (Nickel manganese cobalt) battery market share



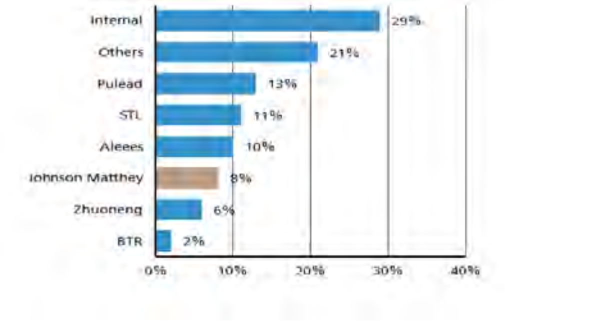
Source: UBS estimates, IHS

Figure 107: 2016E LCO (Lithium cobaltite) battery market share



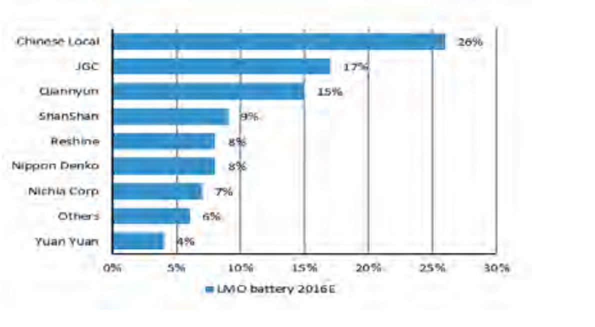
Source: UBS estimates, IHS

Figure 108: 2016E LFP (Lithium iron phosphate) battery market share



Source: UBS estimates, IHS

Figure 109: 2016E LMO (Lithium manganese oxide) battery market share



Source: UBS estimates, IHS

Process Catalysts – smaller risk to the sector, but Clariant exposed

The outlook for process catalysts companies is less negative as the majority of the technologies are related to chemicals production, but nevertheless there is some exposure to refinery catalysts amongst both European (BASF, Clariant, and Johnson Matthey) and US companies (Albemarle and Grace). However, these are much smaller within a group context than the autocatalysts' exposure, with the exception of Clariant, where the Catalysis division is c.20% of EBITDA.

Figure 110: Catalysts exposure to refineries

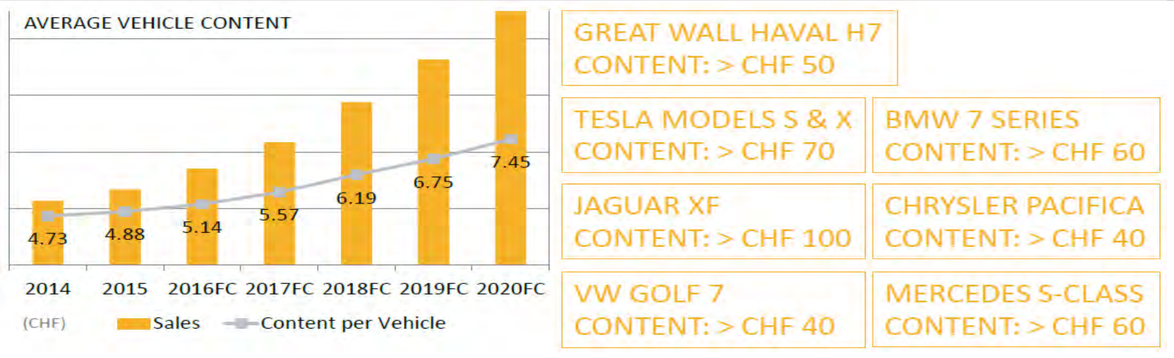
Competitor	Chemicals	Petrochemicals	Refinery	Olefin Polymerisation	Key products	Comments
Sud-Chemie	X	X	X	X	Styrene, Houdry, Syngas, etc	
BASF	X	X	X	X	FCC, Oxidation, HCS, Custom, Houdry, Styrene, Hydro, Polymerisation	Large player with strong product base but conservative growth profile
Johnson Matthey	X		X		Syngas, HCS, Traps, Engineering	Strong commitment to catalyst business with strong marketing and service
Haldor Topsoe	X	X	X		Syngas, HT, HC, Oxidation (FA), (Fluid Bed Dehydro)	Strong catalyst and technology provider with upside through R&D and engineering
CRI		X	X		Styrene Catalyst, Selective Hydro, EO, HT, HC, Isom, Dewax	Main player in petrochemicals with resources for organic growth
Axens		X	X		HT, Traps, Isom, Selective Hydro	Good process know-how and R&D with willingness to grow
Uop		X	X		SPA, HC, Isom, Zeolite	Strong market position and branding in refinery. Weaker in petrochemicals
Albermarle	X		X	X	FCC + HT	Focus on refinery catalysts
Grace			X		FCC + HT	Focus on refinery catalysts
Degussa	X				HCS, Custom	Strong base in fine chemicals
ExxonMobil		X			Zeolite Catalysts	large resources but business not core to group

Source: Clariant 2014. Note: Süd Chemie is owned by Clariant and Degussa is Evonik

Adhesives, sealing and bonding: Sika a likely beneficiary

EVs require more acoustic dampening when compared to an ICE car due to the absence of engine noise, which results in a plethora of other disturbing noises in the cabin (e.g. from wind or tyres). Also, heat-absorbing structures around the batteries require adhesive fixing, while special body structures need reinforcement solutions. We believe Sika, with its product portfolio ranging from structural adhesives, acoustic systems to lamination adhesives to reinforce systems, is best positioned to benefit from higher content per unit. Sika Automotive has been growing by double digits in LCY since 2012 and we expect this trend to continue at a similar pace (UBSe +9% p.a. 2017-21E). While content per vehicle currently stands at just above CHF5 per unit, an EV like Tesla (models S & X) already requires >CHF70 per unit, a similar amount as required by high-end and premium cars. On a side note, content per unit in China is still only around half of the global average (2016 cCHF2.6 per unit), with the stated ambition of doubling by 2020. Sika's current exposure to auto is CHF485m (2016), c8% of the group, and it directly caters to OEMs, with all the players worth mentioning on its customer list. In addition, Sika generates another cCHF250m of sales in transport (i.e. rail and track) and cCHF200m in auto aftermarket (wind-shield replacement).

Figure 111: Vehicle content for Sika products



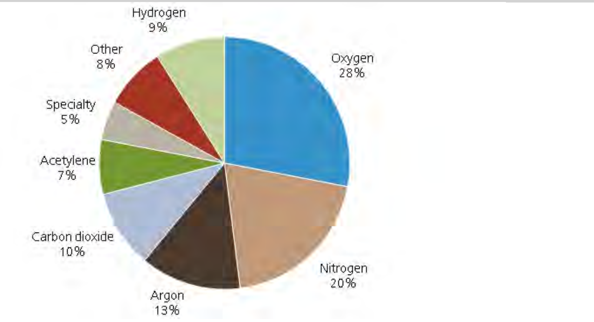
Source: Sika

We note that EMS-Chemie has a similar exposure through its EMS-EFTEC segment, where EMS commands a leading cost position and generates strong margins (UBSe 20% on EBIT). Products include plastisols for sealing (e.g. underbody), waxes for cavities and corrosion protection, adhesives for windows and sound-dampening. While we would expect EMS-EFTEC to benefit to a similar extent as Sika from an increasing EV penetration, the impact for the group is less clear. EFTEC accounts for c. one-third of the Higher Performance Polymers division, with the EMS-GRIVORY (engineering plastics such as PA6, PA12, PA66, PPA) accounting for the balance. Here, EVs also pose a threat in the sense that an electric engine needs much fewer parts, there is less corrosion from oil or chemicals, and no heat. EMS-Chemie will therefore need to increasingly focus on finding solutions for interior and exterior parts as well as the powertrain.

Industrial Gases: negative impact on hydrogen demand – too small to matter

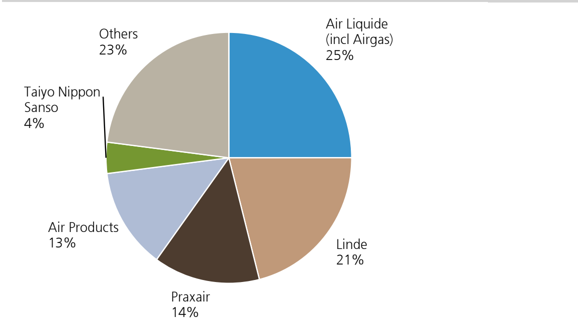
Finally, we should focus on the potentially negative impact of electric vehicles on the industrial gases industry. Gases have a role to play in oil refining, with the injection of hydrogen designed to aid with the de-sulphurisation process. Not all of the global hydrogen market is purely for oil refining, but it does represent a lion's share of the 9% of the market globally for industrial gases. That said, our oils team estimates the total hit to oil demand as likely to be only 1-2% by 2025, given the fact that diesel for passenger vehicles is only 3% of total oil demand. Thus, while this is a real risk, it looks to be a manageable one for all the key global players.

Figure 112: Industrial gas demand (US$m)



Source: UBS estimates

Figure 113: Global market share for total gases



Source: UBS estimates

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Korea Auto Tech: LG companies

EV impact on sector … **Growth:** **Margins:** **ROIC:** **Valuation:**

KEY FINDINGS

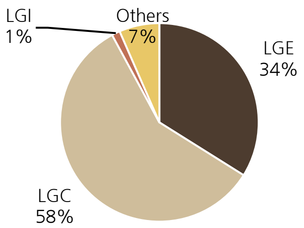
Q: What did we learn from the teardown?
Our teardown analysis suggests that a large portion of the powertrain of the GM Bolt (c93%), as well some of the infotainment, is done by LG tech companies (LG Electronics, LG Display and LG Innotek), with no less than 15 different components.

Q: What was the most non-consensual finding?
The total value created by the LG group was higher than our estimates, and also a higher portion of the total car BOM than we expected. If the sales of GM Bolt are better than our expectation, the magnitude of the positive impact to the LG group would be higher than the market currently expects.

FINANCIAL IMPACT

Q: What will be the impact on the industry?
We expect that revenue contributions from EV would continue to grow to all the LG tech affiliates. It is, however, more material for LG Chem (battery cells) and LG Electronics (part of 'Vehicle Components'). From a profits contribution though, EV should remain more meaningful for LG Chem (15% of UBSe OP in '20) vs. LGE (24%).

Powertrain component value breakdown by supplier for GM Bolt – source UBS



The list of components that LG affiliates supply to GM Bolt – source UBS

LG Electronics	LG Chem
Battery pack	Battery cells
Traction motor	**LG Display**
Inverter	LCD display panels
Onboard charging module	**LG Innotek**
Power distribution units	Battery management system
Infotainment modules	DC-DC converter
Climate control system	Power line communication module

SECTOR HEALTH CHECK

Q: Is the industry prepared for disruption from EVs?
We understand that the LG group has worked closely with global auto OEMs and maintained solid relationships with them. For some of the projects at GM (like Bolt), the LG affiliates are currently sole vendors. We believe that EV will remain a core priority for the LG Group.

SECTOR VALUATION

Q: Could the trend to EVs lead to a change in sector valuation multiples?
We believe that EV is a key valuation driver for LG Chem. For LG Electronics, EV and Infotainment matters, but it remains less important than TVs and Appliances, while Mobile may continue to drag profits down. The Autos segment overall is less material for LG Display and LG Innotek.

STOCK IMPACT

Q: What stocks should be impacted most positively and negatively?
The growth of EVs is overall positive for all stocks, but much more meaningful for LG Chem, in our view.

MOST FAVOURED on the theme

Stock	2018E PE	EPS impact 2025	Comment
LG Chem	10x	>30%	UBS APAC Key call
LG Display	6x	>10%	UBS APAC tech team Most Preferred

LEAST FAVOURED on the theme

Stock	2018E PE	EPS impact 2025	Comment
LG Electronics	12x	>25%	-

Q: What else should investors know? / the sector impact in more detail
The auto tech business is a new revenue source for LG affiliates, so most of them haven't generated profits. However, the companies guided for strong revenue growth on the back of strong order flows, and therefore they expect the operating margin to improve gradually. LG group has a solid relationship with GM, and they are supplying most of the value of the powertrain of GM Bolt, but the global market share is still not significant. LG affiliates are trying to broaden the customer base.

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Metals & Mining Commodities

EV impact on sector … **Growth:** ↗ **Margins:** ↗ **ROIC:** → **Valuation:** ↗

KEY FINDINGS

Q: What did we learn from the teardown?

The Bolt has more aluminium, copper & manganese than comparable ICE vehicles. Battery composition (60KWh, NMC 1-1-1 cathode, ~0.9-1.0 kg LCE/KWh, ~1.1kg Graphite/KWh) was within expectations, but total battery costs were less than expected, pointing toward faster EV growth & demand for battery and related commodities.

Q: What was the most non-consensual finding?

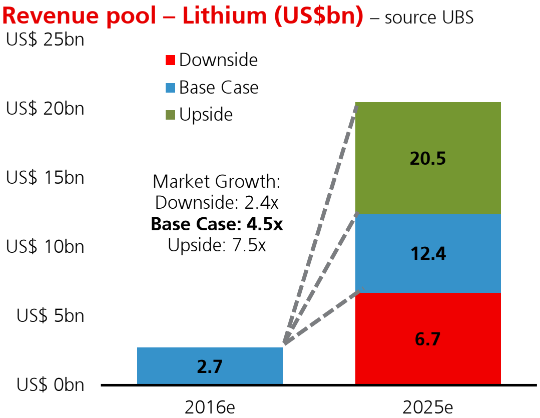
The lower-than-expected battery pack & management system costs. This is now anticipated to drive faster EV penetration rates thanks to total cost of ownership ICE vehicle break-even tipping points being reached sooner.

FINANCIAL IMPACT

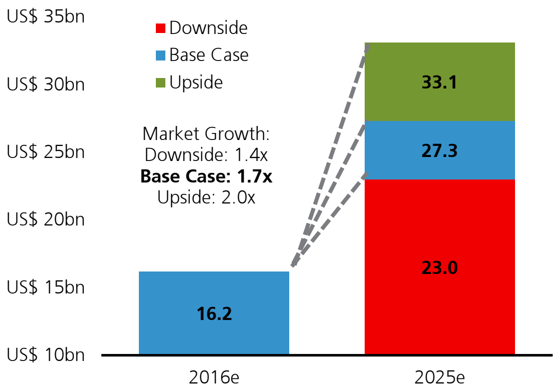
Q: What will be the impact on the industry?

Strong demand for battery and non-battery EV materials will tighten demand-supply balances, resulting in higher prices than otherwise. The combination of strong demand growth and higher prices will incentivize new supply to be developed which, in the case of battery raw materials especially, should drive transformative industry growth.

Revenue pool – Lithium (US$bn) – source UBS



Revenue pool – Graphite (US$bn) – source UBS



SECTOR HEALTH CHECK

Q: Is the industry prepared for disruption from EVs?

Yes and no. While prospective EV growth potential presents a major opportunity for revolutionary growth, challenges abound, including long and challenging lithium project development and ramp-up timelines, and qualification of new graphite supply for battery component makers with a near-zero tolerance for impurities.

SECTOR VALUATION

Q: Could the trend to EVs lead to a change in sector valuation multiples?

The listed Lithium & Graphite mining sector includes many companies looking to fund & build greenfield projects. These don't trade on earnings multiples because they are not yet in production, instead trading on net present value or EV/t of resource multiples. Only some of these will fully make the transition into production & cash flow.

STOCK IMPACT

Q: What stocks should be impacted most positively and negatively?

US: Albemarle (ALB, Neutral): We believe the diversified specialty chemicals producer is well placed to expand production and capture substantial lithium market growth via its tier 1 Chilean brine and West Australian hard-rock assets.

MOST FAVOURED on the theme

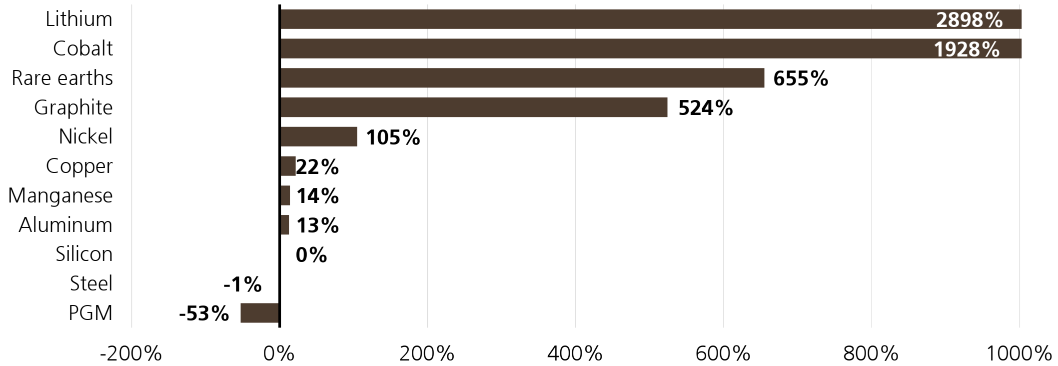
Commodity	Comment
Lithium	Sufficient new supply near term if funded, but delay risks are real as project execution takes time; new projects are needed longer term to support EV penetration rates
Cobalt	Supply is tight; produced as a by-product, also dependent on risky Central African supply. Demand to be moderated as NMC chemistry moves from 1-1-1 to 8-1-1 early next decade
Graphite	Sufficient graphite exists to supply battery growth, currently ~7% of total demand; but project qualification for battery use is a real hurdle, as are alternate anode materials longer term
Nickel	Elemental supply is plentiful, but less in the preferred Ni hydroxide form; EV growth & shift to more Ni intensive cathodes should lift Ni hydroxide demand from sulphide and laterite projects
Rare Earths	Supply highly dependent on China, which dominates the global trade; new experimental magnets with less/no REs may help the global RE supply chain meet EV demand growth

KEY BATTERY COMMODITY THEMES

Q: Can battery raw materials supply a total EV revolution?

Below is projected EV-related commodity demand assuming 100% of passenger vehicles (approx. 100mn units) are EV, as per Bolt specifications. Relative to today's market size, Lithium and Cobalt demand increase by factors of 29x and 19x, respectively. Rare Earths & Graphite demand lifts by factors of 5x-6x, while Nickel demand doubles. In a world of full EV penetration, the battery raw material supply chain needs to expand dramatically.

Commodity demand change – 100% EV – source UBS



CHEMISTRY SUBSTITUTION

Q: Are substitutes available to displace current Li-ion chemistries?

There are many competing battery chemistries with variable raw materials in the cathode, anode and electrolyte, offering variable performance. Higher raw material prices may see changes in chemistry, hence substitution. For example, high Cobalt prices should reinforce changing NMC chemistry ratios of 1-1-1 (nickel-manganese-cobalt) to 8-1-1 by early next decade, resulting in cobalt demand likely growing less quickly than overall EVs.

GRID RENAISSANCE

Q: How will electricity grids change to support the EV revolution?

EVs need to be fuelled with electricity, preferably from low carbon sources such as renewable (hydro/solar/wind) or nuclear, for there to be a carbon dividend from migration from combustion engines. This should lead to a step-change investment requirement in the grid and also for charging stations. While not analysed in this report, this is likely to be materially positive for copper and aluminium demand, above and beyond the estimates above.

NICKEL HYDROXIDE

Q: Is the world's Nickel chain ready to feed EV battery growth?

Most mine supply growth and investment in the past five years has been in low-grade nickel laterite ores, which are processed into a nickel-pig-iron product of 3-10% Ni and 85-90% Fe as stainless steel feed. This source is not suitable for battery use, which uses Nickel Hydroxide. Producers of Nickel Hydroxide may stand to benefit and receive premium prices.

LITHIUM PROJECT RISKS

Q: Is Lithium supply as easy to ramp up as it is abundant?

Lithium is relatively abundant. Yet successfully designing, building, commissioning and maintaining output from brine and hard-rock deposits is more technically challenging than many other mineral commodities. A shortage of experienced knowhow, lengthy development timelines, process plant issues and quality differentials present challenges likely to result in more gradual supply growth than developers may wish for.

GRAPHITE QUALITY

Q: How important is graphite quality?

Graphite too is relatively abundant. Battery anode manufacturers currently have a preference for high-quality synthetic graphite that features near-zero impurities, as impure graphite in anodes leads to safety and performance issues. Graphite producers need to convince battery customers of the merits of their product, often through a qualification process lasting many month/years.

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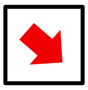
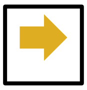
Platinum and Palladium

EV impact on sector … **Demand:**  **Supply:**  **Market balance:** 

PIVOTAL QUESTIONS

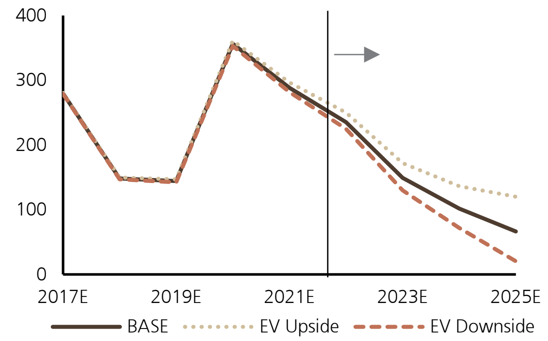
Q: What is the impact of higher EV penetration on platinum and palladium demand?

Higher EV penetration translates to lower platinum and palladium demand, driven by a decline in automotive demand. However, our calculations do not suggest a significant deviation from our previous estimates over our forecast period out to 2021. We estimate only low-single-digit percentage declines vs our previous auto demand forecasts. In turn, this implies that, all else being equal, our current estimates for platinum and palladium market balances are still broadly in line with our previous expectation that the platinum market is likely to remain relatively balanced, while the palladium market should continue to be in deficit. For now, we don't see much influence on our price targets as a result of the recent changes in our colleagues' expectations for EVs. We continue to see considerable downside risks for our platinum price forecasts and upside risks for palladium. If anything, palladium upside risks have probably moderated slightly.

Q: Is the market likely to ease or tighten depending on the level of EV penetration?

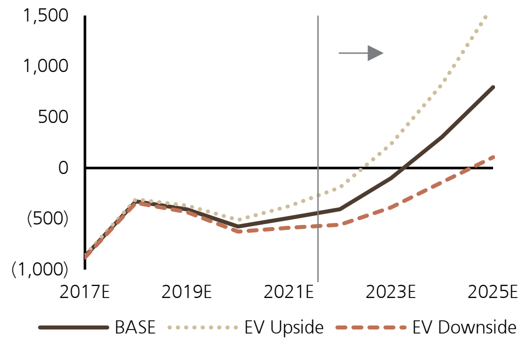
Higher EV penetration corresponds with lower automotive demand and would therefore tend to ease PGM markets, while lower penetration rates vs the base case would result in higher automotive demand and, in turn, tighter PGM balances. We expect the palladium market to be more sensitive to fluctuations in EV market share, given that gasoline vehicles would be most affected, and for this impact to be more pronounced in the long term, particularly as BEVs gain more traction. Beyond our forecast period, much would depend on the supply response. But given limited visibility on the long-term supply side response, we refrain from making strong conclusions.

XPT balance under different EV scenarios



Source: UBS

XPD balance under different EV scenarios



Source: UBS

UBS VIEW

We continue to estimate a relatively balanced market for platinum and sizeable deficits in palladium, over our forecast period out to 2021, even under different EV penetration scenarios. We think the divergence in price action between the two metals and the clear preference for palladium among investors is likely to continue, underpinned by prevailing themes in the auto sector.

EVIDENCE

The platinum:palladium ratio has come under considerable pressure this year as investors increasingly favour the latter. There have been signs of fundamental strength in palladium, but this has likely been amplified by investor flows, reflected in elevated Nymex positioning and the positive turn in ETFs. Similarly, while platinum fundamental signals have indeed been weak, pressure on prices has likely been compounded by investor selling.

SIGNPOSTS

Trends in the auto sector will be important, particularly diesel shares in Europe and global EV penetration. The platinum:palladium price ratio will also be key and we will be monitoring whether certain levels eventually trigger a response from the industry in terms of autocatalyst loadings. We will also be closely watching indicators such as forwards and sponge premium to assess demand as well as investor flows via Nymex positioning and global ETFs.

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Precious Metals Strategist

Semiconductors

EV impact on sector … **Growth:** **Margins:** **ROIC:** **Valuation:**

KEY FINDINGS

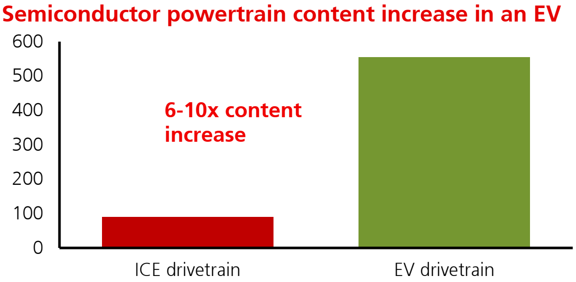
Q: What did we learn from the teardown?
Semi content in the EV drive train is c6x higher. Watch out for further research on the semi content in the Bolt, but focusing on the EV drivetrain we found the semi content in the powertrain increased c6-10x (c$580 compared to the $60-90 content we believe is present in an ICE powertrain today). Major suppliers into the Bolt include Infineon (supplies the IGBT module) and NXP/Freescale (supplying multiple MCUs).

Q: What was the most non-consensual finding?
Content increase higher than many expect. The shift to EV content is widely expected to be a significant driver of semi content growth, but we believe that a $490-520 increase in the powertrain alone is much higher than many people expect. We believe the total within the powertrain could even be higher than this as not every single chip could be seen, especially in the battery cells with the energy storage subsystem.

FINANCIAL IMPACT

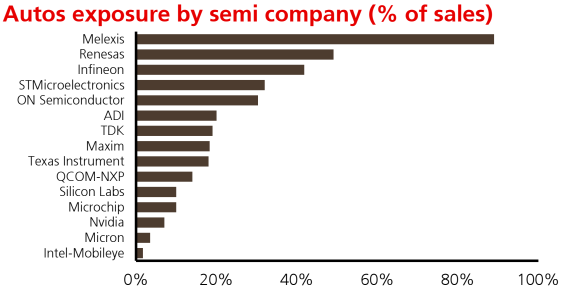
Q: What will be the impact on the industry …
Sustained high revenue growth in auto semis. We expect that the powertrain will be one of the fastest-growing areas of semis content as we shift to EV drivetrain with 6-10x higher content, particularly given our overall positive conclusions on the profitability of an EV, and hence the potential cost points that could be met to stimulate adoption. Globally, autos is expected to be one of the fastest-growth areas for semis, as has already been seen in recent years, having grown at a CAGR of 8% between 2012 and 2016 compared to the wider industry of 3.4%.

Semiconductor powertrain content increase in an EV



Source: UBS estimates

Autos exposure by semi company (% of sales)



Source: Company data (2016 reported)

SECTOR HEALTH CHECK

Q: Is the industry prepared for disruption from EVs?
Yes. Autos is already seen as the key driver of growth for many of the analog semi names and as such there has already been significant capex investment into capacity to support this growth (e.g. Infineon has significant capacity in 300mm that can continue to support growth). The US Semis industry appears prepared for higher semis sales to EV given sustained double-digit growth from the auto segment from recent electrification and efficiency trends, and we would expect this to continue from greater adoption of HEVs and EVs.

SECTOR VALUATION

Q: Could the trend to EVs lead to a change in sector valuation multiples?
It already has. The growth expected for semis from the shift to EV and autonomous has already led to an increase in multiples for analog semis (including Infineon, STMicro, TI, ADI, Maxim) to 12x 12m fwd EV/EBITDA vs. 5y average 8x.

STOCK IMPACT

Q: What stocks should be impacted most positively and negatively?
Within the teardown, we mostly found content from Infineon, NXP/Freescale and STMicro, although we are conscious this is just one EV. More generally, the semis names most exposed to automotive are Melexis, Renesas, NXP and Infineon. We expect that Infineon will be one of the most positively impacted by EV powertrain given its IGBT exposure, although over time we could see more competition as the industry moves to SiC solutions (STMicro is more competitive here). Of the other US Semis, TI, Maxim and ADI all have c15% exposure to autos semis.

MOST FAVOURED on the theme

Stock	2018E PE	Comment
Infineon	18x	One of most exposed to autos and particularly to the power content increase in an EV drivetrain. Valuation is our concern.
Texas Instruments	20x	Autos has growth from 11% to 18% of sales in 5 years, driven by infotainment, power management, and signal conditioning.

LEAST FAVOURED on the theme

Stock	2018E PE	Comment
Melexis	26x	We have concerns on market share and valuation – Sell.
STMicro	16x	Solid exposure to autos but SiC opportunity should take time.

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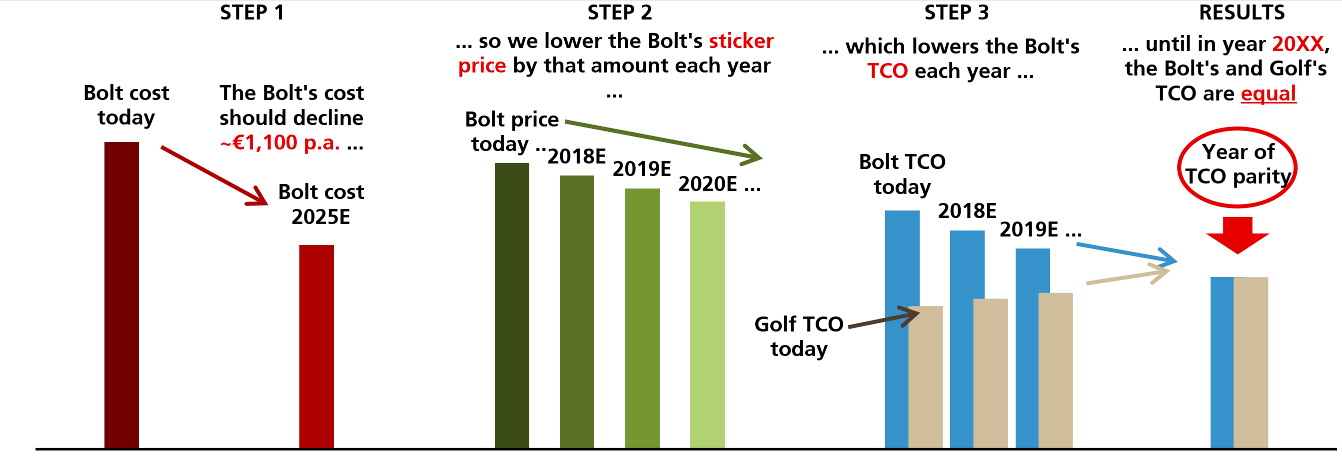
Appendix

How do we estimate total cost of ownership (TCO) parity?

STEP 1: ESTIMATING THE YEAR OF TCO PARITY

To estimate the year of total cost of ownership (TCO) parity, we tie the Bolt's sticker price to the annual expected decline in GM's cost to produce it. The annual cost decline is based on our and Munro's forecast prices for the battery and other components in the Bolt in 2025. We model the cost decline linearly. Based on our price forecasts, it comes to ~$1,100 p.a. For the Golf, we model 0.5% cost inflation p.a., but also a 2% increase in fuel efficiency p.a. As the Bolt's sticker price declines in line with its costs, so does its TCO. The parity year is the one at which annual TCO of the Bolt matches that of the Golf.

Figure 114: How we estimate the year of TCO parity between the Chevy Bolt and VW Golf

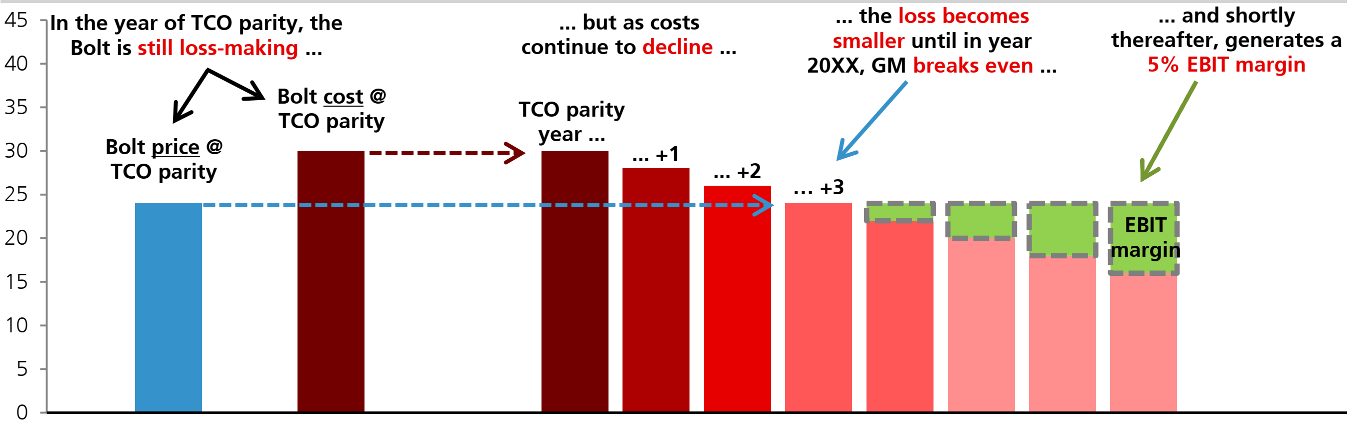


Source: UBS estimates

STEP 2: ESTIMATING THE YEAR OF EBIT BREAKEVEN

To estimate the year that GM breaks even on the Bolt, we first lock in the sticker price at which TCO parity is achieved (from step 1). As the Bolt's costs continue to decline each year on the back of battery and parts cost declines and higher volumes, the profit margin rises. Once the Bolt's total costs equal its sticker price, GM breaks even. The margin then increases until it reaches 5%. Based on our modelling, we are able to identify in which years this is likely to happen, by region.

Figure 115: How we estimate the year in which GM breaks even on the Bolt



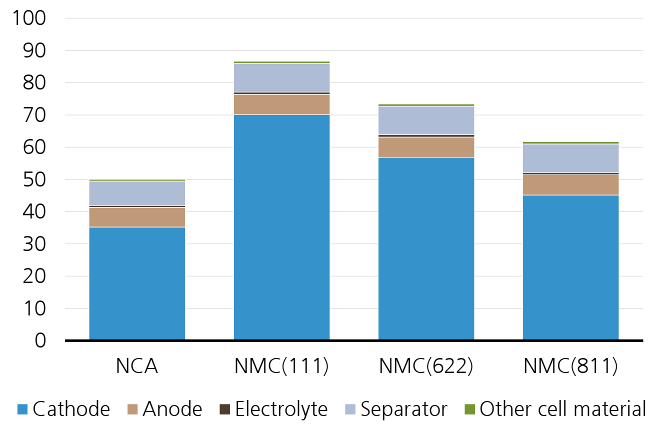
Source: UBS estimates

Figure 116: TCO analysis – core assumptions

Region		US	Germany	China	Japan
Currency		$	€	RMB	¥
Distance		miles	km	km	km
Gasoline fuel metric		Gallons	Litres	Litres	Litres
Universal inputs					
USD exchange rate		-	0.9	7.0	112
Annual driving distance	miles/km	9,000	15,000	15,000	15,000
Maintenance cost BEV	Cent / mile/km	2.6	2.3	18	286
Maintenance cost ICE	Cent / mile/km	6.1	5.5	43	683
Gasoline cost today	per gallon / litre	2.70	1.40	6.8	130
Gasoline cost 2020+	per gallon / litre	3.00	1.50	7.0	140
Cost of electricity	per kWh	0.15	0.30	0.55	15.0
Lease scenario					
Purchase method		3 year lease, 10% down-payment			
Time of ownership	years	3			
Residual value	%	50%			
Interest rate	%	3.5%			
Lifetime scenario					
Purchase method		Cash purchase			
Time of ownership	years	15			
Residual value	%	0%			
Battery replacement cost	In 2025	11,700	10,636	81,900	1,310.4k

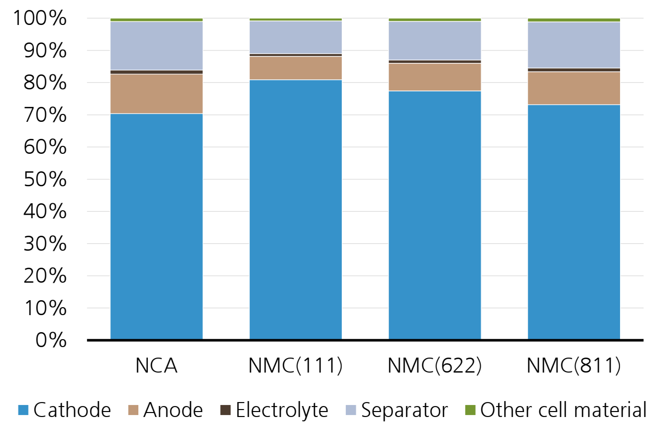
Source: UBS estimates

Figure 117: Battery active materials cost ($/kWh)



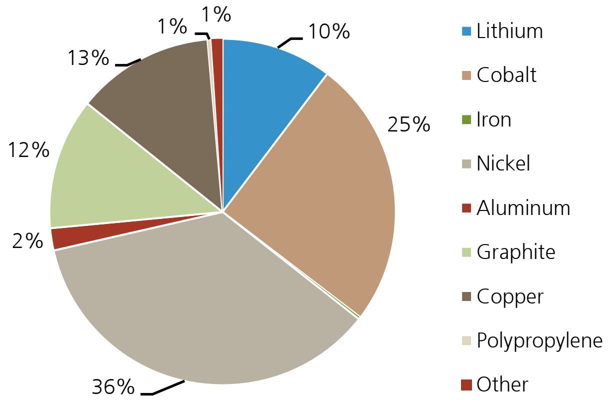
Source: UBS estimates

Figure 118: Active material cost (% of total bill of mat's)



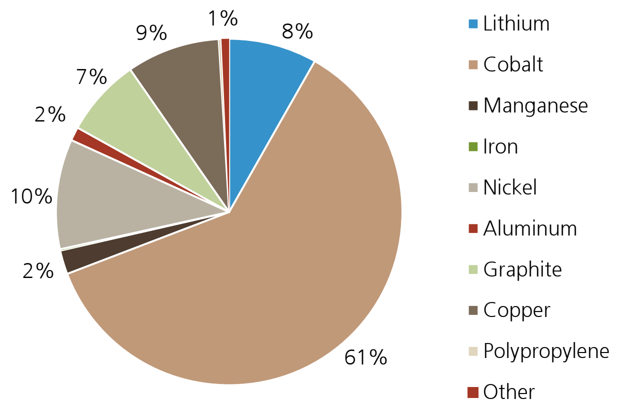
Source: UBS estimates

Figure 119: Total active material bill of materials (NCA)



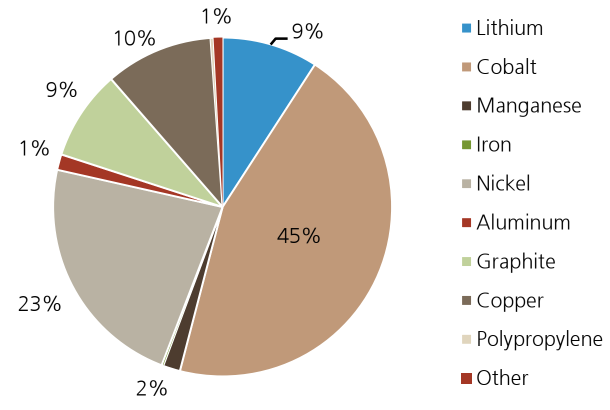
Source: UBS estimates

Figure 120: Total active material bill of materials (NMC111)



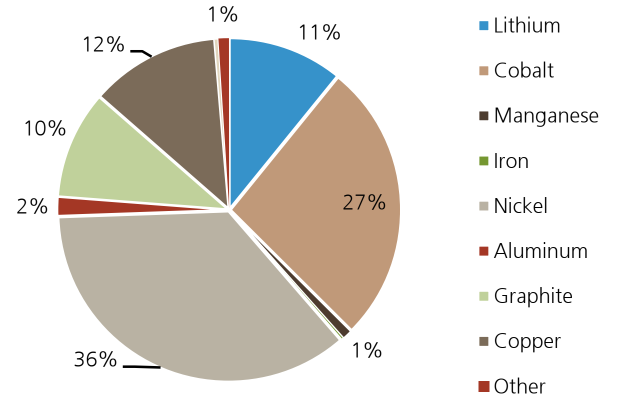
Source: UBS estimates

Figure 121: Total active material bill of materials (NMC622)



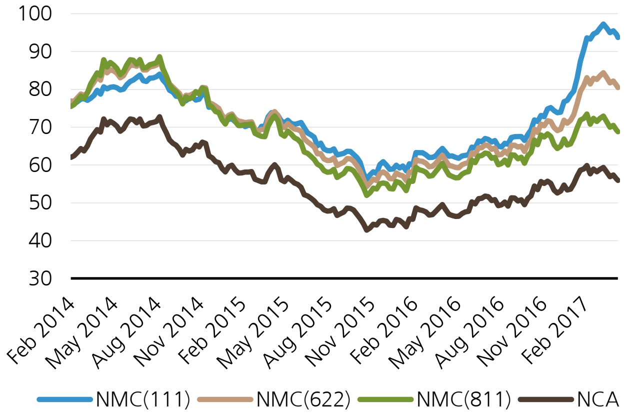
Source: UBS estimates

Figure 122: Total active material bill of mat's (NMC811)



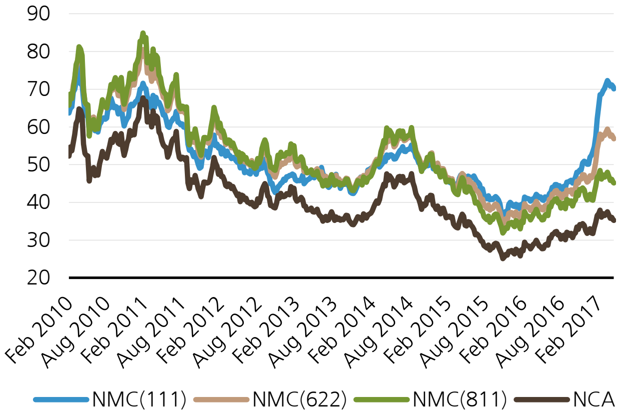
Source: UBS estimates Note: NMC based on NMC(111) cell chemistry

Figure 123: Li-ion total active cell material cost by technology ($/kWh)



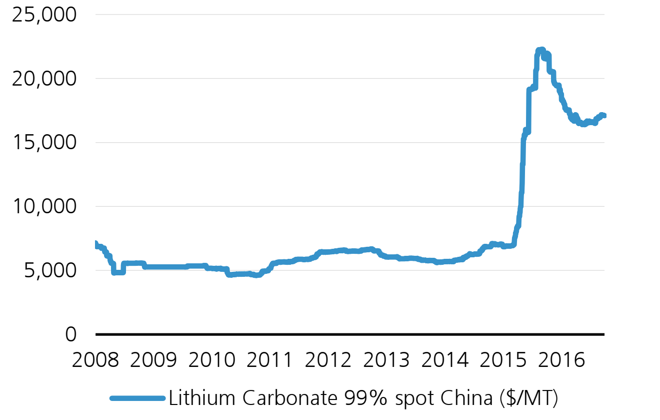
Source: Datastream, Bloomberg, UBS estimates

Figure 124: Li-ion cathode cost by technology ($/kWh)



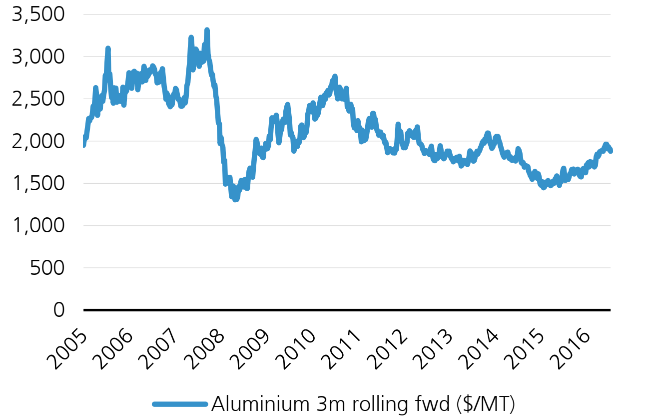
Source: Datastream, Bloomberg, UBS estimates

Figure 125: Lithium Carbonate 99% spot China ($/MT)



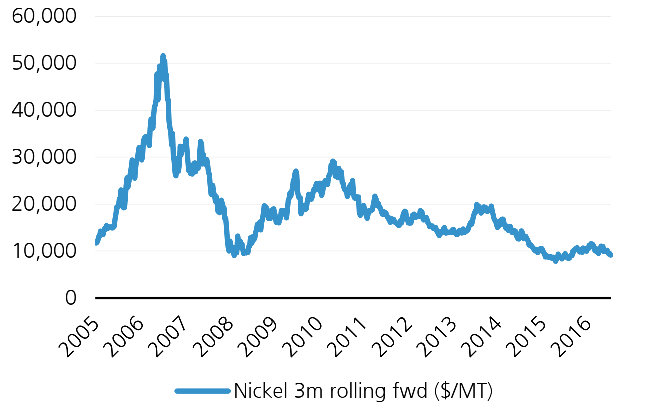
Source: Asian Metals

Figure 126: Aluminium 3m rolling fwd ($/MT)



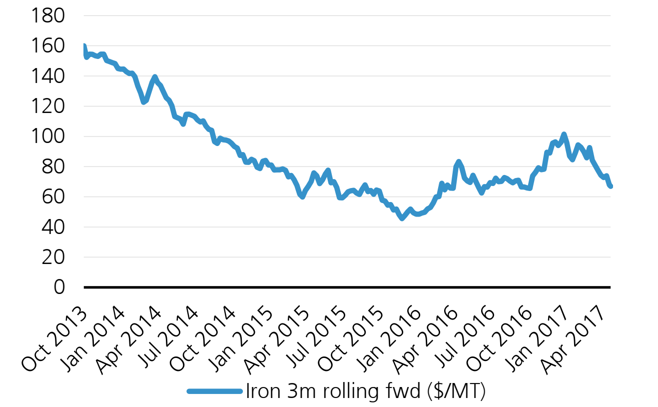
Source: Bloomberg

Figure 127: Nickel 3m rolling fwd ($/MT)



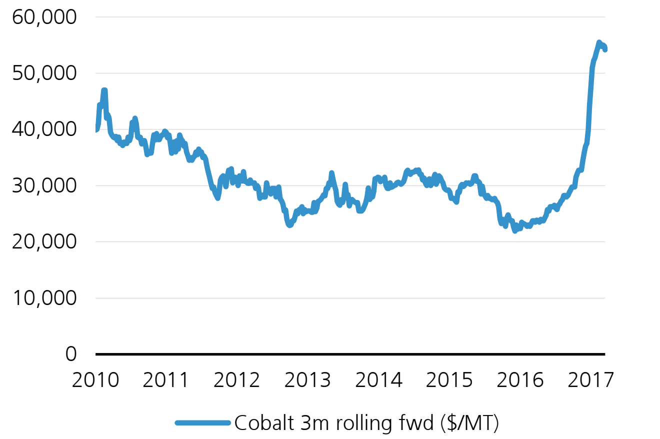
Source: Bloomberg

Figure 128: Iron 3m rolling fwd ($/MT)



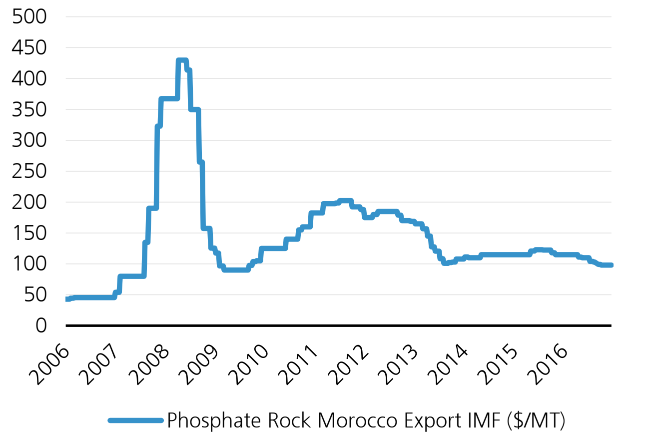
Source: Bloomberg

Figure 129: Cobalt 3m rolling fwd ($/MT)



Source: Bloomberg

Figure 130: Phosphate Rock Morocco Export IMF ($/MT)

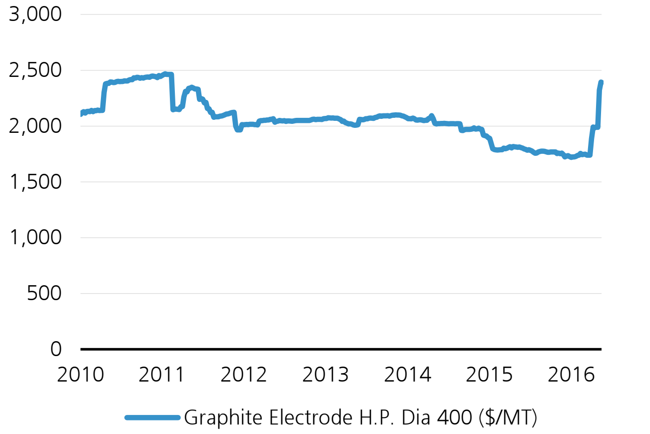


Source: Bloomberg

Figure 131: Manganese Spot ($/MT)

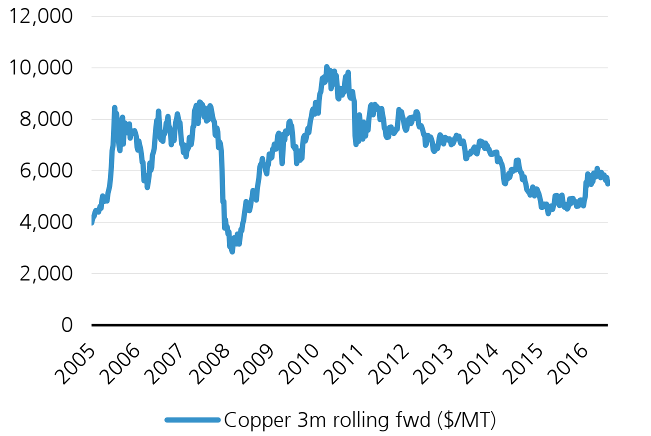
Source: Bloomberg

Figure 132: Graphite Electrode H.P. Dia 400 ($/MT)



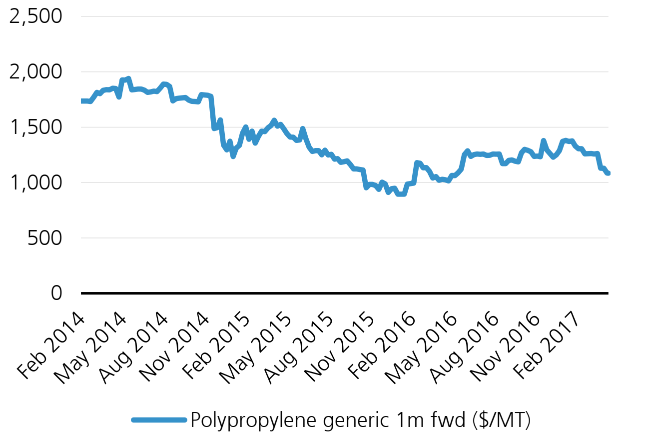
Source: Asian Metals

Figure 133: Copper 3m rolling fwd ($/MT)



Source: Bloomberg

Figure 134: Polypropylene generic 1m fwd ($/MT)



Source: Bloomberg

Figure 135: External battery cost estimates

Total pack cost $/kWh	Time of est.	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
LG Chem	2017									200-250								
Daimler	2016							200-300					150					100
Carnegie Mellon University	2016								190-400									
Cairn Energy Research Advisors	2016								200-240				168					149
Nat. Renewable Energy Lab. (NREL)	2016						217-278											
Panasonic	2016										190-222							
Tesla	2016									190			150					
MIT (Sadoway)	2016							300										
Ford	2016												120 (cell)					95 (cell)
Tesla	2015												100					
GM	2015									145-245			120-220		100-150			
MIT (Industry expert interviews)	2015							200-300			170							
Stockholm Environment Institute	2015	600-1250	410-1100	400-880	280-820	280-700	250-500											
Johnson Matthey	2015							300										
Argonne National Lab	2015											109						
Tesla	2014					200-300							150-200					100
US Dept. of Energy	2014					325	300								125			
MIT (Sakti et al.)	2014						190-330											
Umicore	2014	1100					360						200					
Australian Renewable Energy Agency	2014						550			300			200					
Advanced Automotive Batteries	2014					310	280	260	250	240	230	215	190		170			150
VTT Technical Research Centre of Finland	2014							185-215										
USABC (Industry)	2013												250					
Argonne National Lab	2013					220-360												
Johnson Matthey	2012				500-900													
LG Chemical	2010		625															

Source: Sources as names in table

Figure 136: Key technical features Chevrolet Bolt vs. VW Golf

Chevrolet Bolt LT		VW Golf Wolfsburg 1.8 TSI
36,620	**Base price ($)**	23,515
	Dimensions – exterior	
1,616	Base curb weight (kg)	1,371
417	Length (cm)	425
160	Height (cm)	145
176	Width (cm)	180
260	Wheelbase (cm)	264
	Dimensions – interior	
2,673	Passenger volume (l)	2,648
1,178	Front legroom (l)	1,167
1,124	Front headroom (l)	1,087
1,034	Rear legroom (l)	1,008
1,073	Rear headroom (l)	1,079
	Performance specs	
Electric	Propulsion	Internal combustion
200	Horsepower	170
360	Torque (Nm)	270
145	Top speed (km/h)	200
6.5	0-100 km/h (sec)	7.3
	Fuel efficiency (EPA)	
128	MPG city	25
110	MPG highway	35
119	MPG combined	29
383	Range (km)	617
0	g CO_2 / km	192
	Powertrain description	
60kWh lithium ion battery	Fuel storage	50l fuel tank
Permanent magnetic drive motor	Engine	1.8l 4 cylinder turbocharged DI ICE
Single-speed integrated gearbox	Transmission	6-speed automatic transmission

Source: General Motors, Volkswagen, UBS

Figure 137: BEV line-up (ex China)

OEM	Model name	Range (EPA) km	Price $	Battery capacity kWh	Fast charging time mins	Power HP	Battery supplier
2009							
Daimler	Smart Electric Drive	110	26,070	18	n/a	75	Tesla (Panasonic)
2010							
Mitsubishi	i MiEV	100	23,760	16	~30	67	GS Yuasa
Peugeot	Peugeot iOn	110	19,635	15	~30	67	GS Yuasa
Peugeot	Citroen C-Zero	110	19,635	15	~30	67	GS Yuasa
2011							
Renault	Twizy	100	7,700	6	n/a	17	LG Chem
Renault	Kangoo Z.E.	110	22,330	22	n/a	60	AESC / LG Chem
Renault	Fluence Z.E.	100	28,600	22	n/a	94	AESC / LG Chem
Nissan	Leaf (24kWh)	120	29,040	24	~30	107	AESC
2012							
Tesla	Model S 70D	385	92,400	70 / 85	~30-45	315	Panasonic
Tesla	Model S 90D	460	108,350	90	30-45	373	Panasonic
Ford	Focus Electric	76	29,194	23	n/a	130	LG Chem
Bolloré	Bluecar	200	20,900	30	n/a	68	-
Honda	Fit EV	135	35,970	20	n/a	75	GS Yuasa
2013							
Renault	Zoe	170	23,650	22	~30	88	LG Chem
BMW	i3	135	38,500	19	~30	170	Samsung SDI
Volkswagen	VW e-Up!	120	29,700	19	~30	82	Toshiba
FCA	Fiat 500e	140	32,010	24	n/a	111	Samsung SDI / Bosch
GM	Chevy Spark EV	135	25,960	19	~30	140	LG Chem
2014							
Volkswagen	VW e-Golf	135	38,500	24.20	~30	115	Panasonic
Daimler	Mercedes B-Class ED	140	43,120	28	n/a	179	Tesla (Panasonic)
Kia	Soul EV	160	30,800	27	~30	111	SK Innovation
Nissan	e-NV200	170	26,400	24	30	109	AESC
2015							
Tesla	Model X	350	88,000	70 / 85	~30-45	328	Panasonic
Nissan	Leaf (24kWh – upgr.)	135	29,040	24	~30	107	AESC
Nissan	Leaf (30kWh)	170	33,990	30	~30	107	AESC
2016							
BMW	i3 (upgrade)	185	38,500	30	~30	170	Samsung SDI
Peugeot	Citroen e-Mehari	100	30,580	30	~30	48	Bolloré
GM	Chevy Bolt	385	37,400	60	~60	200	LG Chem
Daimler	Smart Fortwo	110	24,200	18	~30-45	81	LG Chem
Renault	Zoe (upgrade)	300	35,200	41	~60	91	LG Chem
2017							
Hyundai	Ioniq EV	200	36,300	28	~60	120	LG Chem
GM	Opel Ampera-E	380	36,620	60	~60	200	LG Chem
Volkswagen	VW e-Golf (upgrade)	200	39,490	36	~30	135	Samsung SDI
Daimler	Smart Forfour	110	24,860	18	~30-45	81	LG Chem
Daimler	Smart Cabrio	110	27,720	18	~30-45	81	LG Chem
Honda	Clarity EV	130	-	-	-	-	-
Ford	Focus Electric (upgr.)	120	-	34	~30	145	LG Chem

Source: Manufacturer data, EPA, Media reports, UBS

Figure 138: BEV line-up (ex China) – continued

OEM	Model name	Range (EPA) km	Price $	Battery capacity kWh	Fast charging time mins	Power HP	Battery supplier
2017							
Hyundai	Ioniq EV	200	36,300	28	~60	120	LG Chem
GM	Opel Ampera-E	380	36,620	60	~60	200	LG Chem
Volkswagen	VW e-Golf (upgrade)	200	39,490	36	~30	135	Samsung SDI
Daimler	Smart Forfour	110	24,860	18	~30-45	81	LG Chem
Daimler	Smart Cabrio	110	27,720	18	~30-45	81	LG Chem
Honda	Clarity EV	130	-	-	-	-	-
Ford	Focus Electric (upgr.)	120	-	34	~30	145	LG Chem
2018							
Tesla	Model 3	300+	35,000	28	~30	-	Panasonic
Volkswagen	Audi Q6 e-tron	500	80-100k	95	-	-	LG Chem / Samsung SDI
Nissan	Leaf (upgrade; tbc)	300+	-	-	-	-	AESC
Nissan	Micra EV	-	-	-	-	-	AESC
JLR	Jaguar I-Pace	335	55,000	90	-	400	-
2019							
Volkswagen	Porsche Mission E	500	-	-	~15	582	-
Volkswagen	2nd Audi BEV	500	-	-	-	-	-
Volkswagen	VW I.D.	400-600	30,000	-	~30	170	-
Volkswagen	Seat BEV	-	-	-	-	-	-
Volkswagen	Skoda Kodiaq BEV	-	-	-	-	-	-
Daimler	Generation EQ	500	50-60,000	70	-	400	SK Innovation (tbc)
Volvo	BEV	-	35-40,000	100	-	-	-
Aston Martin	RapidE (tbc)	300+	200,000+	-	-	800	-
Ford	BEV (tbc)	-	-	-	-	-	-
Hyundai	3 more BEVs by 2020	-	-	-	-	-	-
Kia	2 more BEVs by 2020	-	-	-	-	-	-
Mitsubishi	RVR BEV (by 2020)	-	-	-	-	-	-
BMW	Mini BEV	-	-	-	-	-	-
Mazda	BEV	-	-	-	-	-	-
Lucid Motors	Air	390	55,000	-	-	-	-
Subaru	BEV	-	-	-	-	-	-
2020+							
Tesla	Roadster (upgrade)	-	-	-	-	-	Panasonic
Tesla	Model Y (small SUV)	-	-	-	-	-	Panasonic
Volkswagen	3rd Audi BEV	500	-	-	-	-	-
Volkswagen	2nd Porsche BEV (tbc)	-	-	-	-	-	-
Volkswagen	Up to 20+ BEVs	-	-	-	-	-	-
BMW	X3 BEV	-	-	-	-	-	-
BMW	i-Next	500	-	-	-	-	-
FCA	Maserati Alfieri BEV	-	-	-	-	-	-
Daimler	9 more EQ BEVs	-	-	-	-	-	-
Renault	Low-cost BEV (China)	-	-	-	-	-	-
Faraday	BEV (tbc)	-	-	-	-	-	-
Subaru	BEV	-	-	-	-	-	-

Source: Manufacturer data, EPA, Media reports, UBS

**UBS Evidence Lab provides our research analysts with rigorous primary research. The team conducts representative surveys of key sector decision-makers, mines the Internet, systematically collects observable data, and pulls information from other innovative sources. It applies a variety of advanced analytic techniques to derive insights from the data collected. This valuable resource supplies UBS analysts with differentiated information to support their forecasts and recommendations—in turn enhancing our ability to serve the needs of our clients.*

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The automobile sector has in the past exhibited 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. Interest rates are also a key driver of sector earnings as they affect demand and mix as well as earnings of the OEMs' financial services arms.

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Buy	FSR is > 6% above the MRA.	46%	30%
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Source: UBS. Rating allocations are as of 31 March 2017.
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2:Percentage of companies within the 12-month rating category for which investment banking (IB) services were provided within the past 12 months.
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4:Percentage of companies within the Short-Term rating category for which investment banking (IB) services were provided within the past 12 months.

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Company Disclosures

Company Name	Reuters	12-month rating	Short-term rating	Price	Price date
ABB Ltd[5, 6b, 6c, 7, 13, 16]	ABBN.S	Sell	N/A	CHF24.11	18 May 2017
Aisin Seiki	7259.T	Buy	N/A	¥5,540	19 May 2017
Albemarle Corp[16]	ALB.N	Neutral	N/A	US$110.00	18 May 2017
Analog Devices Inc.[16]	ADI.O	Neutral	N/A	US$80.48	18 May 2017
Asahi Kasei	3407.T	Buy	N/A	¥1,072.0	19 May 2017
Atlas Copco A	ATCOa.ST	Buy	N/A	SKr314.90	18 May 2017
Autoliv[16]	ALV.N	Sell	N/A	US$103.57	18 May 2017
BASF SE[2, 4, 5, 7, 14]	BASFn.F	Buy	N/A	€85.65	18 May 2017
BMW[7, 22]	BMWG.F	Neutral	N/A	€85.00	18 May 2017
BorgWarner Inc.[16]	BWA.N	Buy	N/A	US$40.13	18 May 2017
Clariant[4, 5, 6b, 6c, 7, 13, 18a, 59]	CLN.S	Buy	N/A	CHF20.57	18 May 2017
Continental	CONG.DE	Buy	N/A	€202.10	18 May 2017
Daimler[22]	DAIGn.DE	Buy	N/A	€67.72	18 May 2017
Dana Incorporated[2, 4, 5, 6a, 6c, 7, 16]	DAN.N	Neutral	N/A	US$19.26	18 May 2017
Delphi Automotive Plc[16]	DLPH.N	Buy	N/A	US$85.13	18 May 2017
Denso[7]	6902.T	Neutral	N/A	¥4,769	19 May 2017
Ems-Chemie[5]	EMSN.S	Sell	N/A	CHF653.00	18 May 2017
Faurecia	EPED.PA	Sell	N/A	€44.47	18 May 2017
FCA[5, 7, 16]	FCHA.MI	Neutral	N/A	€9.36	18 May 2017
Ford Motor Co.[16, 26a]	F.N	Buy	N/A	US$10.79	18 May 2017
General Motors Company[6c, 7, 16]	GM.N	Buy	N/A	US$32.47	18 May 2017
GKN[5]	GKN.L	Buy	N/A	350p	18 May 2017
Hella	HLE.DE	Buy	N/A	€45.11	18 May 2017
Hexagon AB	HEXAb.ST	Buy	N/A	SKr382.30	18 May 2017
Honda Motor[16]	7267.T	Neutral	N/A	¥3,050	19 May 2017
Hyundai Mobis	012330.KS	Buy	N/A	Won260,000	18 May 2017
Hyundai Motor[7, 18b]	005380.KS	Buy	N/A	Won165,000	18 May 2017
Infineon Technologies AG[7]	IFXGn.DE	Neutral	N/A	€19.10	18 May 2017
Johnson Matthey[5, 7]	JMAT.L	Sell	N/A	3,080p	18 May 2017
Kennametal Inc.[16]	KMT.N	Sell	N/A	US$37.15	18 May 2017
Kia Motors	000270.KS	Neutral	N/A	Won38,200	18 May 2017
Kuka	KU2G.DE	Buy	N/A	€104.80	18 May 2017
Lear Corporation[6c, 7, 16]	LEA.N	Buy	N/A	US$141.92	18 May 2017
LG Chemical	051910.KS	Buy	N/A	Won280,500	18 May 2017
LG Display[7, 16]	034220.KS	Buy	N/A	Won29,500	18 May 2017
LG Electronics[7]	066570.KS	Neutral	N/A	Won79,100	18 May 2017
Magna International[16]	MGA.N	Neutral	N/A	US$44.37	18 May 2017
Maxim Integrated Products Inc.[16]	MXIM.O	Neutral	N/A	US$46.45	18 May 2017
Mazda Motor[13]	7261.T	Buy	N/A	¥1,532.0	19 May 2017
Melexis NV	MLXS.BR	Sell	N/A	€76.74	18 May 2017
Michelin	MICP.PA	Buy	N/A	€117.40	18 May 2017

Company Name	Reuters	12-month rating	Short-term rating	Price	Price date
Nissan Motor	7201.T	Sell	N/A	¥1,093.5	19 May 2017
Panasonic	6752.T	Neutral	N/A	¥1,366.0	19 May 2017
PSA Group	PEUP.PA	Neutral	N/A	€18.52	18 May 2017
Renault[7]	RENA.PA	Buy	N/A	€86.19	18 May 2017
Renesas Electronics	6723.T	Neutral	N/A	¥944	19 May 2017
Rheinmetall	RHMG.DE	Buy	N/A	€85.07	18 May 2017
Samsung SDI[7, 22]	006400.KS	Buy	N/A	Won151,500	18 May 2017
Sandvik	SAND.ST	Sell	N/A	SKr133.50	18 May 2017
Saras[2, 4, 5]	SRS.MI	Neutral	N/A	€2.25	18 May 2017
Schaeffler	SHA_p.DE	Neutral	N/A	€15.14	18 May 2017
Siemens[2, 4, 5, 7]	SIEGn.DE	Buy	N/A	€128.35	18 May 2017
Sika[5, 6b, 6c, 7]	SIK.S	Buy	N/A	CHF6,190.00	18 May 2017
SKF B	SKFb.ST	Sell	N/A	SKr176.20	18 May 2017
STMicroelectronics[5, 7, 16]	STM.PA	Neutral	N/A	€14.49	18 May 2017
Subaru	7270.T	Sell	N/A	¥3,812	19 May 2017
Sumitomo Chemical	4005.T	Buy	N/A	¥613	19 May 2017
Suzuki Motor	7269.T	Buy	N/A	¥5,167	19 May 2017
Tenneco Inc.[16]	TEN.N	Buy	N/A	US$55.16	18 May 2017
Tesla, Inc.[13, 16, 26b]	TSLA.O	Sell	N/A	US$313.06	18 May 2017
Texas Instruments Inc.[16]	TXN.O	Buy	N/A	US$79.23	18 May 2017
Toyota Motor[7, 16]	7203.T	Sell	N/A	¥5,965	19 May 2017
Tupras	TUPRS.IS	Buy	N/A	TRY94.95	18 May 2017
Umicore	UMI.BR	Buy	N/A	€58.50	18 May 2017
Valeo	VLOF.PA	Buy	N/A	€62.78	18 May 2017
Visteon Corp.[4, 5, 6a, 6b, 7, 16]	VC.N	Buy	N/A	US$99.90	18 May 2017
Volkswagen[7, 13, 22]	VOWG_p.DE	Buy	N/A	€138.50	18 May 2017
W. R. Grace & Co[16]	GRA.N	Buy	N/A	US$70.20	18 May 2017

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

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