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Bright spark: Electric vehicles and energy impact

The rise of electric vehicles has attracted media and analytical attention far beyond their current small market share. For consuming countries, they offer technological advances, energy security and, above all, environmental sustainability. Motorists enjoy superior performance and lower fuel bills, while range and cost continue to improve. Electric cars are approaching competitiveness with conventional vehicles, though hurdles remain. But how fast will they acquire a mass market? What impact does this have on future oil demand? And what responses are available to major oil exporters?

Lola-Drayson B12/69EV, zero emission 850 horsepower Le Mans Prototype car

Executive Summary

- **Electric vehicle penetration** is growing rapidly from a very small base, making projections range widely.
- **Electric vehicle improvements and take-up** have tended to be under-estimated by mainstream forecasters.
- Adoption will shift from being driven by subsidies to **economics and performance** in the mid-2020s.
- Most focus has been on light passenger vehicles, but **public transport and freight** could surprise.
- Within a decade, electric transport will likely be **limiting or capping oil demand growth.**

Implications for Middle East Oil Producers

- **Leading oil exporters** face a significant challenge, especially as higher oil prices encourage the faster development and deployment of electric transport.
- **Improving the internal combustion engine** may keep it in play for longer, but not indefinitely.
- **Oil-dependent economies** can hedge by investing in various parts of the electric vehicle ecosystem.
- **Gas exporters** may be less exposed initially, due to increased electricity consumption and the need for flexible generation.

Electric vehicles are being driven by improving technology and environmental concerns

Electric vehicles (EVs) have attracted support so far because of three main advantages:

- Zero greenhouse gas emissions (while driving of course; manufacture and electricity generation still release greenhouse gases);
- Zero local air pollution (no emissions of particulates, nitrogen oxides, sulphur oxides, unburnt hydrocarbons, carbon monoxide);
- Improved energy security: by eliminating the dependence of transport on oil, countries can instead use electricity generated from diverse and often local resources (gas, coal, nuclear, renewables).

From a motorist's point of view, EVs have other advantages over conventional internal combustion engine (ICE) vehicles. They can have better performance (acceleration), they are quieter, and require less maintenance (fewer moving parts – 18 in a Tesla versus 20000 in a typical ICE car; lower operating temperatures; and regenerative braking). They also have much lower fuel costs due to higher efficiency and the lower price of electricity per unit versus gasoline or diesel, even when accounting for transmission losses.

However, EVs have long suffered from drawbacks related to battery technology. The energy density of gasoline is about 100 times that of a lithium-ion battery. This is partly offset by the EV's higher efficiency and simpler engineering, but nevertheless the battery makes up about 60% of the power-train's weight and half the vehicle's cost. This limits the range. Battery performance deteriorates in very hot or cold weather. Charging stations are still not widely available in many markets, and charging times are long (an hour even with a fast charger), making EVs inconvenient for long journeys. Because of battery deterioration and the improving technology in newer EVs, resale value is lower than for conventional vehicles. (On the other hand, batteries could be sold for stationary applications and replaced with new ones).

Therefore, adoption of electric cars has been driven, so far, mainly by mandates, subsidies and other incentives. These policies include, in various countries:

- Tax credits and VAT exemption on the purchase price
- Subsidies on the purchase price
- Exemptions from registration tax
- Tax exemptions for corporate vehicles
- Use of high-occupancy lanes
- Bans on the use of conventional vehicles in cities
- Outright bans on the sale of new conventional vehicles (in prospect: Norway and Netherlands 2025, India 2030, UK 2040)
- Free parking and exemption from road and ferry tolls
- Free charging
- Fleet purchases of electric vehicles by government (e.g. city buses)
- Fleet vehicle fuel efficiency or CO_2 emissions standards by automaker that are impossible to meet without selling growing amounts of hybrid or electric vehicles (effectively sales of ICE vehicles then subsidise those of electric vehicles)
- Zero Emission Vehicle mandates for carmakers

London, Paris, Madrid and Mexico City are among major cities considering an outright ban on diesel and gasoline vehicles to reduce local pollution in the 2025-2030 period.

Electric vehicle adoption is still low, but growing

The close attention to electric vehicles (EVs) springs from what they might do, not what they have done so far. As FIGURE 1 shows, sales and the overall global fleet have grown very rapidly, particularly from 2011 onwards. But at the end of 2016, there were about 2 million electric (plug-in hybrid (PHEV, which can charge their battery directly or by using an on-board gasoline or diesel engine) and battery (BEV)) vehicles worldwide, from a global fleet of about 1.2 billion vehicles of all types. The share of new sales had risen to 1.1% by 2016.

The key adopters so far are China and the US, because of the size of their markets, and Norway, as it has by far the highest adoption level, due to generous incentives. 28.76% of new sales in Norway in 2016 were electric, compared to just 1.37% in China and 0.91% in the US. Adoption in India, the other key market for future transport growth, is still miniscule (4800 vehicles in 2016).

FIGURE 01: **ELECTRICITY VEHICLE FLEET BY COUNTRY**[1]

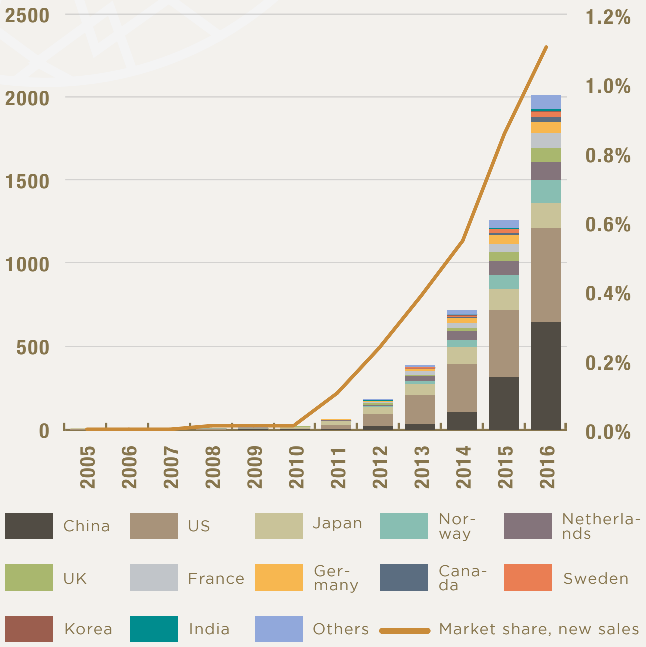
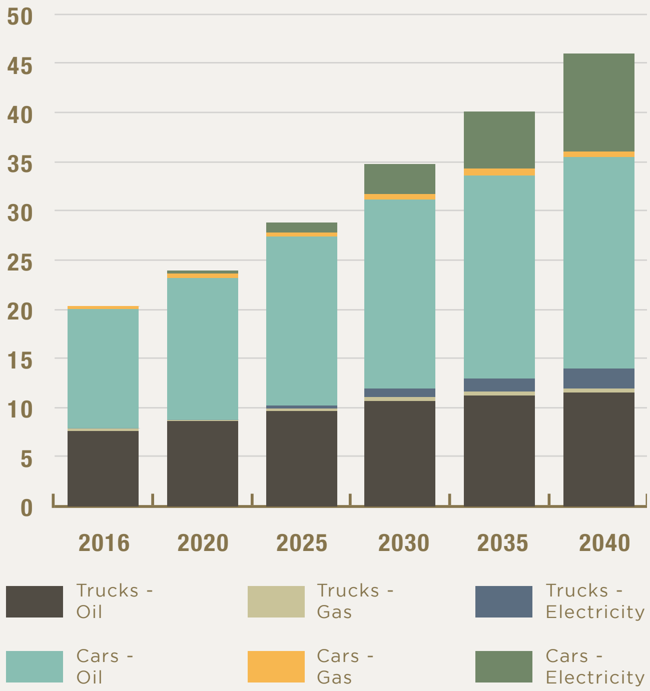


FIGURE 02: **VEHICLE-KILOMETRES TRAVELLED BY TYPE**



Tesla has captured the headlines, but all major vehicle manufacturers are introducing electric models. Volvo has said it will not launch any new non-electric/hybrid models. China sees EVs as a way to overcome its failure to compete effectively in manufacturing conventional vehicles. Competition between many different expert manufacturers is likely to lead, as for solar power, to innovation and rapid cost declines. Automakers that fail to develop competitive EV offerings face eventual obsolescence.

At such an early stage of adoption, forecasts depend on numerous assumptions on technology and cost improvements, concurrent advances in conventional internal combustion engine (ICE) vehicles, government policies, fuel prices, and consumer preferences. It is hard to compare the various forecasts, which have different assumptions for the total vehicle fleet, definitions of 'mass adoption', and time-frames.

Bloomberg New Energy Finance (BNEF) sees 54% of new car sales in 2040 being electric[2]. By this point, 33% of the global vehicle fleet of some 1.6 billion would be electric. Conversely, BP has more vehicles (1.97 billion), of which plug-in hybrids and battery vehicles represent 16%[3]. BP points out, though, that because of higher fuel efficiency, electric vehicles will be driven more (FIGURE 2).

The three key markets are China, the US and Europe, because of their large vehicle fleets, combined with growing environmental pressure (in China, Europe and some US states), industrial policy (China), and wealthy motorists (US and Europe). Lower fuel taxation in the US, along with a possible weakening of fuel efficiency standards, is likely to lead to slower adoption there than in Europe.

Technical improvements are driving EVs towards competitiveness

Improvements in range and battery cost have come much faster than mainstream forecasters expected, and the IEA, EIA, BP and BNEF have all increased their forecasts of future EV take-up.

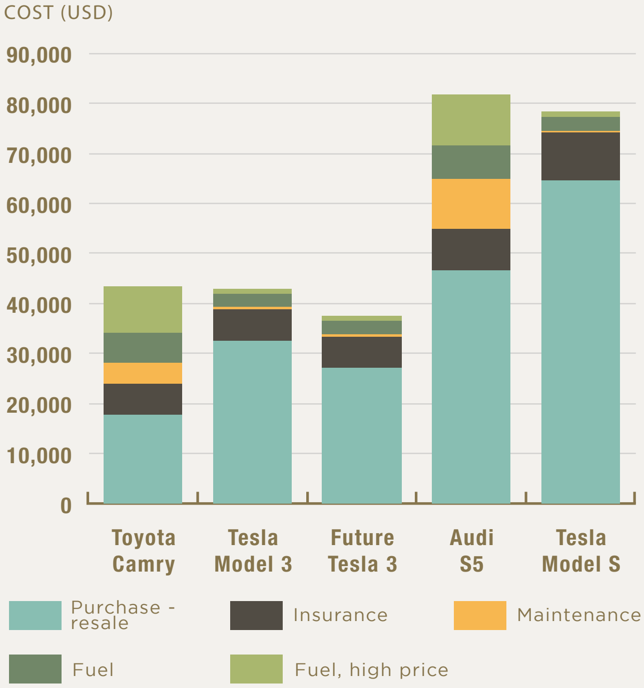
Near-term improvements include a decrease in charging to 80% of capacity to 15-20 minutes by about 2022; an increase in range by 2020 to 400-500 km for luxury vehicles and 400 km for mid-size vehicles; and continued falls in battery costs, down from more than $900 per kilowatt hour (kWh) in 2009 to less than $300 in 2016, with some car-makers claiming $180-200 per kWh today.

The battery for a mid-range EV comprises about half the car's cost. Scaling-up production and improving technologies may reduce Li-ion battery prices by 70% by 2030. Energy density has improved three times since 2010.

FIGURE 3 compares the total cost of ownership for some popular and comparable ICE and EVs (assumptions in the end-notes), including purchase minus eventual resale value, fuel, insurance and maintenance. This comparison excludes any taxes, subsidies or incentives. Total cost of ownership will vary depending on kilometres driven, so an EV will be more cost-effective for a high-mileage driver.

This chart indicates that a Tesla Model 3 is somewhat more expensive with US gasoline prices than a Toyota Camry (but arguably a better car). Similarly the Tesla Model S is more expensive than an Audi S5. However, with UK gasoline (petrol) prices, the costs are very similar. The EVs benefit from lower fuel and maintenance costs. A 17% drop in purchase price (by reducing the battery cost, assuming no other cost reductions) would make the near-future Tesla S3 significantly cheaper than the Camry in the UK. However, the up-front cost of about $30,000 would still be more than the Camry's $24,500, deterring motorists with less available cash.

FIGURE 03: **TOTAL COST OF OWNERSHIP FOR ICE AND EVS**[4]



Advanced batteries could bring EVs forward more quickly. New chemistries and designs are constantly being announced – lithium metal, lithium-air, cobalt-nickel, carbon-based proton batteries - but bringing them to commerciality faces challenges of reliability, safety (lithium batteries being prone to fires), endurance and manufacturing costs.

The key take-off point is seen between 2025-30, when electric vehicles become competitive without subsidies, driven by plunging Li-ion battery costs. Plug-in hybrids are more complex due to the dual power-train, and so pure battery-electric vehicles are likely to be preferred except for heavy and long-range applications.

The adoption of electric vehicles will require the major expansion of charging points, including fast 'superchargers', at homes, work-places, parking spots and along highways. This conversely will become more attractive as electric vehicle penetration grows.

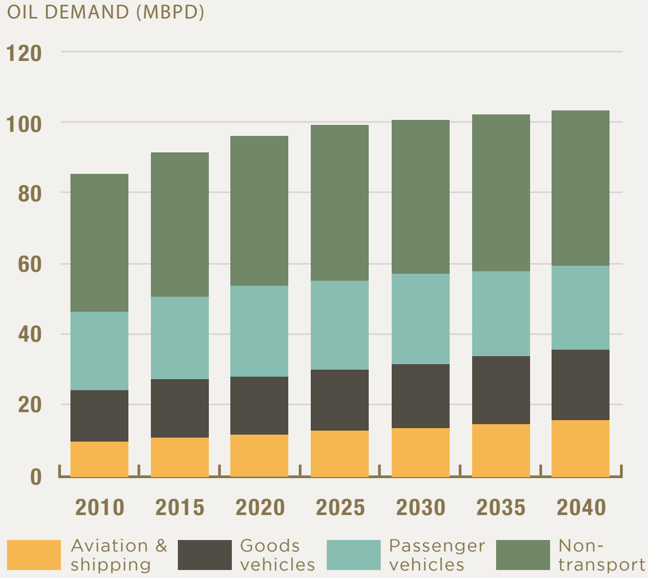
This eventually has a significant impact on fuel demand

These projections are much more aggressive than the IEA's (FIGURE 4), in which passenger vehicle fuel demand grows from 23.9 million bpd worldwide in 2015 to a peak of 25.3 Mbpd in 2025, and then declines only a little to 23.5 Mbpd by 2040. Road freight, aviation and shipping keep growing significantly, while non-transport uses (particularly petrochemicals) rise even faster.

Incidentally, the IEA's 'non-transport' category includes lubricants, and this may fall as electric vehicles don't have engines that require lubrication.

In BP's view, demand from cars, at 18.7 Mbpd in 2016, falls very slightly to 18.6 Mbpd in 2040. This is a combination of +22.6 Mbpd from increased travel, -18.2 Mbpd from improved fuel efficiency, -2 Mbpd from ride-sharing, and -2.5 Mbpd from EVs.

FIGURE 04: **IEA'S OIL DEMAND FORECAST BY SECTOR**[5]

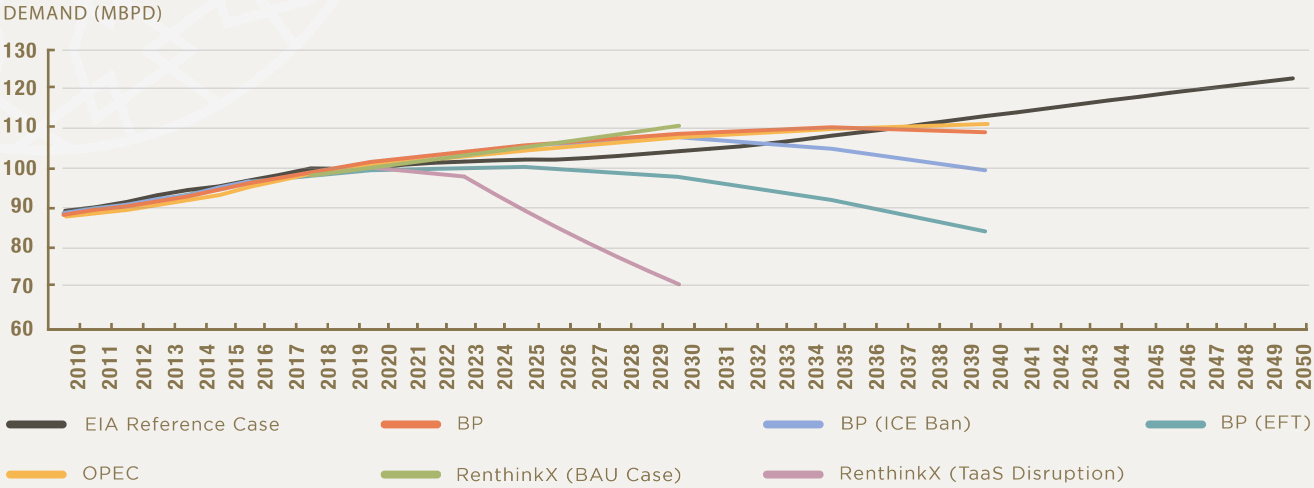


The effect of electric vehicles is therefore again quite modest, though it does contribute to overall oil demand flatlining from 2030 onwards. Improvements in ICE efficiency will be more important than EVs in reducing oil demand at least over the next decade. However, BP does present other scenarios: 'ICE Ban' and 'Extra-Fast Transition' (shown in FIGURE 5 along with other scenarios). In EFT, total oil demand peaks in 2024 and is down to around 85 Mbpd by 2040.

One more aggressive forecast, assuming mass adoption of electric autonomous vehicles, was produced by RethinkX (transport-as-a-service, TaaS). However, overly aggressive assumptions on cost and penetration make this unrealistic.

By contrast, BNEF sees electric vehicles totalling a third of the global fleet by 2040, which would displace 8 million barrels of gasoline and diesel daily. Conversely, it would require 1800 terawatt hours of electricity (from total global generation by 2040 of 36000 TWh). Most of this extra electric demand is likely to be supplied by a mix of renewables (solar, wind and others) and gas.

FIGURE 05: **SCENARIOS FOR OIL DEMAND WITH FAST EV ADOPTION**



Applying BNEF's electric vehicle take-up to the IEA's projections would suggest that, instead of still growing to reach 103.5 Mbpd by 2040, world oil demand would have peaked and fallen back to about 97.3 Mbpd, just above the level of 2020.

Vehicle electrification is not only about passenger cars

Perhaps because of the success of Tesla, electric passenger cars have received the most attention from media, consumers and analysts. However, five other transport modes require serious consideration.

Bikes and scooters: Ride-sharing electric scooters are being pioneered by companies in the US such as Jump (now acquired by Uber) and Bird[6]. China has more than 200 million electric motorcycles[7], and electric bicycles are becoming increasingly popular in Europe. It is questionable, of course, how much such vehicles replace ICE cars, and how much they simply add to transport demand or substitute for walking or public transit.

Heavy goods and passenger transport: Most forecasts assume little penetration of EVs into heavy goods transport (trucks). Tesla unveiled an electric truck in November 2017[8], but it seems to have dropped down the priority list[9]. However, electric trucks could reach cost-parity with ICEs between now and 2030, though long-range trucks will only become competitive after that[10]. Heavy short-range vehicles which make frequent stops, such as delivery vehicles, tractors, garbage trucks, haulage around ports and fork-lifts, may be the best early adopters.

Since shorter-range trucks consume less fuel, the take-up of EVs has a relatively modest impact on fuel demand, displacing perhaps 1.5 Mbpd by 2040 and 3.5 Mbpd by 2050. Nevertheless this is not insignificant, given that the IEA predicts a rise in road freight oil demand of 3.9 Mbpd in 2040.

China has been leading in the deployment of electric buses, with Shenzhen (near Hong Kong) a pioneer, and BYD the leading manufacturer. Shenzhen has more than 300,000 electric buses, and its latest policy is that electric construction vehicles are promoted, all new light-duty trucks should be electric by 1st May, and by 31st December 2018 all new taxis will be EVs[11]. Electric buses are beginning to attract attention for other polluted metropolises including London, Paris and New York. Electric buses are already displacing some 279,000 bpd of diesel demand worldwide[12].

Rail: Much rail is already electrified, and trains take their power from overhead lines or a third rail. However, pollution and congestion concerns may drive a growing adoption of urban mass transit, high-speed rail and goods trains to replace cars, short-haul aviation and long-haul shipping. In the Gulf, Doha and Riyadh are building metros, Dubai's already operates, and Abu Dhabi, Bahrain, Jeddah, Kuwait, Madinah and Makka are planning them. On the continental scale, routes across Eurasia are being pioneered by China's 'Belt and Road' initiative.

One possible game-changer here is the 'Hyperloop', which propels goods or passengers at high speed in pods down a vacuum tube, and which could replace air or high-speed rail for medium distances (100 km or so).

Marine: Electric and hybrid ships are being developed to reduce pollution. The 2020 International Marine Organisation ruling to limit the sulphur in bunker fuel, and the subsequent work to reduce the shipping industry's carbon dioxide emissions, for now promotes LNG-powered vessels. But battery ships could be attractive for short routes, such as ferries and supply vessels, particularly in environmentally-sensitive waters[13]. The autonomous electric container vessel under development by Norway's Yara and Kongsberg will have a range of 120 kilometres.

Aviation: Electric aeroplanes may appear unlikely because of the low energy-density of batteries compared to kerosene. However, Airbus and others are developing short-range, light battery aircraft[14] which could be useful for city transport. Some designs have ranges of up to 1100 km, with 9-12 passengers, while concepts exist for mid-range planes carrying more than 100 passengers for intra-European flights. Electric engines have advantages of not needing to be large (so a single plane could carry many, improving safety and aerodynamics) and they are easier to control and steer than jets. However, long-range electric planes are a long way off.

Electric transport can be part of a radically different energy system

Some visions of electric vehicles see them essentially playing the role of ICE vehicles today. However, they can change the transport-energy nexus in at least two ways.

Firstly, electrification potentially combines well with on-demand autonomous vehicles, which are likely to drive long daily distances, as they will have multiple users, a high capital cost to recover, and no issue of driver fatigue. Autonomous vehicles can find a point to charge themselves while waiting to serve a customer.

Secondly, their batteries can provide valuable services to the grid. With smart systems, they can charge when surplus electricity is available (at off-peak times or when there is abundant solar or wind power). They could feed power back into the grid to meet surges in demand, earning their owner additional income. When old batteries are replaced, they would still have sufficient capacity to be useful in stationary grid support or, for instance, connected to a home with solar generation.

The rise of electric vehicles is, though, not completely straightforward

Electric vehicle adoption, though, faces six significant medium-term challenges.

Subsidy withdrawal: As EVs become more competitive, governments will reduce subsidies and other benefits. This will slow the rate of adoption. It is unavoidable to do otherwise, as these incentives will become unaffordable or impractical. For instance, free parking, dedicated lanes and so on will be useless when a large share of vehicles are electric. Governments will also need to start taxing EVs, or the electricity that goes into them, to make up from losses from fuel taxation, a major share of revenue for European governments in particular.

Competition: ICE engines continue to improve in efficiency, and Saudi Aramco is sponsoring research into breakthrough engine types, including opposed pistons, and compression-ignition gasoline engines. It is also researching on-board carbon capture to eliminate greenhouse gas emissions. While these are probably not long-term solutions, they could keep the ICE competitive for longer, especially in emerging markets with poorer electricity reliability, lesser environmental regulations, and lower incomes to afford expensive vehicles.

Alongside electrics, hydrogen continues to attract attention as a zero-carbon future fuel for ships and aeroplanes and even ground transport, potentially powering fuel cells. At least initially, hydrogen is likely to be made from natural gas (or oil), which could be a climate-friendly process if combined with carbon capture and storage.

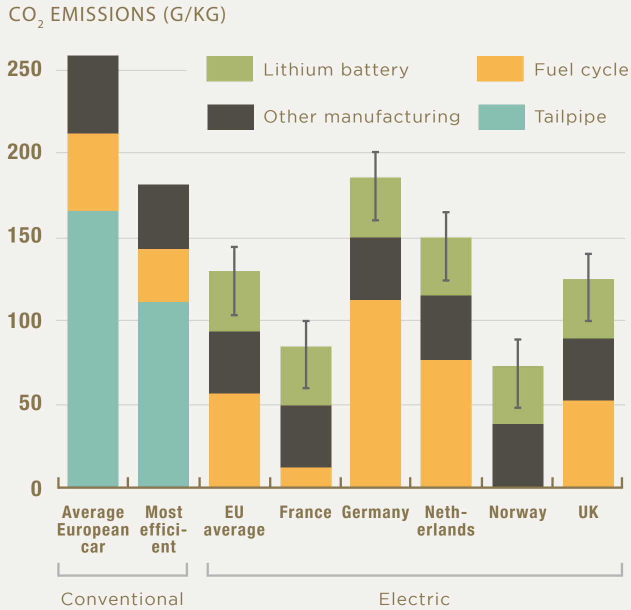
Falling oil prices: If oil demand begins to drop because of EV adoption (as in FIGURE 5), oil prices will also fall, maintaining the competitiveness of ICE vehicles. This would not prevent EVs from gaining market share but could slow adoption significantly, especially if major oil exporters respond to their loss of market by ramping up production to keep prices low.

Infrastructure: The availability of charging stations is still inadequate, especially in remote areas and in many developing countries. Electric grids will have to be reinforced locally to deal with surges of demand. At a national or regional level, charging times will have to be aligned with generation to avoid demand spikes in the early evening. The ideal time may vary with weather as solar and wind power are increasingly adopted.

Environmental impact: The manufacture and recycling of electric vehicles has to be done while observing environmental protections. More significantly, electric vehicles still create emissions while charging, unless power generation is completely decarbonised. An electric vehicle emits less greenhouse gases than an ICE vehicle unless charging on a very high-carbon grid (almost entirely coal-powered). The marginal generator, called on to meet the additional demand, will likely be gas (or in some places coal) in the short run.

FIGURE 6 illustrates this in the case of Europe. European power generation varies from mostly nuclear (France), nearly all hydro (Norway), to a mix with substantial coal (Germany), or with more gas (Netherlands and UK). Life-cycle CO_2 emissions from the average European car are always worse

FIGURE 06: **LIFE-CYCLE EMISSIONS FROM CARS IN EUROPE**[15]



than an EV, but the most efficient ICE is slightly better than an EV in Germany. EV life-cycle emissions vary by a factor three depending on the carbon intensity of the power grid. In a coal-heavy country such as Poland or India, this would be even worse.

However, this will become less important as more renewable (or nuclear or carbon capture) power is deployed, and manufacturing improves.

Critical materials: As currently built, EVs use lithium, cobalt, nickel and graphite for their batteries[16], four times more copper than a traditional vehicle (due to more wiring), and rare-earth metals in the motors (neodymium, praseodymium and dysprosium; though Tesla, Renault and BMW use non-rare earth materials). Lithium is employed in many batteries, not just for EVs, and rare-earths are used in wind turbine motors, consumer electronics and elsewhere.

There is no shortage of reserves and potential resources of these materials. However, 65% of cobalt is mined from the Democratic Republic of Congo (DRC), and all graphite and 80% of rare-earth metals currently mined comes from China. This creates supply-chain dependence and the potential for bottlenecks, price rises and boycotts. Artisanal mining in the DRC is socially and environmentally harmful.

Therefore reducing raw material use, developing alternatives, stepping up recycling, and encouraging new mining projects in diverse locations will all be important for meeting the rapid rise in demand for these inputs.

Conclusions: Implications for the Middle East

The low level of penetration today of electric vehicles, their relatively high cost, and their significant drawbacks against ICE vehicles, may encourage complacency. EV take-up is still mostly driven by government incentives. But their market share is growing fast and technological improvements will make them competitive in a growing number of markets in the 2020s. Environmental pressures mean that European governments in particular will increasingly mandate their use. This threatens a sharper fall in oil demand than the relatively rosy predictions of the IEA and BP, but even these show a flattening of total oil demand in the 2030s.

Major Middle East oil exporters can consider hedging against the adoption of electric vehicles in a number of ways. These include:

- Investing in improved ICE vehicles;
- Encouraging other sources of oil demand (such as petrochemicals), or other mobility (such as hydrogen);
- Investing in EVs themselves, either internationally or even in domestic manufacturing. This could cover various parts of the value chain – the vehicle, the battery, critical material inputs, software, charging and electricity retail, or related areas such as autonomous vehicles;
- Removing fuel subsidies and creating the conditions for domestic use of EVs where economically viable;
- Making use of the potential for EVs to combine with power grids to balance renewables, given the region's great solar resource.

Ultimately, whether EVs rise to dominance by 2030, 2040 or 2050, those dates are still well within the lifespan of current Middle East citizens and of long-lived assets such as oil-fields and refineries. The potential for growing EV adoption makes the case for continuing economic reform and diversification even stronger.

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