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The end of the ICE age

At current growth rates, electric vehicles (EVs) will supply all global incremental demand for cars within five years. Demand for conventional internal combustion engine (ICE) cars will then fall inexorably.

- **Where we stand today.** Global car sales are around 80 million vehicles, growing at 2-3 per cent a year, while EV sales will exceed 1 million this year, growing at around 50 per cent a year. In 2017 EVs are likely to supply 20 per cent of incremental car sales.
- **Where the tipping point is**. The tipping point for conventional car sales will come when EVs supply all incremental car demand. That requires incremental sales of 2-3 million EVs.
- **How long to reach all incremental sales**. At the current growth rate of some 50 per cent a year, EVs will account for all incremental sales by 2022. If growth slows to 30 per cent, the tipping point will be 2027.
- **How big EV will be at the tipping point.** Disruption will occur when total EV sales are 10 million and have a market share of 10 per cent. At that stage, the EV fleet will be just under 30 million and its share of the total car fleet will be 3 per cent. For disruption to take place at such a low level of penetration is in line with our findings from research into other energy transitions.
- **Why EV sales growth is likely to remain high.** Many automotive companies decided in 2016 to invest into the EV sector, which will reduce the cost of these vehicles and increase consumer choice. Battery costs continue to fall rapidly, which means that in some markets cost parity with ICE vehicles will be reached by 2020. China leads the way in the deployment of EV technology, while India is waiting in the wings to embark on an EV path.
- **Implications for other markets.** The rise of the EV is yet another indicator of the systemic change in energy markets, and an early warning for oil investors.

Introduction

The purpose of this note is not to add to the voluminous body of work on the prospects for electric vehicles (EVs). Rather, it is to apply to the car market the idea of the "tipping point", which we discussed in our 20 April 2016 note Fossil fuels: The beginning of the end. The tipping point is the moment at which demand for new technology (EVs in this case) makes up all incremental demand. At that point (by definition) demand for the old technology (internal combustion engine (ICE) cars peaks and starts to fall. As the old technology industry shifts from growth to decline, it creates stranded assets and forces radical change.

Our main goal here is to determine how far away the car industry is from the tipping point and to identify the drivers that will have an impact on timing. We will publish a separate note on the implications of this shift for oil markets.

The rise of the EV is just one of a number of factors affecting car markets. Autonomous cars, ride-sharing and car-pooling are all likely to have an impact on total demand and engine type as well. However, they are all sufficiently complex to merit separate analysis. For this reason, we focus solely here on the rise of the EV.

How close are we to peak conventional car

"Peak car" is usually used to refer to the peaking of demand for travel by car in rich/developed countries. In this note, we use a modified version of that term – peak conventional car – to reflect our main focus: namely, the peaking of sales of ICEs.

The calculation of peak conventional car is easy: it is that moment at which the incremental sales of EV exceed the incremental sales of total cars. Below we set out the basic framework for this calculation.

Where we stand today

The global car market

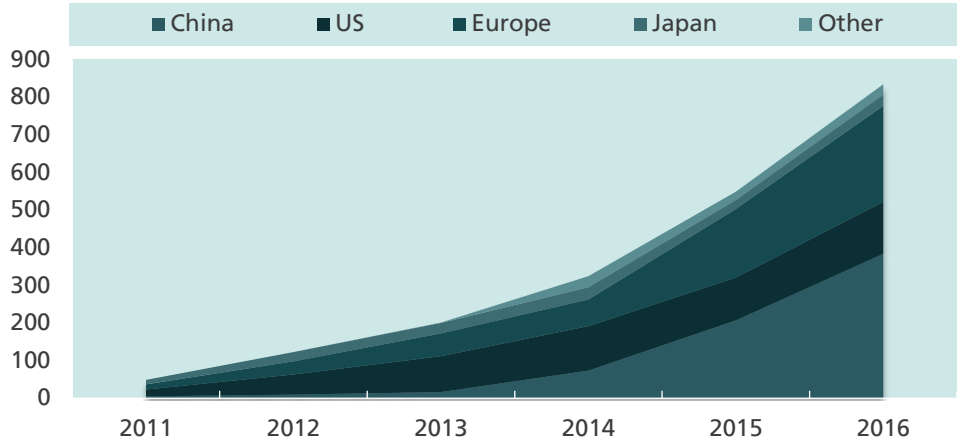
According to BP, there were 890 million passenger vehicles (cars) at the end of 2015, and the consensus is that annual car sales are around 80 million (different ways are used to calculate this figure). According to the International Organisation of Motor Vehicle Manufacturers (OICA), passenger car demand is growing at around 3 per cent a year. So annual incremental demand for cars is 2-3 million vehicles.

The EV market

According to the IEA, EV sales of in 2015 were 0.5 million and preliminary data indicate that they grew by around 50 per cent to 0.8 million in 2016. The compound annual growth rate of EV sales has been 75 per cent since 2011.

China has taken over as the largest EV market, leapfrogging both the US and Europe in 2016 and enjoying a CAGR of more than100 per cent.

Chart 1: Global EV sales (000 units)



Sources: IEA, TSRP estimates.

Share of incremental sales

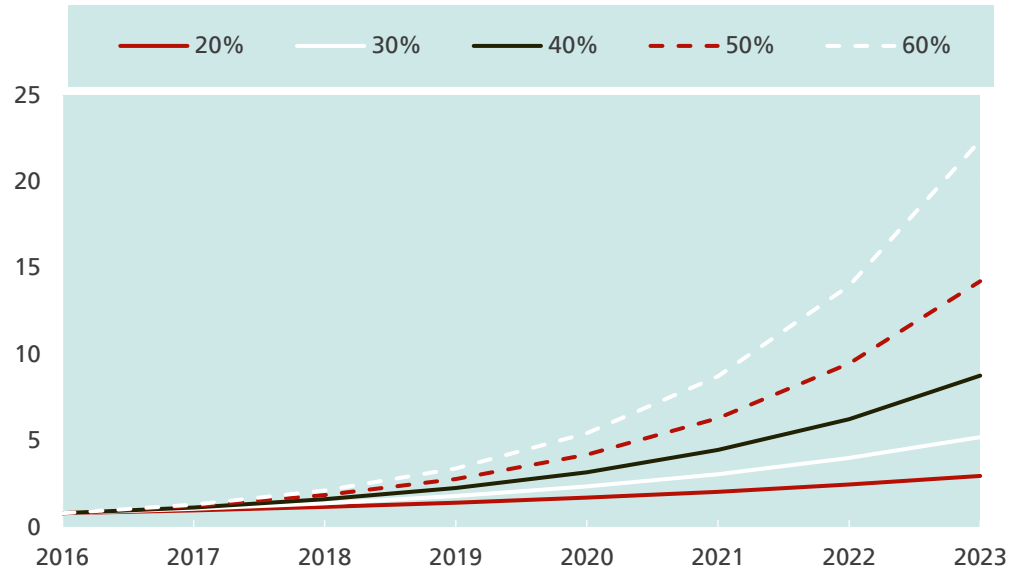
Assuming 3 per cent growth of total incremental car sales in 2016 (2.4 million), incremental sales of EVs (0.3 million) accounted for 14 per cent of that growth.

What growth rates EVs need to reach the tipping point

Total sales at different annual growth rates

We detail below implied EV sales at different annual growth rates (see Chart 2). We choose annual growth rates ranging from 20 per cent (the low end of forecasts) to 60 per cent (the high end). For example, if sales grow at an average of 30 per cent a year, annual sales will be 2.4 million in 2020; at a 50 per cent average annual growth rate, they will be 4.2 million in that year.

Chart 2: Total EV sales at different annual growth rates (mn)



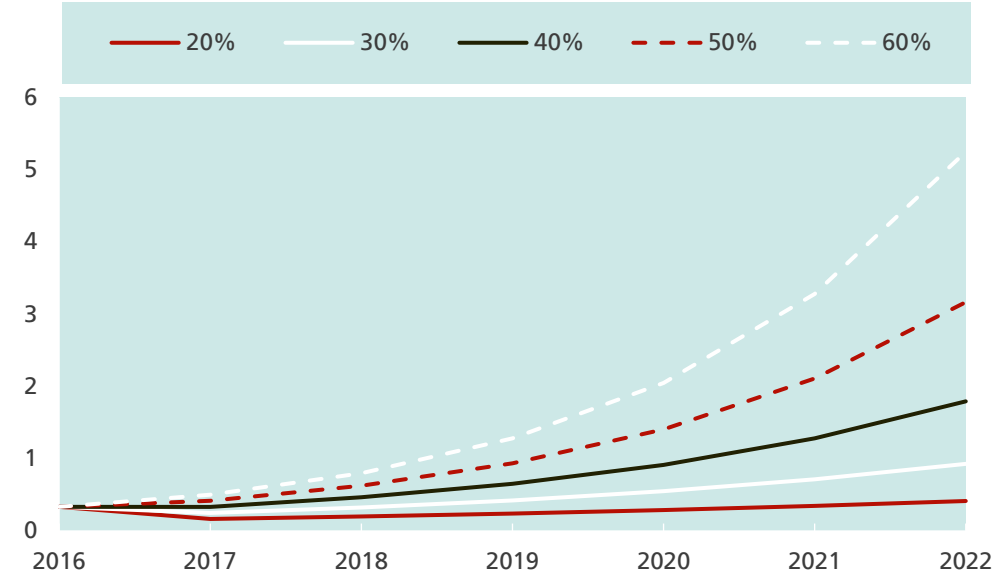
Source: TSRP estimates.

Incremental sales at different annual growth rates

Incremental sales are simply the change in sales from year to another and the key factor in a tipping point calculation. At a 30 per cent annual growth rate, incremental EV sales will be 0.5 million in 2020; and at 50 per cent, that figure will be 1.4 million.

The hurdle rate for EVs to account for total incremental sales is between 2 million and 3 million (which, as noted above, is the current annual incremental demand for all cars at 2-3 per cent growth).

Chart 3: Incremental EV sales at different annual growth rates (mn)

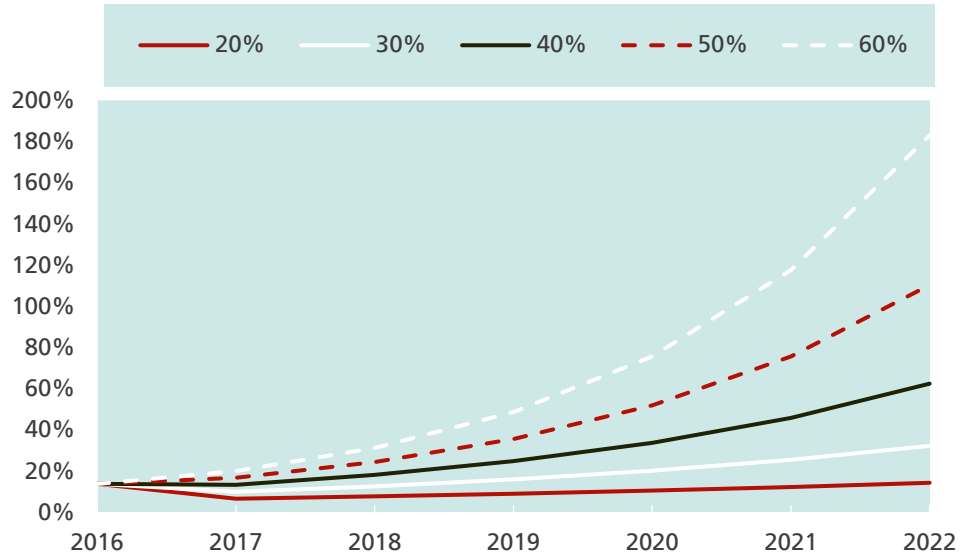


Source: TSRP estimates

Share of EVs in total incremental sales

Assuming 3 per cent annual growth of total car sales, we calculate the share of EVs in total incremental sales (see Chart 4 below). At 30 per cent annual growth rates, EVs will account for 20 per cent of total incremental sales in 2020; at 50 per cent annual growth rates, that figure will be 52 per cent.

Chart 4: Share of EVs in total incremental sales

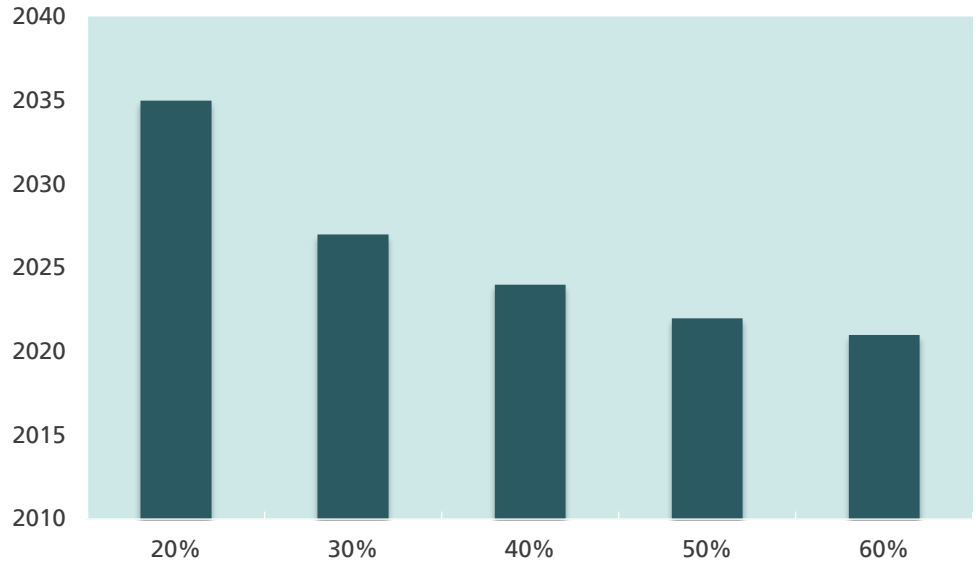


Source: TSRP estimates

When to expect the tipping point

The year of the tipping point is the year when EVs account for all incremental growth. The EV tipping point is 2022 if annual growth is maintained at 50 per cent but 2035 if it drops to 20 per cent.

Chart 5: The year of the tipping point



Source: TSRP estimates.

What markets will look like at the tipping point

EVs

For the purpose of forecasting the tipping point, the share of total incremental sales is the key factor. However, it is also interesting to make rough calculations of other parameters in order to get a sense of how large the EV market will be when disruption occurs.

Below we show the implied nature of the EV market at the tipping point based on the assumption of 50 per cent growth rates for the next five years (see Table 1 below). At lower growth rates, the absolute numbers are similar – it is simply the timing that changes. At very low growth rates (10-20%), the tipping point takes decades.

What is perhaps most interesting about these data is that they imply that EVs will have a disruptive impact on car markets even when EV account for a relatively small part of total sales. This is very much in line with our findings from work we have done on other energy transitions: demand for incumbent products usually starts to fall when the challenging technology accounts for less than 10 per cent of total supply.

Table 1: The implied EV market at the tipping point

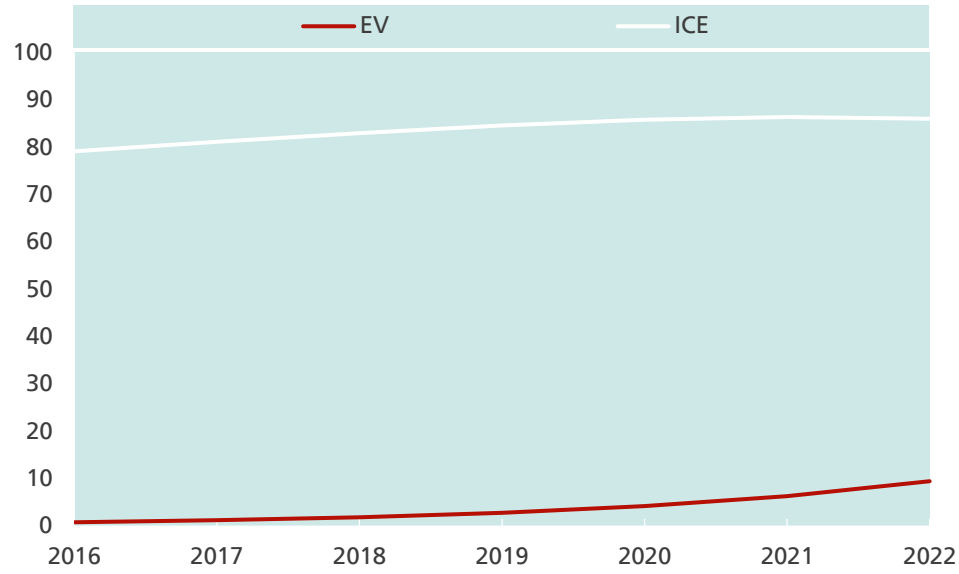
Area	2021	2022
Total EV sales (m)	6.3	9.5
Market share of EV sales	7%	10%
EV fleet size (m)	19	28
Market share of EV fleet	2%	3%

Source: TSRP estimates

Car markets

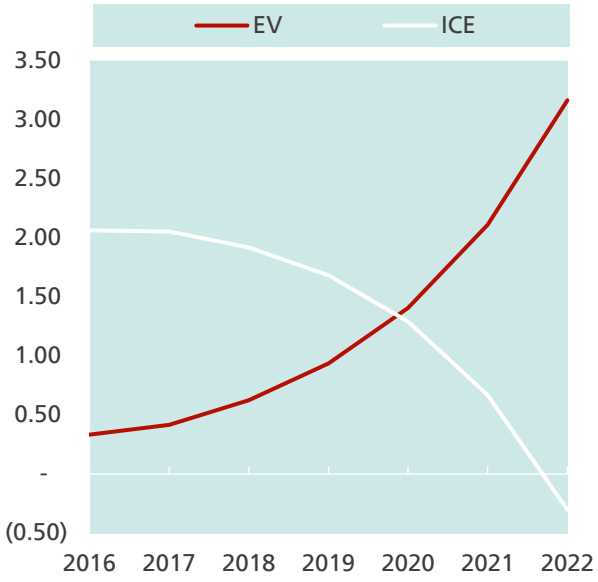
Assuming 50 per cent annual growth of EV sales to 2022, we show total sales, incremental sales and incremental market shares of EVs and ICEs over the same period (see Charts 6-8 below). Interestingly, total sales (Chart 6) seem to show almost no change while incremental sales and market share (Charts 7-8) show radical change. It is presumably the realization of this change to come that has prompted the automotive sector to make strategic decisions in recent months to shift to EVs.

Chart 6: Total sales of cars (mn)



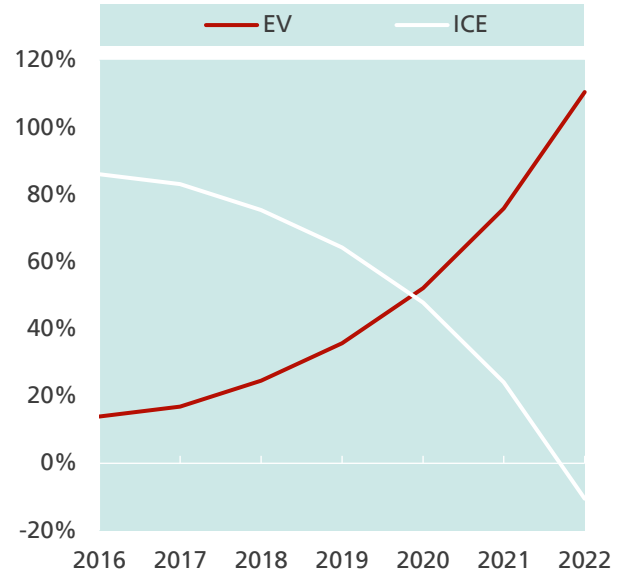
Source: TSRP estimates.

Chart 7: Incremental sales of cars (mn)



Source: TSRP estimates.

Chart 8: Incremental market share



Source: TSRP estimates.

How fast will EV sales rise

The two main variables in any attempt to find the point at which incremental EV sales make up all incremental car sales are, of course, the growth rate of EV sales and that of total car sales.

Currently, there is little disagreement over the annual growth rate of total car sales: most forecasts put it at around 2-3 per cent. A lot of visionary work has been done on the impact of self-driving cars and other such technology, but this subject requires separate analysis and is likely to become more important after the next five years. For the purpose of this current analysis, we make the assumption of a 3 per cent annual growth rate in total car sales. If growth rates are just 2 per cent, then the tipping point would come a year or so earlier.

There is no real consensus on the likely annual growth rate of EV sales, however. For this reason, we examine the arguments for and against rapid EV sales growth and consider the consensus views in light of these arguments. We then set out our own conclusions.

Reasons for rapid EV growth to continue

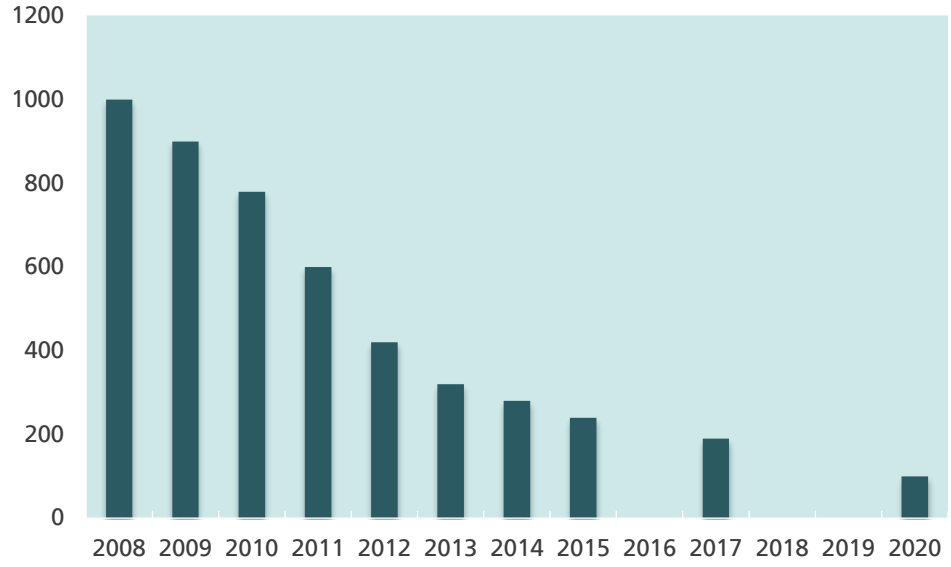
Falling battery prices

As is widely understood, it is the cost of the battery that makes EVs more expensive than ICEs. For example, if a battery costs US$200 per KWh and a car has a 60 KWh battery, then the cost of the battery alone is US$12,000. Falling battery costs have therefore long been a part of the EV growth story.

Battery prices have been falling at an annual average rate of 21 per cent a year since 2008 and have consistently surprised on the downside.

If this rate of decline is maintained, then battery prices will fall below US$100 per KWh by 2020.

Chart 9: Battery prices (US$/ KWh)



Sources: US Department of Energy, Tesla.

Given the entry of so many new competitors into the market, we expect battery costs to continue to fall rapidly.

The shift of car companies to EVs

Ford, GM, VW, BMW and Daimler Benz all made major announcements in 2016 about their shift into EVs. According to Harry Benham of Carbury Consulting, their planned investments add up to US$5-6 billion annually for the next four years or 20 per cent of their total capex.

It is interesting to note that the car sector made this strategic shift when EVs accounted for less than 1 per cent of the total car market. However, the main point about the shift of the car sector is that it will have a very positive impact on the growth of EVs thanks to:

- **More choice**: According to BNEF, consumers can now choose from 100 different EV models; by 2020, that figure will be 200.
- **Lower costs**: The automotive sector is expert at driving down costs. As it pours money and expertise into batteries and electric transmissions, we expect to see prices fall faster.
- **More innovation**: More competition is likely to mean more innovation – in terms of both longer driving distances for batteries and new business models to breach the gap between ICEs and EVs.

The rising regulatory burden on ICEs

There are three political imperatives that are encouraging many governments to support EVs at the expense of ICEs. Many but not all governments, that is. For example, the US is nearly energy-independent, enjoys low levels of pollution per square kilometre thanks to its relatively dispersed population and has an entrenched petrol culture. However, most other countries are not in the same position. They face constraints from:

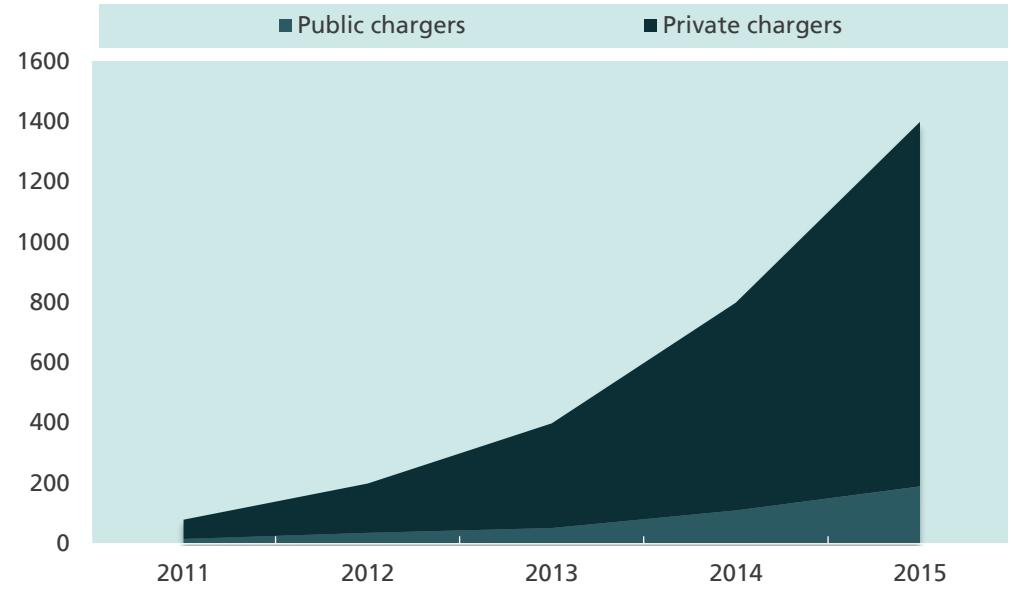
- **Local pollution**: According to the IEA, the burning of oil is responsible for 61 per cent of NOX, 25 per cent of SOX and 10 per cent of PM 2.5 emissions. The mayors of cities from Oslo to Amsterdam are planning to prevent the entry of ICEs in the 2020s.
- **Global warming**: The global transport sector accounts for 28 per cent of energy demand. As the UK Committee on Climate Change argues, it is imperative to decarbonize the transport sector if anthropogenic carbon emissions are to be cut.
- **Energy independence**: As we have noted previously, China and India lack oil and do not wish to increase their dependence on other countries for supplies. EVs are the obvious way for them to achieve greater independence. If recent rhetoric from President Trump becomes reality, China will be encouraged to go down this path at a faster speed.

All the above means that many governments will seek to curtail demand for ICEs and encourage the growth of EVs.

The rapid build-out of infrastructure

One of the developments that has most surprised commentators over the last few years is how quickly it has been possible to build out EV infrastructure. The reasons for this development are the regulatory pressures identified above and the ease for some householders to install an EV charger. Below we report IEA data on the infrastructure build-out (see Chart 10), which show that the number of charging points has been doubling every year since 2011. This hardly suggests the chicken and egg problem, which is so commonly cited as an impediment to the growth of EV sales.

Chart 10: EV charging stations worldwide (000)



Source: IEA.

Meanwhile, many governments have plans to increase the EV infrastructure. China, for example, plans to build 5 million charging points by 2020 and to increase its public charging points tenfold to 0.5 million over the same period.

Cost parity

The calculation of cost parity between ICEs and EVs is based on a large number of assumptions, including tax rates on petrol, cost per KWh of battery, distance driven per KWh of battery, required range and so on. Each country has different norms pertaining to each of these factors.

However, many of the variables can be assumed, leaving us with a relatively simple model comprised of the two key factors of cost per KWh of an EV and driving distance per KWh. On the assumption that the annual cost of electricity is around US$1,000 less than the cost of petrol and that an EV drivetrain costs around US$3,000 less than an ICE one, we can calculate a payback time for an EV without subsidy.

For example, with a required range of 250km and a distance travelled per KWh of 6 km, the required battery size would be about 40 KWh. At US$150 per KWh of battery costs, the total battery cost would be US$6,000. Assuming an electric drivetrain that is US$3,000 cheaper than the petrol equivalent, the total price gap would be US$3,000. Assuming electricity costs US$1,000 a year less than petrol, the payback time would be three years.

Table 2: Payback time (in years) based on battery price and distance per KWh

	Battery price US$/ KWh			
Distance km/ KWh	250	200	150	100
4	13	10	6	3
6	7	5	3	1
8	5	3	2	0
10	3	2	1 -	1

Source: TSRP estimates.

Assuming a driving distance of 6 km per KWh, it is possible to calculate the payback time based on the required range. For example, if the required range is 200 km and the cost of the battery is US$200 per KWh, the payback time is four years.

Table 3: Payback time (years) based on battery price and required range

	Battery price US$/ KWh			
Required range km	250	200	150	100
400	14	10	7	4
350	12	9	6	3
300	10	7	5	2
250	7	5	3	1
200	5	4	2	0
150	3	2	1 -	1

Source: TSRP estimates.

The rule of thumb in the car industry is that a payback time of less than three years is required in order to motivate consumers to switch from one option to another. Give that governments are anxious to nudge consumers out of ICEs and into EVs, we consider this three-year threshold to be somewhat conservative.

Once cost parity is reached (or is in sight), a host of innovative models from auto manufactures and governments can be expected to help bridge the gap. This, in turn, is likely to mean that the current very high cash subsidies for EV buyers can gradually be dispensed with.

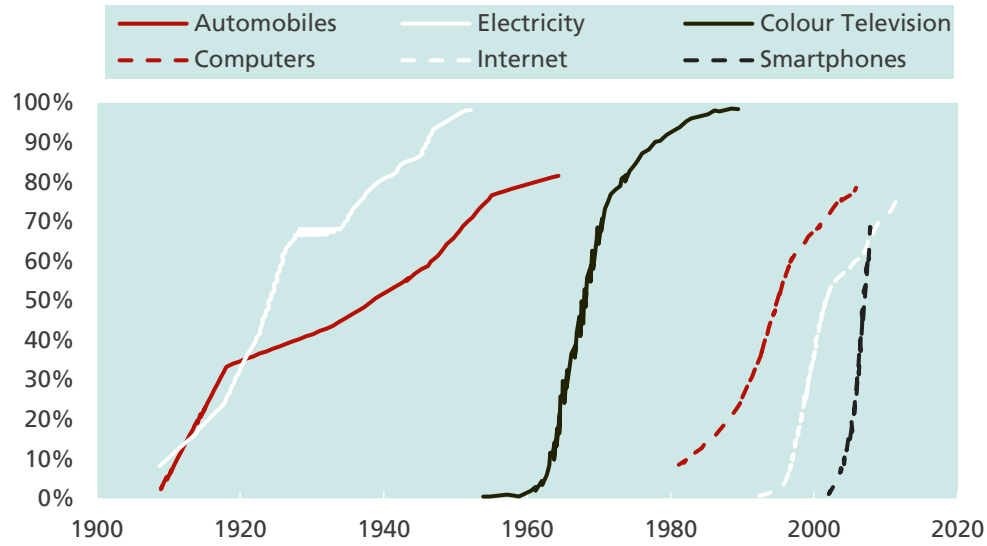
Moreover, once cost parity is reached, consumers may simply opt outright for this superior technology. As we pointed out in our 16 November 2016 note Marginal change moves markets, a similar phenomenon was observed when consumers moved from gas to electricity for lighting or from coal to oil for transport.

Consumer adoption

Some consumer technologies grow extremely rapidly, as highlighted in Chart 11, which is the well-known Blackrock chart on household penetration of key technologies in the US. A century ago, it was automobiles and electricity; in more recent times, it has been mobiles,

the internet and smartphones. Certain products and areas have seen penetration rise very rapidly– from less than 5 per cent to more than 70 per cent.

Chart 11: US household penetration



Source: Blackrock.

The optimists believe that the EV will follow such a growth path as costs fall and consumers adopt a technology that many see as superior. Those who argue for slower growth point to high costs, subsidies and so on. So the core debate is, once again, about battery costs.

Our view is that the US will, in fact, be a laggard in the adoption of this technology. The type of penetration growth rates seen in the US in previous generations are now likely to characterize the emerging markets.

Chinese leadership

As we set out in our 11 July 2016 note China: Leader of the new energy future, China has more powerful reasons to embrace the EV than does either Europe or the US. Those reasons include:

- Higher levels of population concentration and pollution;
- Higher level of oil import dependency and official concerns about that dependency;
- Leapfrog ability – as a laggard in the global automotive race, China has every incentive to embrace a new technology that could offer a leadership opportunity;
- Government leadership: well aware of the returns to technology leadership, the government has designated the EV as an industry of focus;
- Workshop of the world – China already produces most of the parts of the EV;

- Track record – China has a track record of leadership in electric transmission technologies (the two most commonly cited examples are electric buses and electric bikes; China has over 200 million electric bikes while Europe and the US are lagging with less than 10 million in total; and
- Good at building infrastructure – the government is planning to build a massive EV charging infrastructure.

India is embracing the EV

India faces similar issues to China in terms of pollution and oil dependency. It, too, has a flourishing car industry and a government keen to embrace renewables.

As the costs of EV fall rapidly, India does not need to follow the fossil fuel-intensive path of the ICE. It can go straight to the EV.

Energy Minister Piyush Goyal has spoken of his desire for India to have an electric vehicle-based transport system by 2030.

Reasons for EV growth rates to slow

In this section, we review the arguments most often made about why EV sales will stop growing. Because we regard many of these arguments as overstated, we include some counterarguments as well.

'We've heard it all before'

The reasoning behind this argument is that for years now, EV promoters have been telling us that the technology is about to take off. Governments frequently had ambitious EV sales targets that were not met.

To some extent, we understand this perspective, and it is indeed necessary to be very cautious about projections for this industry. However, as we set out above, the big difference between today and the past is that costs are now comparable between ICEs and EVs. And it is cost and not government fiat that will make all the difference here.

Battery costs will stop falling

Another line of argument is that battery costs will stop falling rapidly – a view that underpins the relatively modest EV sales growth projections by some oil companies.

We have no crystal ball for predicting future battery costs, but we note that for years they have been falling faster than expected. We expect costs to continue to fall rapidly as more resources are allocated to battery technology.

Governments will run out of subsidies

The argument is that EVs will require subsidizing for a decade or more. And as the industry grows, so governments will be obliged to rein in those subsidies, which will lower the growth rate.

However, this argument is really just a variant on the battery cost argument. As noted above, we believe that the EV will be able to compete without subsidies in the emerging markets by 2020.

Lack of infrastructure

The internet is full of photographs of unfortunate individuals running cables down the side of buildings to charge their EVs – hence the conventional argument is that the necessary infrastructure for EVs will take a long time to build and will be prohibitively expensive.

We think that this reflects teething troubles and is not a systemic problem. Most countries have an established grid, so adding EV capacity to it is not especially difficult. Most users charge their EVs at home – something that can be done with a relatively inexpensive connector. And specialist EV charging companies, owners of supermarkets and public car parks and others are building out charging stations in public locations. As noted above, the number of EV charging points has been doubling every year since 2011.

The law of big numbers

Here the argument is as follows: it is of course easy to grow from a low base, but it is much harder to do so from a higher base. In other words, as demand increases, growth can be expected to slow.

While this is true, it is also the case that the growth slowdown may not come for several years. In the context of 900 million cars, 2 million EVs is still a small number.

Not everyone likes EVs or can have one

One argument often made is that EVs will not take off because a particular group of users does not like them or because they cannot have them. There are a lot of people living in flats with no on-street parking who would struggle to charge their cars at home, for example. And there are a lot of people who, for reasons best known to themselves, have a preference for burning lots of oil.

This is an argument that we addressed, in broad terms, in our 12 December 2016 note Renewable intermittency – no barrier to transformation; and the same point can be made here: disruption to incumbents happens at relatively low levels of penetration of the challenging technology.

For the EVs to disrupt conventional car markets, 100 per cent penetration is not required. Indeed, as we noted above, it merely requires 10 per cent of new car sales and 3 per cent of the total fleet to be EV.

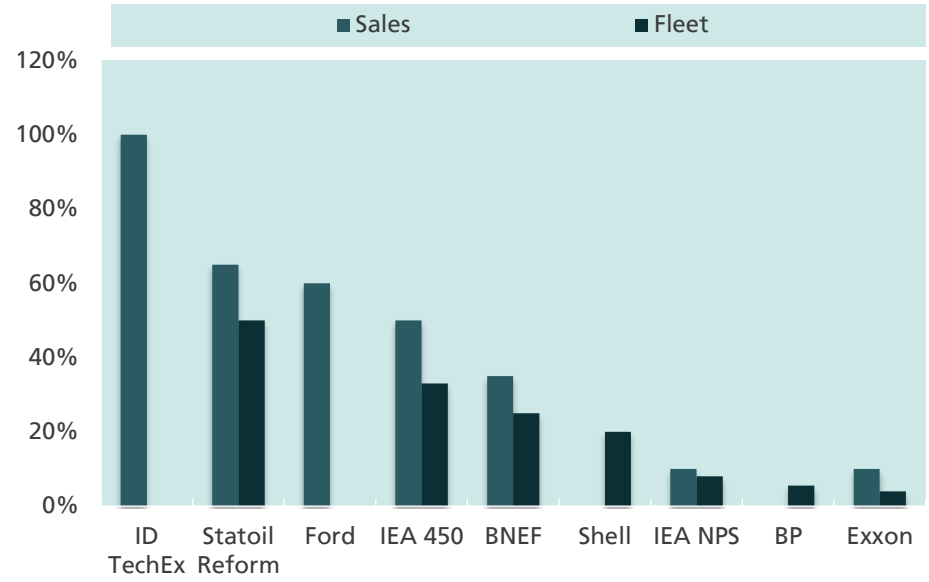
And it is, of course, much easier to reach 3 per cent fleet penetration and 10 per cent sales than it is to get to the mythical 100 per cent that EV detractors seem to require. Those who initially adopted the EV

were the rich, but the next to do so will likely be taxi companies, delivery vans, Chinese people who want the capacity to drive but are not allowed to buy an ICE, second car users in the West, low mileage users in the emerging markets and so on. Combined, these groups represent a large number of potential EV drivers.

Other views

There is a wide range of views on the likely development of the EV. Each organization tends to have a different way of expressing this, so we summarize the available data for each company in terms of the share of the total car fleet in EV and the share of EV sales at the end of the respective forecast period. Most forecasts are up to 2040, but BP's forecast is to 2035 and Ford's to 2030.

Chart 12: EVs as share of end-of-forecast-period sales and fleet



Sources: IDTechEx, Statoil, Ford, IEA, BNEF, Shell, BP, Exxon

Chart 12 above makes clear that although the range of views is wide, one thing stands out: the consensus formed by IEA, BP and Exxon (and most often used by oil investors) is very conservative compared with the views of the others. While those who form the oil consensus on EVs may be right to be so conservative, they are out on a limb.

The IEA short-term view

The IEA provides more details about its model used in its "New Policies Scenario". That model is a three-part one based on growth rates of the stock of EVs of 50 per cent to 2020, 25 per cent to 2025 and 10 per cent to 2040. The IEA forecasts a fleet of 10 million EVs in 2020 and 30 million in 2025. The main reason for projecting slowing growth appears to be that the IEA still believes that the EV will be US$5,000 more expensive than the ICE in Europe – even at a battery cost of US$100.

However, the most interesting part of the analysis is that the IEA nonetheless foresees 50 per cent average annual growth rates until 2020; moreover, the forecast level of 30 million total EVs in 2025 implies that the tipping point would be passed before then.

How credible is 50 per cent growth until 2020

It is, of course, one thing to forecast growth on a spreadsheet, but it is another to make the cars.

For this reason, it is worth asking if the implied growth levels we are talking about are achievable. At 50 per cent growth rates, total EV sales in 2020 would be 4 million and the total EV car fleet 12 million. These are credible numbers within the context of what countries and companies are seeking to do. China is planning for 5 million EVs by 2020, France for 2 million, Germany for 1 million and Japan for 1 million.

Our view

We believe that the average annual growth rate of EV will be between 40 per cent and 60 per cent for the next five years thanks to falling battery costs, the entry of the major car companies into the market and the leadership of China. We expect cost parity to be reached with ICEs by 2020 and believe that this means high growth rates will continue. Thus we incline towards the assumption of a 50 per cent average annual growth rate until at least 2022. This would be sufficient for peak ICE demand within the next five years.