EVolution

Electric vehicles in Europe: gearing up for a new phase?

Amsterdam Round Tables

In collaboration with
McKinsey&Company

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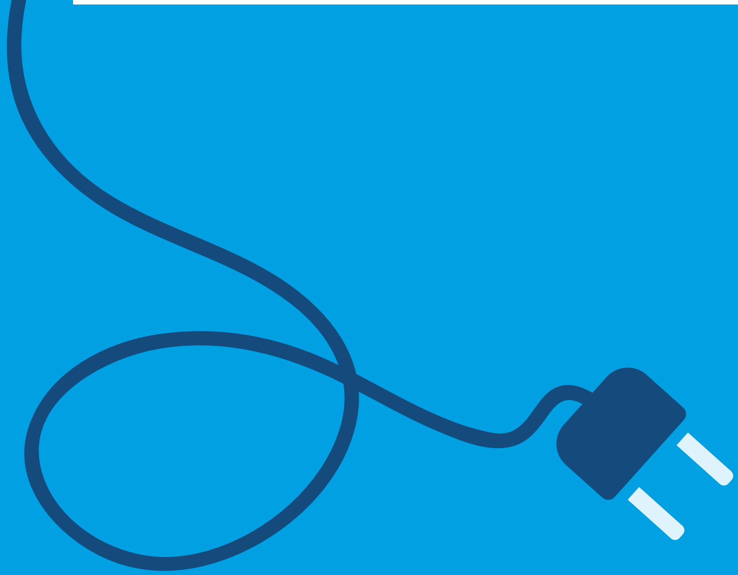


This report is an initiative by the **Amsterdam Roundtables Foundation** and has been prepared in collaboration with McKinsey & Company. The report content draws upon McKinsey's insights in the electric vehicle sector and is enriched with interviews with representatives from public authorities, grid operators, smart grid solutions providers, charging technology companies, charging service providers, car manufacturers, and mobility service providers.

CONTENT PAGE

Introduction

Electric mobility relates to electrification of the automotive powertrain – there are several powertrain alternatives under development, with different storage solutions and different sources of propulsion (Exhibit 0.1).

In the past few years, Europe has gone through the initial adoption phase of electric mobility. After a "turbulent" period of excitement and promise as well as disappointment, it is now possible to formulate a clearer view on the development of electric mobility to date and its drivers going forward.

Although global and European sales figures are still small (below 1% of new car registrations), we see that in some pockets, growth has picked up speed – driven by government support, an improved offering of electric vehicles (EVs) by the automotive industry, and a growing familiarity and willingness to buy on the side of the consumer. In Norway, one such growth pocket, the top-selling car models in September, October, and December of 2013 were battery electric vehicles (BEVs). In November of last year, EVs reached 12% of sales in Norway.

The gradually increasing momentum behind EV adoption – both from the side of the consumer and the automotive industry – suggests that electrified powertrains will play an important role in Europe's mobility going forward. Going beyond the initial "hype," the next few years will be a period of further maturation of the EV industry, nurtured by government support. In the longer run, as a result of EU regulation, automotive powertrains are likely to further diversify, resulting in a portfolio of powertrains, with electrified alternatives to the traditional combustion engine. The rate of adoption of electric powertrains will depend on several factors in addition to fleet emission regulation, such as fuel price and battery pack price development.

This report intends to provide a fact-based perspective on the status and current developments of the e-mobility ecosystem in Europe and is structured into five chapters.

"Chapter 1: Placing EV dynamics in industry context" will provide an overview of current EV adoption in Europe and the forces driving it, focusing on government, industry, and consumers.

"Chapter 2: Cars, components, and cost" describes the current portfolio of automotive powertrains and how these might develop in the short and long run. The chapter elaborates on the technology development of battery packs and outlines drivers that will shape the future of the powertrain portfolio.

"Chapter 3: Charging infrastructure" discusses the status of charging technology and the charging infrastructure roll out in Europe, describes charging behavior of the initial group of EV drivers, and highlights several public and private initiatives to drive further expansion of the charging infrastructure.

"Chapter 4: Distribution and delivery" dives into the implications of a shift towards electric mobility for the power sector, outlining both challenges and opportunities for players involved.

"Chapter 5: Innovative business models" details several of the more innovative approaches to mobility, which have the potential of disrupting traditional value chains and could enable further uptake of EVs.

ELECTRIC VEHICLE DEFINITIONS

Electric mobility relates to electrification of the automotive powertrain, and in this report, we will refer to EVs (electric vehicles) as all vehicles for which an electric motor is the primary source of propulsion. This includes plug-in hybrid electric vehicles (PHEVs), range-extended electric vehicles (REEVs), battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs), but excludes (conventional) hybrid electric vehicles (HEVs). We will explicitly mention when hybrids are included in the definition.

Exhibit 0.1

Today's powertrain portfolio

Defined as EV in this report | ✓ Primary | (✓) Secondary

From one technology…

Internal combustion engine

… To a portfolio of powertrains				Propulsion		Energy generation/source		
				ICE	E-motor	ICE[1]	Plug-in[2]	Fuel Cell[3]
ICE  Volkswagen Golf	Internal Combustion Engine	Driving with conventional combustion engine only		✓		✓		
HEV  Toyota Prius	Hybrid Electric Vehicle	Driving with combustion engine and/or e-motor		✓	(✓)	✓		
PHEV  Mitsubishi Outlander PHEV	Plug-in Hybrid Electric Vehicle	Driving with combustion engine and/ or e-motor, plug-in to recharge battery		✓[4]		✓	✓	
REEV  BMW i3 with range extender	Range Extended Electric Vehicle	Driving with e-motor only, ICE & plug in (or fuel cell) used to recharge battery			✓	✓	✓	✓ *Currently in pilots*
BEV  Nissan LEAF	Battery Electric Vehicle	Driving with e-motor only and storing energy in battery			✓		✓	
FCEV  Hyundai ix35 fuel cell	Fuel Cell Electric Vehicle	Driving with e-motor only and storing energy in hydrogen			✓		(✓)	✓

1 In HEV, PHEV and REEV, energy is also generated through regenerative braking
2 To charge battery
3 Usually generates electricity that directly powers drivetrain; alternative concepts in discussion (e.g. fuel cell as range extender or FCEV with plug-in)
4 Primacy of ICE or E-motor in PHEV varies across models
SOURCE: McKinsey

Chapter 1
Placing EV dynamics in industry context

Europe is entering the initial adoption phase of electric mobility, with sales moving beyond the margin of 1% in some countries. 2013 was an important year with strongly increased momentum. Although EU-wide sales numbers are not yet impressive, some pockets of growth have clearly emerged, with high uptake rates in countries such as Norway and the Netherlands.

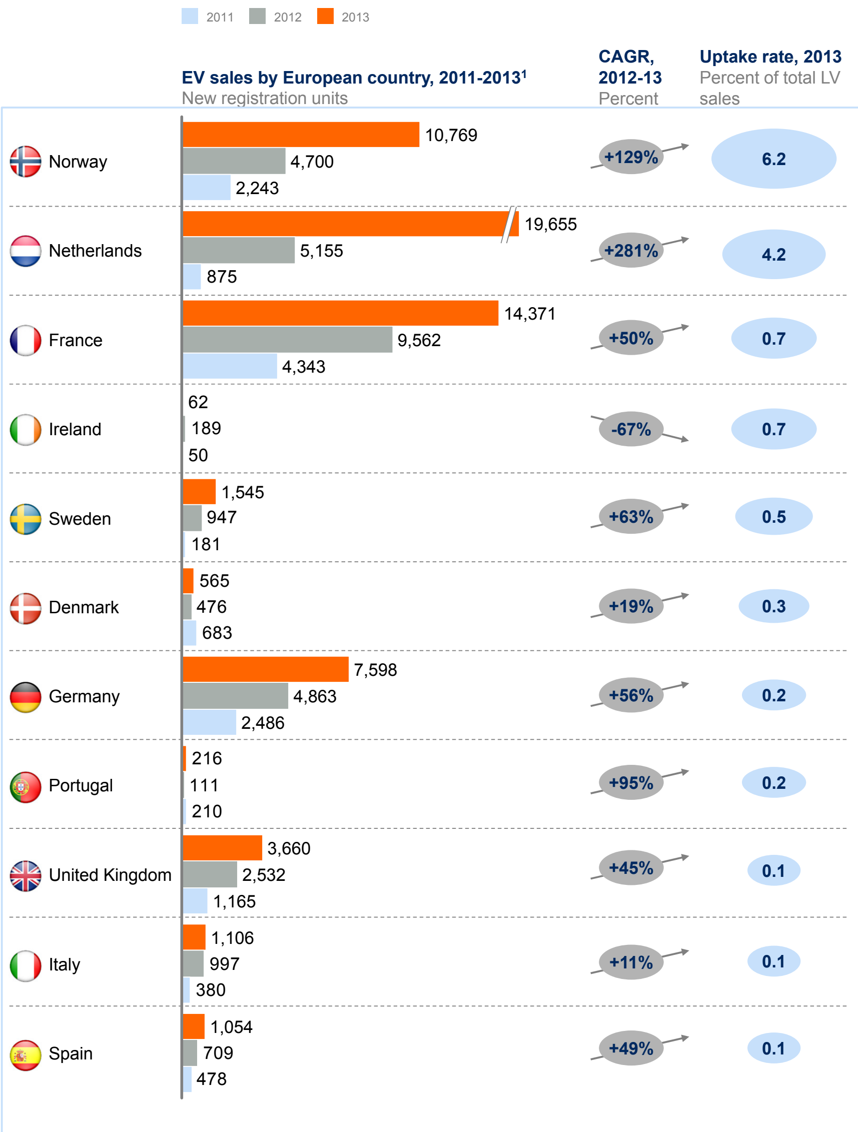
After decades in which the traditional internal combustion engine (ICE) has been the dominant automotive powertrain, the industry has started to diversify its powertrain portfolio. As the first alternative to pure ICE powertrains, conventional hybrids (HEVs) have gained a significant market share in the last two decades. For example, Toyota has already sold more than 6 million of its flagship Prius models to date, roughly 10% of which in Europe. Today, signs of a shift toward fully electrified powertrains are becoming apparent. Sales of EVs in Europe excluding conventional hybrids are negligible – less than 1% of total new car sales. However, there is reason to believe that we are entering a phase of early EV adoption. 2013 marked the year in which global sales of Nissan's fully battery electric LEAF reached 100,000 units, and Tesla has already sold 25,000 of its recently introduced Model S. On the regulatory side, the European Commission has shown its support for the further adoption of electric mobility by proposing a directive on the deployment of alternative fuels infrastructure in January 2013 which explicitly supports clean fuel transport and proposes specific targets on enabling infrastructure deployment (directive being discussed by EU parliament in March 2014).

At a more granular level, several European countries are seeing significant EV uptake rates. Norway is the clear frontrunner in Europe with EVs adding up to 6.2% of total car sales in 2013. The share of EVs in new sales reached 12% of new vehicle registrations in November 2013 (1,434 of a total of 12,079), and for three months in 2013 a full BEV was Norway's overall top-selling model of the month (Nissan LEAF in September, and Tesla Model S in October and December 2013).

The Netherlands is the European runner-up with more than 4% of new car sales falling into the EV category in 2013. France, Germany, and the UK are showing high EV sales growth rates of ~50%, but EVs have a smaller share of overall market (Exhibit 1.1).

Exhibit 1.1

Norway and Netherlands are clear frontrunners in EV uptake, with France, Germany and UK sales material and growing significantly



1 Data for 2013 partly estimated based on monthly data availability through 2013 (depending on country September, October or November)

SOURCE: IHS Automotive Driven by Polk, Association Avere, Autovereniging RAI, ACEA, Elbil.no, Gronnbil, Agentschap NL, SMMT

The adoption of electric mobility in Europe is driven by three main forces: consumer demand, industry developments and government stimulus.

Consumer demand

Early adoption in Europe took off in 2013 and seems set for further expansion in 2014. Currently, the uptake appears to be restricted to specific customer segments in selected countries in Europe. High costs, range anxiety, and low awareness are the most often cited barriers to EV adoption by the broader customer pool. Nevertheless, there is a sizable segment of early adopters who are willing to switch to EVs in spite of these barriers.

McKinsey research on early EV adopters in megacities (Shanghai, New York, and Paris) shows that this group is composed of mainly higher-income consumers with a distinct set of attitudes and behaviors. These observations are in line with recent findings in Norway, where early adopters are primarily high-income, well-educated consumers who are looking to save money, are concerned about the environment, or both.

At an estimated 20-30% of the population in New York and Shanghai, these early adopters present a significant market opportunity and are comprised of two sub-groups: “trendy greens” (trendy, environmentally conscious, and willing to try new technology) and “TCO sensitives” (care about the total cost of ownership, willing to change travel habits).

Although many factors such as design, brand, and performance are all important consumer considerations, three key motives for early EV adoption emerge:

- **Carbon footprint reduction.** The desire to reduce their carbon footprint is a motivator for environmentally conscious consumers to buy EVs. Some are even willing to pay a premium for the zero- or low-emission alternatives to ICE. For example, 29% of Norwegian EV buyers cite “environment” as their primary reason for purchase.

- **Driving and usage benefits.** Additional benefits are afforded to drivers of EVs by many governments and cities in an effort to stimulate EV sales. These benefits may include preferential parking permits in dense urban areas (e.g., City of Amsterdam) or the ability to drive in bus and taxi lanes and save considerable time during rush hours (e.g., City of Oslo).

- **Cost savings.** Without subsidies, EVs are significantly more expensive than ICE cars. But in some specific cases, as a result of government subsidies, EV models are cheaper than their ICE counterparts. Consumers looking to benefit from these types of regulations are drawn to EV, because they provide a cheap mobility solution in the recent period of high fuel prices in Europe. For example, in Norway, EVs are more attractive than ICEs on a TCO basis as a result of subsidies that include exemption from purchase tax, VAT, toll road charges, registration tax, and annual circulation tax.

Of all of the factors that may motivate consumers to buy an EV, the (perception of) cost competitiveness, whether in terms of TCO or purchase price, is critical for large-scale EV adoption. Many experts believe that for most consumers, price (or more importantly, cost) is the key decision driver. A study in Norway found that for 41% of EV buyers, the primary reason to buy an EV was "to save money". This share of price-conscious EV buyers is likely to be even higher in the general population compared to early EV adopters.

Customers that operate entire vehicle fleets (such as corporations, car rental agencies, and governments) are also among early adopters of EVs. A substantial share (almost 50%) of the passenger cars in Europe are not individually owned, but belong to a corporate fleet. For some fleet owners, the adoption of (partially) electric vehicles is easier to implement and more attractive than it might be for individual consumers. This will especially be true for companies that have a fleet with predictable driving patterns and thus vehicle or range requirements, combined with an intensive use of vehicles (high number of kilometers per vehicle per year) – which would improve the relative TCO of EVs in comparison to ICEs due to lower fuel and maintenance costs.

Corporations that have started to "green" their fleets are also driven by ambitious emission reduction plans, attractive subsidies, or both. As in the case of individual early adopters, both the environment and TCO seem to be important decision factors. Intermediary companies, such as lease companies, are also active in the EV space to meet increased demand from fleet customers (Exhibit 1.2).

Exhibit 1.2

Electrification of commercial fleet: La Poste, Athlon

LA POSTE

- La Poste postal delivery service has the largest corporate car fleet in France with a total of 50,000 vehicles, and has set a target to deploy 10,000 EVs by 2015
- La Poste plans to test hydrogen fuel-cell range extenders on Kangoo Z.E. electric delivery vans (to be delivered in Q1 2014) – which should double the vehicle's range from 160 to 320 km
- These aspirations show a willingness to switch to EV on a large scale – already 2,000 Kangoo EVs are in use as of September 2013
- In partnership with additional 7 businesses and universities, La Poste is investing in development of a standard smart EV charging system and network

ATHLON CAR LEASE

- Athlon Car Lease offers mobility solutions to corporate clients (fleet management, operational leasing, mobility services) and is one of the largest independent leasing companies in Europe
- Athlon has taken several steps to promote sustainable mobility and EVs (and accommodate growing demand in these areas):
  - Program "Fully Charged" to offer the first leasing contracts for EVs
  - Advisory services to assist clients to transition to lower-emission fleets
  - Electric highway project to introduce 3,500 EVs along the A15 highway in the Netherlands

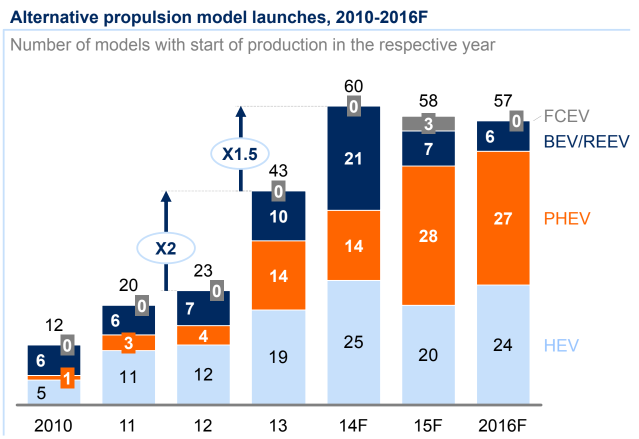
SOURCE: The New Motion; La Poste annual report; Press search

Industry developments

Major OEMs have by now released or announced EV models. The number of EV releases (including hybrids) has increased every year since 2010, and 2014 estimates are for a total of 60 new EV models (including HEVs) to go into production, a large number of wich (21) will be BEVs (Exhibit 1.3).

Exhibit 1.3

The number of EV model launches doubled in 2013 compared to 2012, and is projected to grow by 50% in 2014



SOURCE: IHS Automotive Driven by Polk, January, 2014

Current sales numbers as well as planned releases show that PHEVs and BEVs will be the dominant EV powertrains in the near future. More diversity and more availability of EV cars on the market will likely meet the requirements of more consumer segments, making EVs attractive to a larger audience.

An often-used measure to compare the cost for different cars and their respective powertrains is TCO. The key cost driver in the EV TCO equation is the battery pack. As a result of economies of scale, battery prices are decreasing, but are not yet low enough to make EVs cost competitive (for details, see Chapter 2). Other component innovations also improve the EV proposition – for example, lightweight carbon fiber results in lower weight of cars and thus increased range. Technological advancements and cost reductions across the EV value chain are beneficial for EV adoption. For example, charging infrastructure (slow and fast chargers) has become standardized, and costs are coming down as a result of growing economies of scale. Further, OEMs and suppliers are investing more in EV production platforms, which differ significantly from those for ICE-based cars, bringing overall EV manufacturing costs down further.

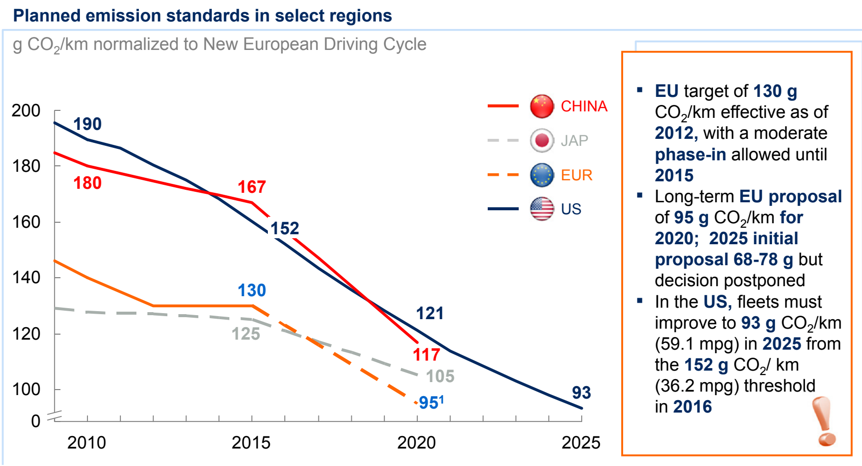
Government stimulus

To varying degrees, governments are promoting EVs across Europe by providing a range of subsidies and other benefits, both on the demand and supply side.
Reducing emissions (both CO_2 and NOx) is one of the key reasons, but other considerations (such as economic benefits or gaining a technological edge) also play a role.

The EU's CO_2 reduction targets for transport are ambitious compared to the US, China and Japan (Exhibit 1.4) – aiming for a 95 g CO_2/km cap by 2020; and regulations are likely to further tighten beyond 2020. For example, in 2013, a target of 68-78 g CO_2/km was proposed for 2025, with the final decision on post-2020 targets likely to be reached in by 2016.

Exhibit 1.4

Governments around the world are setting ambitious targets for light vehicle CO_2 emissions



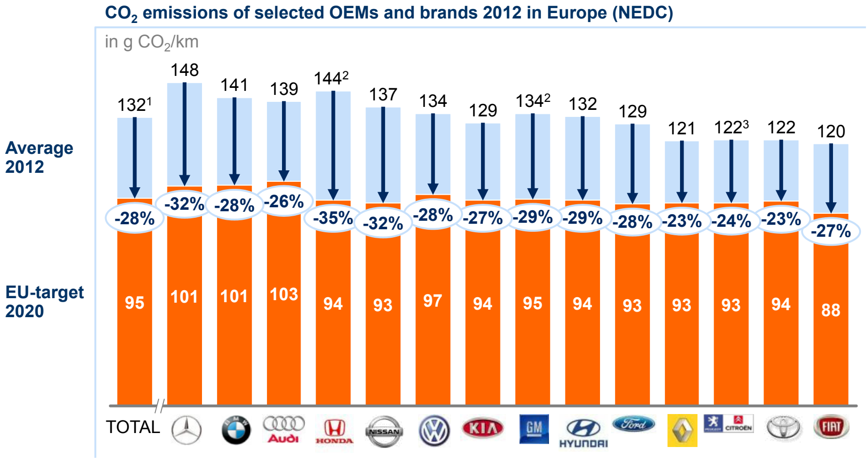
1 European Commission proposal for 2020; voting deferred at end of June 2013 (earliest time of approval currently May 2014), path 2015-2020 unclear
SOURCE: ICCT; Press search, McKinsey

These tightening regulations are pressuring OEMs to reduce their fleet emissions– which will be challenging with ICE optimization alone. The gaps between current emissions and 2020 targets vary, but for all major OEMs a significant reduction (on average 28%) is required (Exhibit 1.5). Achieving the emission reduction targets beyond 2020 will require some form of electrification.

Exhibit 1.5

Major OEMs need to cut fleet emissions by ~30% by 2020 to meet EU emissions target

EUROPEAN UNION



1 Average of top 20 brands
2 Data from 2011; 2012 numbers not officially published yet
3 Average of Peugeot 121.2 and Citroen 122.0 and average difference Peugeot -7.3 and Citroen -3.4
SOURCE: European Commission; Press search

Similarly with CO_2, regulation of NOx emissions is also tightening with the EU Air Quality Directive of 2008. As a result, cities (the prime centers of air pollution, and threatened with EU fines if they do not improve) are taking steps to promote electric mobility.

Another push for EV growth from the governments of most major European countries comes from the desire for higher energy independence and a shift towards a less oil-intensive transport sector. Last but not least, governments in countries with major OEMs are prioritizing the development of EV technology with the aim to pioneer the technology and keep the value chain in the country.

To accomplish the goals of emissions reduction, energy independence, and technology ownership, many governments in Europe have set EV adoption targets in the past few years. Combined EU targets (to be negotiated with member states) amount to 8-9 million EVs on the road by 2020, but targets and timelines vary widely by member country. France, for example, has a goal of 2 million EVs on the road by 2020; Germany aims at 1 million by 2020; Spain hopes to reach this number by the end of 2014, The Netherlands has set its 2020 EV target at 200,000, followed by an ambitious 1 million EVs just five years later in 2025. These targets are aspirational and may be difficult to achieve in most countries, but they signal strong commitment and support for large-scale EV adoption from national governments.

Governments are investing in EV infrastructure and mobility programs to encourage supply

Many governments are making investments in EV-enabling infrastructure (e.g., charging stations, special parking spots). For example, Estonia installed fast chargers throughout the country (165 in total) and ensured that every city with at least 5,000 inhabitants hosts at least one station.

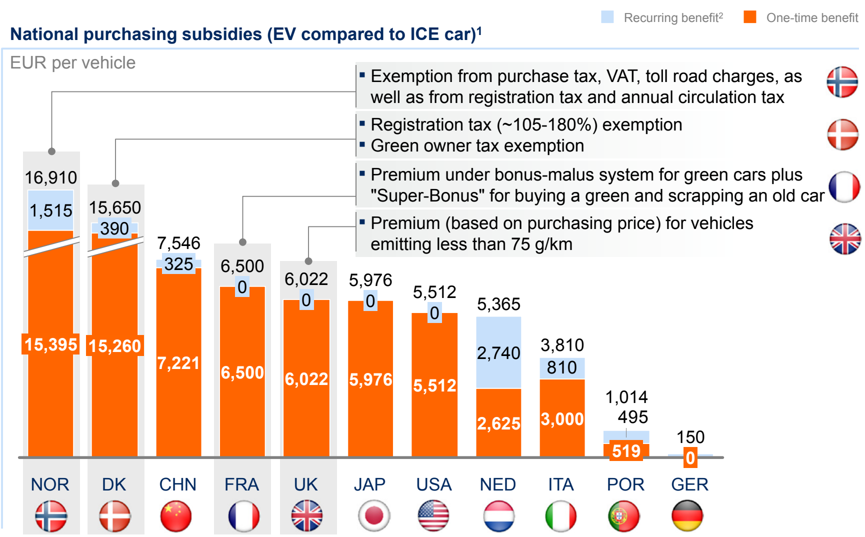
For some years already, governments in Europe have been dedicating funds to EV-related R&D. There is also significant support from governments for mobility programs, which address environmental problems, congestion problems, or both. For example, the city of Amsterdam has made available special citywide parking permits for electric car sharing fleets.

Subsidies, tax breaks, and special driving privileges incentivize demand

Many European governments and cities (e.g., Norway, Denmark, the Netherlands, France, UK, as well as Oslo, Amsterdam, Paris, and London) are incentivizing consumers to opt for electric mobility, each with their own schemes. Norway is the most generous, offering a broad package of subsidies amounting to ~EUR 17,000 when compared to the purchase of a compact class ICE car; UK pays back to buyers a one-time premium of GPB 4,000-7,000 (based on purchasing price) for all vehicles emitting less than 75 g/km (Exhibit 1.6).

Exhibit 1.6

Stimulating EV demand: Governments



1 Calculations (annual benefits) based on compact class car vs. xEV (subsidies are usually created in a way that also new/fuel efficient cars receive benefits, e.g. taxes based on CO2 emissions); only national subsidies counted – additional local subsidies/incentives might exist
2 Cumulated recurring benefit assuming a 5 year holding period

SOURCE: Tax authorities; Press search; McKinsey

Another element of EV demand stimulus is tax breaks. Purchase, lease, and road taxes are among the burdens being eased by governments to make EVs a more attractive alternative to consumers. For example, in the Netherlands, the income tax addition for full electric lease cars was 0% in 2013 and 4% in 2014 (versus 14-20% for ICE cars).

Other benefits offered by governments (mostly cities) include the use of special driving lanes, preferential or free parking, and waiving of toll fees. For example, in Paris, an EV owner enjoys reduced toll and parking fees, while in Oslo EVs are allowed to drive in bus and taxi lanes – both cities attemp to incentivize EV adoption (Exhibit 1.7).

Exhibit 1.7

Stimulating EV demand: Cities

	Amsterdam	Paris	Barcelona	London	Oslo
Subsidy per EV (on purchase price)	▪ EUR 5,000 / 10,000 / 40,000 for passenger car / taxi[1] / truck	▪ EUR 4,000-7,000 premium (one-time grant)	▪ 25% (up to EUR 6,000) off	▪ 25% (up to GBP 5,000) off	▪ Exempt from 25% VAT and purchase tax
EV benefits	▪ No waiting list for parking permits ▪ 4 parking garages with free charging ▪ Exempt from registration tax and annual circulation tax	▪ Reduced toll and parking fees ▪ For Autolib': free parking, exempt from road and registration tax, access to bus lanes	▪ Up to 75% road tax reduction ▪ Free parking in regulated areas ▪ Free charging at road-side stations, hotels and university (for e-bikes)	▪ Exempt from congestion charge and road tax	▪ Exempt from all non-recurring vehicle fees, including road tax ▪ No parking fees or toll payments ▪ Access to bus & taxi lanes
EV car sharing service	▪ Launched Car2Go in 2011, 300 vehicles (135 km range)	▪ Launched Autolib' in 2011, 2,000 vehicles (250 km urban range) ▪ e-scooter sharing service (2011)	▪ Launched in 2013 with Madrid, 23 vehicles (200 km range) ▪ e-scooter sharing service (2013)	▪ Launched E-Car club in 2013 (145-200 km range)	▪ Launched Move About in 2009

1 EUR 5,000 subsidy for taxi given by municipality, EUR 5,000 by government

SOURCE: Amsterdamelectric.nl, Rijksdienst voor Ondernemend Nederland, NRC, Autolib', LIVE Barcelona, Source London, Transport for London, Qualcomm, EV city case book (2012), Move About, Gronnbil

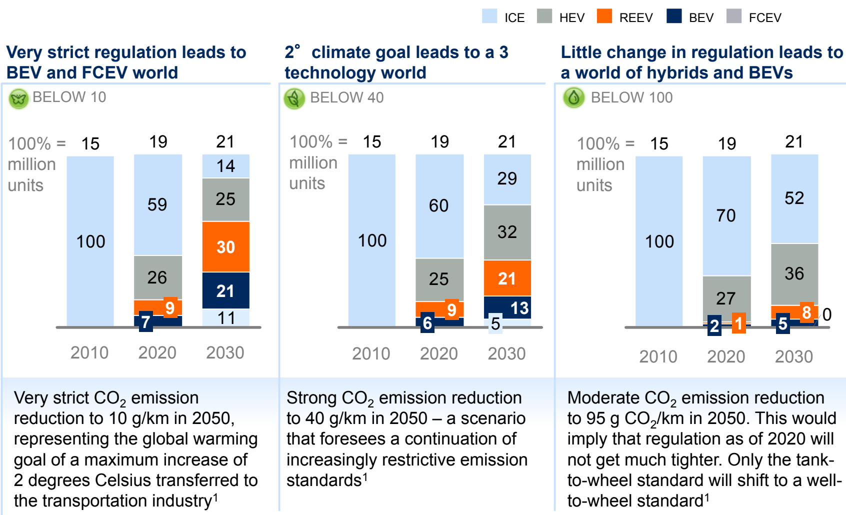
In the longer term, largerscale adoption of electric mobility is expected, which will change the competitive landscape across the value chain. In 2020, optimized ICEs will still be the dominant powertrain in Europe, but towards 2030, electric powertrains will start to play a major role in Europe (and the world), resulting in a diverse portfolio of powertrains (Exhibit 1.8).

How quickly electric powertrains are adopted and what share of the portfolio they will make up will depend on the development of the oil price (more specifically, fuel prices in Europe), the regulatory environment, and infrastructure. However, it is most likely that, in the long run, EVs will become an important and significant part of our everyday life.

Exhibit 1.8

In the long-term EV adoption remains uncertain, driven by regulation

Vehicle sales per powertrain technology in percent of total sales across emissions scenarios



1 For further details on scenarios, refer to Appendix 1

SOURCE: McKinsey – Boost! Powertrain KIP


H_2
e

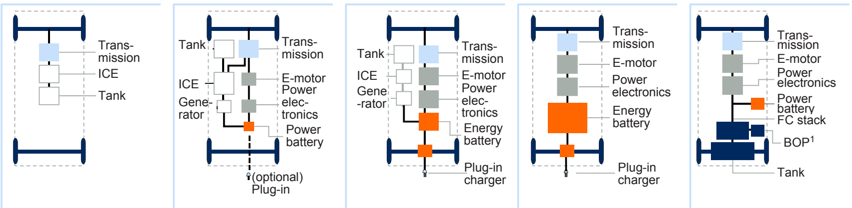
Chapter 2
Cars, components and costs

The ICE powertrain is dominant today and will be the primary source of propulsion in the near future. In the longerterm, several technologies will comprise the powertrain portfolio – including EVs. The speed of EV adoption will – outside of regulation and government subsidies – largely depend on TCO developments, where the battery pack price is a critical component.

The current automotive landscape is comprised of six powertrains – of which three have ICE as the primary source of propulsion (ICEs, HEVs, and PHEVs[1]) and three have an electric motor as the primary mover (REEVs, BEVs and FCEVs) (Exhibit 2.1, 2.2).

Exhibit 2.1
Different powertrain technologies in detail

ICE powertrain | Transmission | Electric powertrain | FC powertrain | Battery



Internal combustion engine, ICE
- Conventional internal combustion engine
- No dependence on electric infrastructure
- High fuel consumption and exhaust emissions
- High range
- Optimization ongoing, e.g., with start/stop automatic

Hybrid electric vehicle (P) HEV
- Parallel hybrid configuration of electric and ICE drive; optional with plug-in (PHEV)
- ICE is primary mover of the vehicle with support from small electric motor
- Small battery charged by the ICE
- Fully electric driving only at low speed for smaller distances
- Better fuel economy than conventional ICE, similar range

Range extended electric vehicle, REEV
- Series hybrid configuration of electric and ICE drive
- Sometimes smaller battery capacity than BEV
- Medium range electric driving
- Vehicle can be plugged-in to charge from the grid
- Small ICE-based generator for larger range as compared to BEV ('range extender')

Battery electric vehicle, BEV
- Purely electric drive
- Large battery capacity, Li-ion technology
- Short-medium range
- Only charging of battery from the grid while stationary

Fuel cell electric vehicle FCEV
- Series configuration of fuel cell system and electric drive
- Fuel cell stack based on (PEM) technology
- Hydrogen tank pressure typically 350 or 700 bar
- Medium-high range

ICE primary source of propulsion | **ELECTRIC MOTOR** primary source of propulsion

1 Balance of plant-various required support components (eg. humidifier, pumps, valves, compressor)

1 PHEV may have either an ICE or an e-motor as the primary source of propulsion depending on the model.

Exhibit 2.2

EV powertrains: Key benefits and hurdles

INDICATIVE[1]

	PHEV	REEV	BEV	FCEV
Environment	▪ Emission reduction because of battery and e-motor, but ICE still primary source of propulsion	▪ Substantial emission reduction compared to ICE – emission only when range extender is used	▪ Zero emission cars[2], far more efficient well-to-wheel than ICE	▪ Zero emission cars[2], far more efficient well-to-wheel than ICE
Benefits	▪ Use of existing fuel infrastructure ▪ Similar range as ICE	▪ Extender provides higher range than BEV ▪ Real electric car, less range anxiety	▪ Pure electric, zero emission car ▪ Charging possible at home / office etc.; infrastructure growing	▪ Range is high ▪ Refueling takes only a few minutes
Hurdles	▪ Low range on just e-motor ▪ ICE is still the primary source of propulsion - substantial emissions on longer trips	▪ Additional complexity and cost compared to a BEV ▪ Extender offers limited additional range	▪ Refueling takes long, even with fast charge at least 20-30 minutes ▪ Relatively low current range ▪ Infrastructure required, availability limited but growing	▪ Energy-intensive to produce hydrogen ▪ Hydrogen infrastructure required – currently very limited

1 Indicative comparison of typical models of xEV powertrains - differences exist by car model and by country. Conclusions also depend on (and might change as a result of) multiple assumptions (for example regarding power mix)
2 Excluding electricity generation for charging the vehicle

OEM powertrain portfolios

Almost all large OEMs have adopted a powertrain strategy that includes the introduction of multiple powertrains in the face of unclear market developments.

The key difference between OEMs is the enthusiasm with which they approach different EV powertrains. Based on January 2014 estimates of the global Start of Production (SOP) of EV models between 2013 and 2016, OEMs are mainly focusing on BEVs and PHEVs, with an estimated 46 and 79 models being released respectively (Exhibit 2.3). Just 3 FCEVs and 2 REEVs are expected to go into production in this time frame, but in the longer term this might change.

The majority of OEMs is investing in fuel cell technology in some way or another. Nissan, for instance, is an early adopter of BEVs with big and early investments in its LEAF model, and sees FCEVs as something for the medium- or longer-term future. Other OEMs, such as Hyundai, Daimler, and China's BYD, have paid much more attention to FCEVs, adding them to their portfolios along with BEVs. Tesla Motors in the US, on the other hand, is pursuing a more specialized powertrain approach, focusing on the BEV powertrain.

Exhibit 2.3

Upcoming model launches suggest further diversification of EV powertrain portfolio

MODELS SHOWN NOT EXHAUSTIVE

LEADING VEHICLE PLATFORMS

Total # of models with expected SOP

	SOP[1] in 2013	2014	2015	2016
BEV	Volkswagen Golf Kia Soul Fiat 500 Nissan A-Van **13**	Tesla Model X Smart Forfour Mercedes Benz B-Class Renault Twingo **20**	Nissan March Skoda Fabia Infiniti EV Mahindra Verito **7**	Volkswagen Polo Audi R8 Toyota iQ SEAT Altea **6**
PHEV	McLaren P1 Mitsubishi Outlander BMW 5-Series Ford Fusion **10**	Hyundai Sonata Audi A3 Porsche Cayenne BMW i8 **14**	Audi A4 Volvo S60 Citroen C4 Cactus BMW C-MPV **28**	Toyota Prius Alpha Volkswagen Polo Lexus CT Volvo V90 **27**
FCEV	**0**	**0**	Honda D-Sedan Hyundai Tucson Toyota D-Sedan **3**	**0**
REEV	BMW i3 **1**	Proton A-Hatch **1**	**0**	**0**

1 SOP = Start of Production, models expected to go in production as predicted by industry analysts

SOURCE: IHS Automotive DRIVEN BY Polk

EV battery technology advanced

Batteries for recent EVs are primarily based on Li-ion technology. Variation comes in the size of the cells and the type of cathodes used:

- **Small-format cells.** Tesla's small-format, the Li-ion-based battery cell (the Panasonic 18650) is believed to be a combination of cathode materials mainly used for consumer electronics (such as NMC, LCO, etc,). Currently, Tesla appears to be the only OEM using these cells and has signed a deal with Panasonic as the preferred supplier to deliver nearly 2 billion cells over the course of four years. This type of cell has been produced at scale for more than two decades and is primarily used in consumer electronics. The cell's composition (the cobalt in the cell does not bind oxygen very tightly, so heating the cell dissociates oxygen and can create a self-sustaining thermal reaction) creates a risk of a reaction if overheated, so the cells require advanced cooling and battery management systems (BMS) to manage cell temperature. Tesla has proprietary cutting-edge technology in cooling and BMS, and the models it has brought to market have qualified for governmental safety requirements. Tesla has started to produce its technology for Mercedes (B-Class) and Toyota (Rav4), with Daimler and Toyota holding small stakes in Tesla.

- **Large-format cells.** Large-format cells are the battery pack of choice for almost all other (traditional) OEMs that have ventured into the EV space. Given the lower energy density of the cathodes used (primarily $LiMn_2O_4$), these cells are potentially less exposed to overheating issues than small-format cells. However, battery packs based on large-format cells are more expensive because they do not benefit from the same economies of scale seen for the 18650 cells. Alternative cathodes such as NCA ($LiNiCoAlO_2$) and LFP ($LiFePO_4$) are also being tested, each with its own cost versus. safety versus. energy density trade-off.

Regardless of their preferred battery type, almost all OEMs have partnered with battery suppliers to drive development of battery pack technology.

TCO evolution

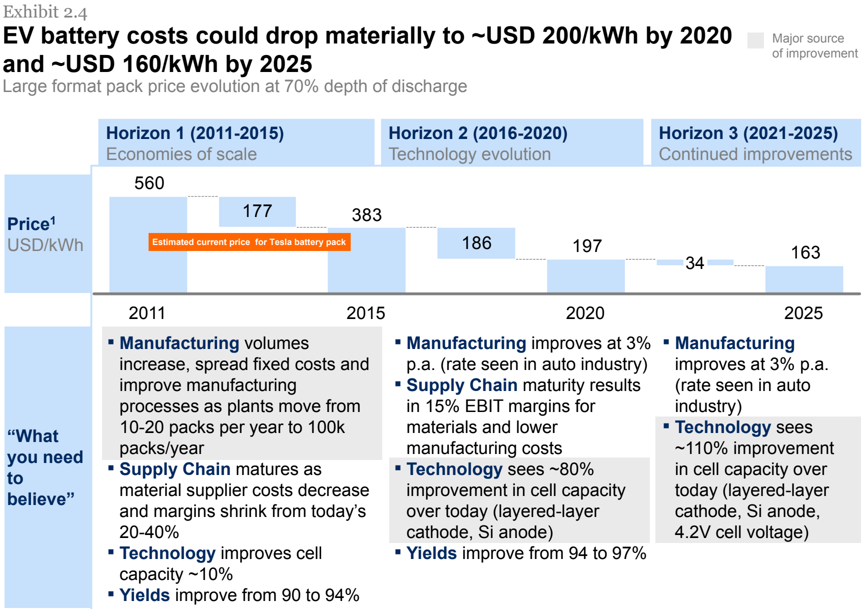
The TCO consists of a car's purchase price, its maintenance and fuel costs, and the infrastructure costs over the lifespan of the vehicle. Sometimes, insurance and financing costs are also included. Currently, estimates for difference in the TCO of EV compared to ICE vehicles vary widely, from ~EUR 5,000 to 20,000 per vehicle (for annual mileage of 20,000 km and a holding period of four years), depending on powertrain type, model, and country, as well as fuel price and other variables.

One important driver of an EV's TCO is the cost of the battery pack. The price of battery packs is declining, but the cost right now is still a major reason that TCO for EVs is significantly higher than it is for ICEs. It is clear that the short-term adoption of EVs is dependent on both demand incentives (subsidies, tax breaks) and consumer willingness to pay extra to bridge the gap. For longer-term mass market adoption, lower battery prices will be an important driver. Large-format battery pack prices are expected to decrease as a result of growing economies of scale (Exhibit 2.4). In the near term (towards 2015), battery costs (large format Li-ion battery packs) are expected to go down to ~USD 350-500/kWh. The main long-term drop, however, will come from technology evolution. The commercial scale introduction of the layered-layer cathode with a Si-anode, for example, could bring prices down to less than under USD 200 by 2020.

Exhibit 2.4

EV battery costs could drop materially to ~USD 200/kWh by 2020 and ~USD 160/kWh by 2025

Large format pack price evolution at 70% depth of discharge



1 Price is to auto OEM for entire vehicle pack assuming 8.7 kWh (PHEV 20) with pack and BMS, 70% depth of discharge, made on US assembly lines

SOURCE: McKinsey analysis

The cost of individual small-format battery cells is already low. Tesla's battery pack prices are significantly less expensive than estimated prices for large packs. Tesla's CTO has mentioned publicly that their battery prices are "half or even a quarter of the price of the industry average."

Further price decreases of small-format battery packs – like the one Tesla developed – may come through the introduction of improved anode and/or cathode materials. Additional cost reduction would be possible if competition increases among producers of certain high-value cell inputs. Improvements due to reduction in cell manufacturing/ assembly costs may be more modest given the maturity of the industry.

While battery prices are central to an EV's TCO, the longer-term perspective involves other factors. First, what it will cost to own an EV compared to an ICE car will also depend heavily on regulatory and oil price developments. Second, the size and use of the car are key determinants. For example, the cost picture for trucks is completely different than it is for small sedans, suggesting potential for a segmented powertrain strategy. An optimized powertrain portfolio will at the same time meet the needs of different consumer segments and full regulatory environmental requirements. An OEM, based on its product and market specifics, may, for example, choose a long-term powertrain portfolio that includes BEV powertrains for small vehicles in urban areas and long-range vans powered by FCEVs.

While many industry and regulatory factors are still unclear, electrification of the powertrain portfolio is very likely. The next 25 years are expected to bring a tightening of CO_2 regulation, which would lead to gradual disappearance of ICE-only vehicles and emergence of a diverse portfolio of electric and partially electric powertrains as predominant. If the current EU regulatory environment (fleet emissions cap of ~95 g/km_2) is maintained beyond 2020 without change, ICE-based propulsion would still dominate the market through 2030. However, if regulations are further tightened from 2020 to 2050, significant powertrain portfolio rebalancing towards EVs would take place by 2030 (Exhibit 2.5).

Exhibit 2.5

Future of powertrain market remains uncertain

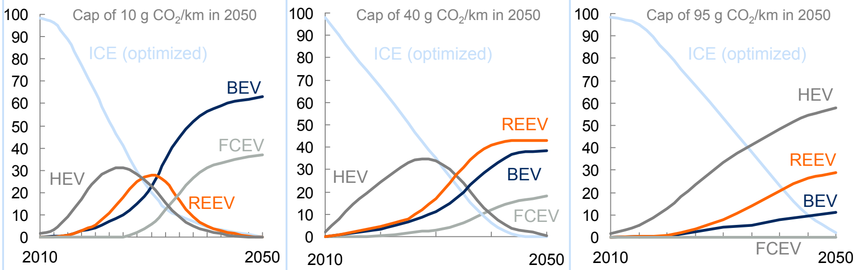
WORLDWIDE

Market share of units produced globally, %

Very strict regulation leads to BEV and FCEV world — "Below : 10"

2° climate goal leads to a 3 technology world — "Below : 40"

Little change in regulation leads to a world of hybrids and BEVs — "Below : 100"



Very strict regulation leads to BEV and FCEV world

- ICE remains dominant until 2025, but loses market share to xEVs
- In the long run, BEVs dominate smaller vehicles and FCEV larger vehicles
- HEV / REEV as bridging technology

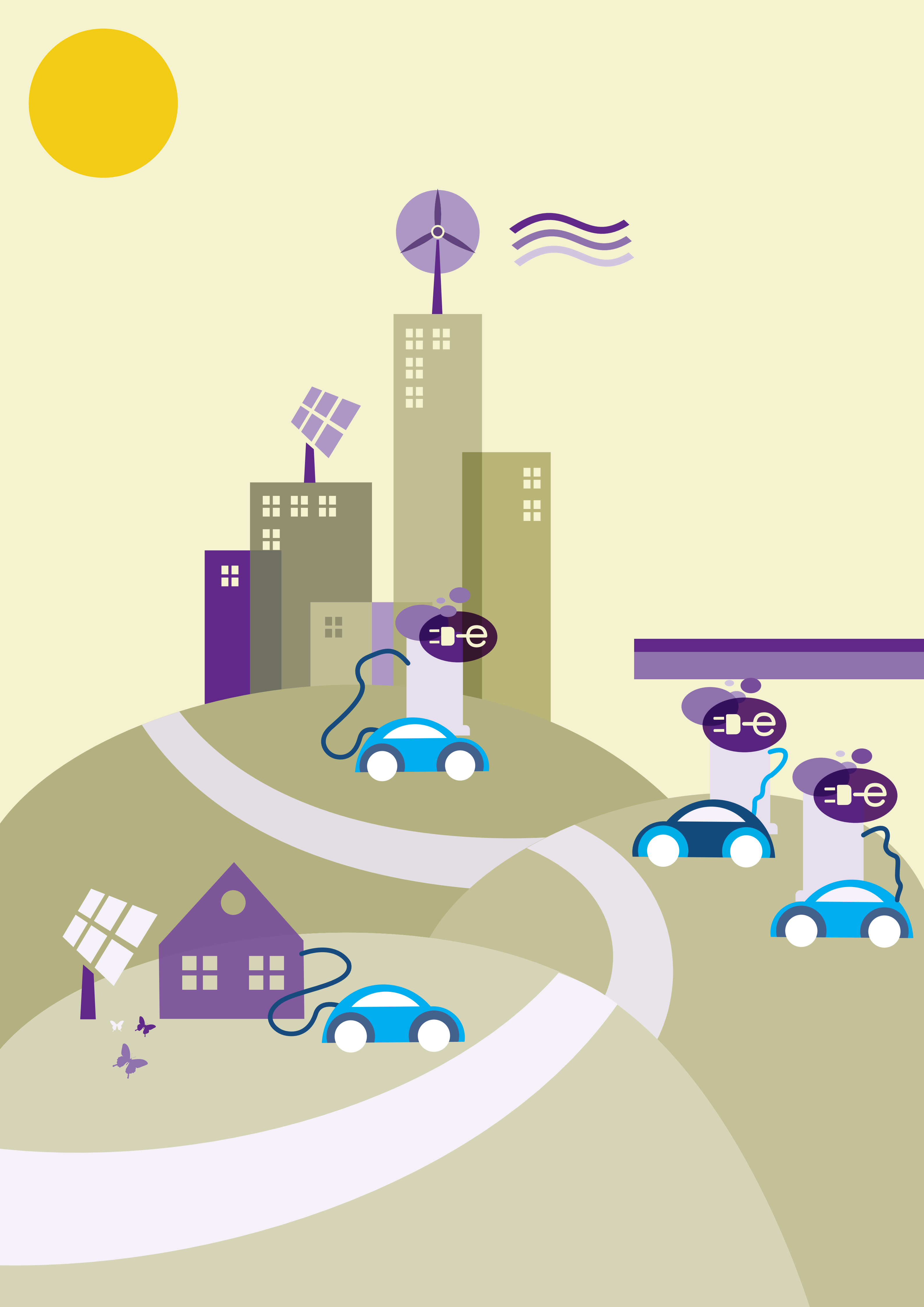
2° climate goal leads to a 3 technology world

- ICE remains dominant until 2025 but loses market share to xEVs
- Over time, BEVs, REEVs and FCEVs dominate small, medium and large vehicles, respectively
- xEVs lead to singular drivetrain scenario

Little change in regulation leads to a world of hybrids and BEVs

- ICE remains dominant until 2035+
- BEV will only become economically competitive post-2030, no infrastructure for FCEV is built
- Long-term HEV and REEV / BEV existence leads to a dual powertrain scenario

SOURCE: McKinsey – Boost! Powertrain KIP



Chapter 3
Charging infrastructure

Together with the growing adoption of EVs, the technology and infrastructure to charge them is developing as well. In several European countries, public sector has taken the lead in installing infrastructure where PHEV and BEV drivers can plug in to charge. EV charging has some marked differences from conventional ICE refueling, and as a result, drivers show a different charging behavior. Technological developments improving the driving range of BEVs, as well as an increasing availability and speed of charging infrastructure, could change charging behavior and the need for charging infrastructure in the future.

Given that the costs for the large-scale deployment of charging infrastructure in Europe are too significant to be borne by public sector alone (one slow two-plug charging station costs ~EUR 2,000 in hardware alone, two charges per vehicle required), one of the most critical challenges for the EV sector is to achieve commercial viability in the deployment of charging infrastructure in the coming years.

Different electric powertrains require specific types of charging or refueling infrastructure (Exhibit 3.1). In fact, from all powertrains under consideration, only (full) BEVs[2] and FCEVs are totally reliant on the new infrastructure to be deployed. BEVs will be the focus of this chapter.

Exhibit 3.1
Electric powertrains: Charging infrastructure archetypes

Focus of Chapter 3

	Energy source				
	GASOLINE/DIESEL	HYDROGEN	BATTERY		
					
	Fueling gasoline or diesel at a petrol station	**Fueling hydrogen at a hydrogen refueling station**	**"Wired" charging using a plug**	**Battery swapping**	**Induction charging**
Description	Conventional gasoline or diesel refueling	Hydrogen refueling (similar to natural gas refueling)	Plugging in to a charging station using a cable and plug	Replacing a battery for a fully charged one at a special swapping station	Battery in the car is charged by wireless induction charging
Time needed[1]	5 min	5 min	4-8 hrs (slow) 20-30 min (fast)	5 min	~2-8 hrs[2]
Suitable for which power-trains	▪ ICE ▪ HEV ▪ PHEV ▪ REEV (gasoline)	▪ FCEV ▪ REEV (hydrogen)	▪ PHEV ▪ BEV suitable for plug-in charging	▪ Special BEVs suitable for battery swapping	▪ Special BEVs suitable for induction charging
Example car	▪ All ICEs	▪ Hyundai ix35 (FCEV)	▪ Renault Zoe (BEV)	▪ Special model of Renault Fluence	▪ N/A (few pilot cars)
Current availability in Europe	Widely available: ~131,000 stations	Very limited: ~80 stations	Limited availability: >20,000 (slow) >1,000 (fast)	Very limited ~50 stations	Not available (few pilots in progress)

1 Time need for full refueling or recharge. For fast-charging of battery, time to reach 80% of battery capacity is commonly used
2 Since induction charging is still in pilot stage, common duration and power level are not yet established; power levels of 22 kW have been achieved
SOURCE: Europia, Fuel Cell Today, Public sources, McKinsey

2 PHEVs, have the option to use a plug to recharge their battery, but can run on their ICE in case the battery is empty. REEVs can use gasoline to power their battery

E-mobility charging infrastructure trends

Together with growing sales of PHEV and BEV models, the availability of charging infrastructure has increased in recent years. There are a few forms of charging that have penetrated the market to varying degrees:

- **Battery swapping** has been piloted on a small scale, but has lost much of its appeal since the bankruptcy in 2013 of Better Place, the company that installed ~55 battery swapping stations in Denmark and Israel. In practice, almost none of the new BEV models being introduced support battery swapping. One exception to this is Tesla, which has demonstrated battery swapping capability for its Model S and has announced that it will pilot battery swapping stations in the US (at its current Supercharger stations).
- **Induction (or "wireless") charging** is still operating at a few pilot locations and is not yet commercially viable. With this technology, a battery is charged using an electromagnetic field generated in the surface underneath the car.
- **Wired charging** dwarfs the other approaches in terms of the scale of deployment and the amount of usage and involves the actual plugging in of the car at an appropriate station. Up to now, the rollout of public wired charging infrastructure for EVs has been driven largely by the public sector via initiatives at city, regional, or country level. More than 20,000 public EV charging stations have been installed throughout Europe by 2013, with more than 1,000 public DC fast-charging stations. While on the rise, the wired charging infrastructure density remains uneven across Europe as a whole. Current deployment is mostly focused on cities, not yet facilitating intercity travel.

In terms of public charging station deployment, Denmark, the Netherlands, Germany, the UK and France are leading the region. Several initiatives to increase the number of charging stations in major cities across Europe have been launched (e.g., Paris, London, Amsterdam), and national plans have been put in place to increase coverage (Exhibit 3.2). This focus on driving coverage has largely been limited to Western Europe, as there are currently almost no charging stations of any type in Eastern Europe.

Exhibit 3.2

In many countries, policy initiatives support the development of charging infrastructure today

NOT EXHAUSTIVE

Overview of policy initiatives for EV charging infrastructure by country[1]

Country	Description	Non-residential[2] charging points installed, 2013
UK	▪ EUR ~44 million for charging points for residential, street, railway, and public sector locations (available until 2015, plans to install 13,500 domestic and 1,500 on-street points)	▪ Slow charger: ~3,000 ▪ Fast charger: ~150
FRA	▪ EUR 50 million to cover 50% of EV charging infrastructure (cost of equipment and installation) ▪ Local administrations are involved in EV infrastructure projects and stimulating sales by increasing the EV share of their fleets and initiating car-sharing projects	▪ Slow charger: ~1,700 ▪ Fast charger: ~100
GER	▪ Four regions nominated as showcase regions for BEVs and PHEVs ▪ German government supports R&D activities for inductive and quick charging technologies and encourages local authorities to establish charging infrastructure ▪ However, build-up of charging stations seen as task of private economy	▪ Slow charger: ~2,800 ▪ Fast charger: ~50
NED	▪ The Netherlands currently has roughly 1.1 charging stations per vehicle, the most EVSE per capita worldwide ▪ Government introduced tax incentives to support creation of charging infrastructure	▪ Slow charger: ~6,000 ▪ Fast charger: ~120
PT	▪ Subsidy of EUR 5,000 for the first 5,000 new electric cars sold in the country ▪ EUR 1,500 incentive if the consumer turn in a used car as part of the down payment for the new electric car	▪ Slow charger: ~1,000 ▪ Fast charger: ~70
ESP	▪ Public incentives for a pilot demonstration project. Incentives for charging infrastructure in cooperation between national and regional government ▪ Movele program (2008-2011, investments EUR ~10 million) targeted ramp up of infrastructure and dispersion of EVs in Barcelona, Madrid, and Seville ▪ Spain's national government sets the goal of putting t 343,510 charging points throughout Spain until 2015	▪ Slow charger: ~800 ▪ Fast charger: ~20
SWE	▪ No general support for charging points besides RD&D (Research, Development and Demonstration) funding (EUR 1 million in 2012)	▪ Slow charger: ~1,000 ▪ Fast charger: ~20
DEN	▪ EUR ~10 million for development of charging infrastructure	▪ Slow charger: ~3,800 ▪ Fast charger: ~120
FIN	▪ EUR 5 million reserved for infrastructure as part of the national EV development program, ending in 2013	▪ Slow charger: n/a ▪ Fast charger: n/a
NO	▪ EUR 1,200 as a subsidy if you put up a EV charging station in Oslo	▪ Slow charger: ~1,300 ▪ Fast charger: ~87

1 Countries sorted by charging infrastructure available; 2 Non-residential only due to missing data for residential charging infrastructure

SOURCE: EVI, University of Duisurg-Essen ("Competitiveness of the EU Automotive Industry in Electric Vehicles"); Netherlands Enterprise Agency; McKinsey

3 European Commission defines less than 22 kW as slow and more than 22 kW as fast. However, charging stations in the range of 20-25 kW are also often termed "semifast".

"WIRED": THE BASICS OF EV CHARGING

Charging PHEVs and BEVs can take several forms. The power level of the charging station (in terms of kW), the electrical current it uses, the plug and type of battery all determine which EVs can be charged where and how long it will take to charge them.

- **Power level.** The power level of the charging source, expressed in kW, is defined by both the voltage (V) and the current (A) of the power supply and determines how quickly a battery can be charged. The power level of chargers ranges rather widely – from 3.3 kW (slow) to 50 kW and higher (fast[3]). Lower power levels are typical of residential chargers and take several hours to fully charge a battery. Chargers of 3.3 kW and 7 kW can charge the battery of a Nissan LEAF in about 8 or 4 hours respectively. For consumers wishing to use higher power levels for charging at home, upgrades of the connection with the local grid are often required. At the other end of the power level range, fast chargers of 43 and 50 kW are available, with Tesla rolling out Superchargers of 120 kW.

- **Electrical current.** Since electricity is provided by the grid in AC and batteries can only store DC, the electricity provided by the grid to the EV needs to be converted. Cars that are able to charge at an AC charging station are equipped with an on-board AC-to-DC converter. With DC fast-charging stations (the most common type), the converter is integrated into the charging station, so that the charging station itself converts AC electricity from the grid into DC electricity for the EV.

- **Plug.** Currently, multiple plugs and sockets are used to connect vehicles to charging stations. For slow charging, a European standard plug (Type 2 "Mennekes") has been proposed as standard, and is most common. For fast charging, three connector standards are currently in use: The Japanese CHAdeMO, US/European CCS "Combo", and Tesla Supercharger.

- **Battery size.** Different EV models have different power level thresholds and current types that they can accommodate, and this capacity is determined by battery size (expressed in kWh). EVs with small batteries (such as many PHEV models) are often able to charge at a maximum of 3.7 kW; these models include the Mitsubishi Outlander, Volvo V60 Plug-in Hybrid, Opel Ampera, Toyota Prius Plug-in Hybrid version (all 3.7 kW). Full BEVs are completely dependent on their battery for their driving range and usually have larger batteries that can handle higher power levels for charging. Examples include the Nissan LEAF (24 kWh battery size, able to charge at 7 kW AC or 50 kW DC), the Renault Zoe (22 kWh battery size, able to charge at AC charging stations, up to 43 kW), and the Tesla Model S (60 kWh or 85 kWh battery, able to charge at 10 or 22 kW AC, or at 120 kW DC using Tesla's Supercharger stations).

In addition to the number of wired charging stations deployed, the type of a station – slow-charging vs. fast-charging – is an important factor in understanding the level of charging network coverage. For public charging network in Europe, current ratio is roughly 20 slow-charging stations for every fast-charging station. Some countries, including Estonia, Norway, Denmark, and the Netherlands, have started initiatives to add more fast-charging stations along highways to facilitate intercity travel. Most of these initiatives are supported by national governments, but some also come about as public-private partnerships or private sector initiatives.

“FAST LANE” – INITIATIVES TO TAKE EV TRAVEL FROM LOCAL TO INTERCITY

Even in countries with relatively extensive public charging station coverage, slow-charging technology limits the uninterrupted travel distance that is possible. Some countries, however, are adding fast-charging stations to their highways, opening up the possibility of intercity (and even international) travel.

In Estonia, the ELMO project initiated by the government in partnership with Mitsubishi, has led to the installation of 165 fast-chargers spread around the country, creating national coverage.

In Denmark, five large utility companies have jointlyinvested in CLEVER, a national electric mobility operator, which has installed 50 fast-chargers, and has announced plans to install 50 more.

In the Netherlands, FastNed has installed the first four of its planned 200 fast-charging stations along existing highway fuel stations based on a commercial business case.

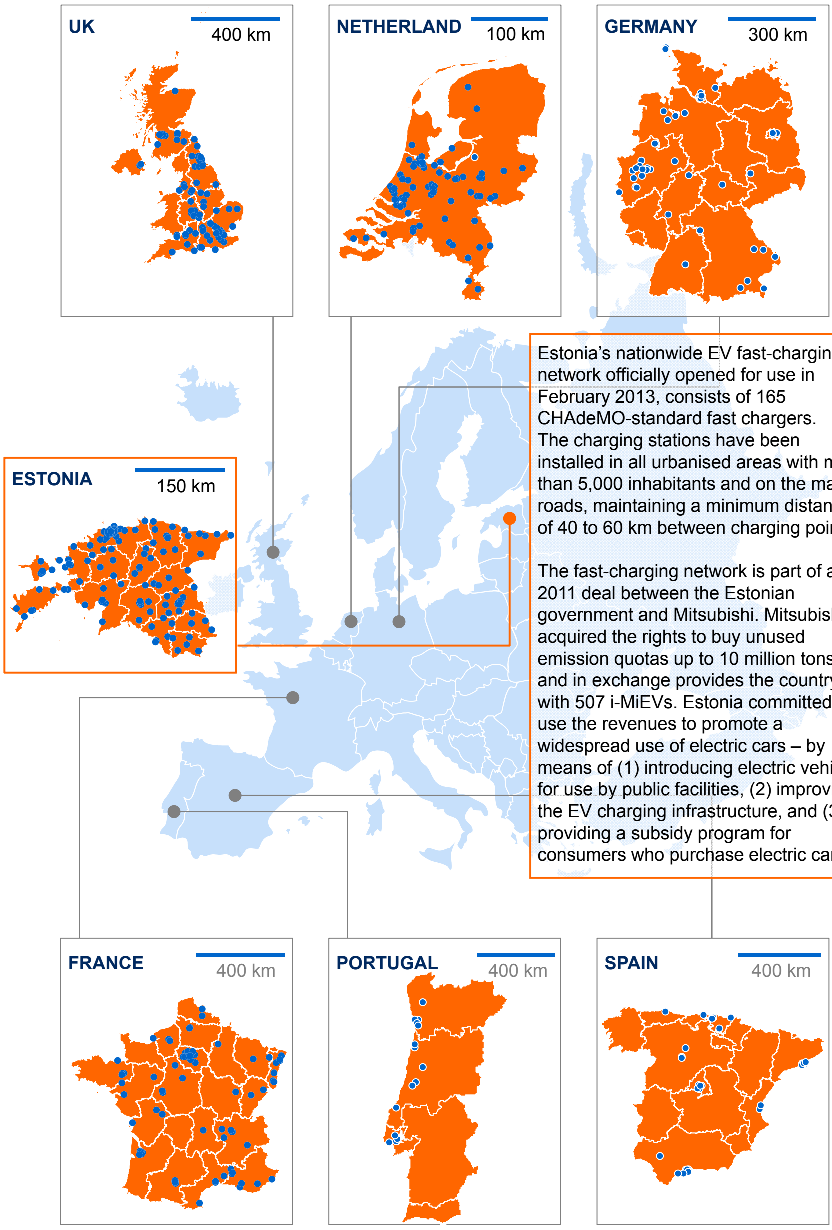
Supported by government funding, several German industry partners have initiated a program to install 8 DC fast-charging stations along the highway from Munich via Nuremberg to Leipzig.

Tesla plans to create corridors throughout Europe by installing 120 kW Supercharger stations along main traffic corridors. 14 stations have already been installed in Norway, Germany, the Netherlands, Austria, and Switzerland.

Exhibit 3.3

Fast charger deployment – Select countries

CHAdeMO fast chargers only



Estonia's nationwide EV fast-charging network officially opened for use in February 2013, consists of 165 CHAdeMO-standard fast chargers. The charging stations have been installed in all urbanised areas with more than 5,000 inhabitants and on the main roads, maintaining a minimum distance of 40 to 60 km between charging points.

The fast-charging network is part of a 2011 deal between the Estonian government and Mitsubishi. Mitsubishi acquired the rights to buy unused emission quotas up to 10 million tons, and in exchange provides the country with 507 i-MiEVs. Estonia committed to use the revenues to promote a widespread use of electric cars – by means of (1) introducing electric vehicles for use by public facilities, (2) improving the EV charging infrastructure, and (3) providing a subsidy program for consumers who purchase electric cars.

SOURCE: CHAdeMO 2013; Estonia electromobility program (ELMO)

A new charging behavior

There are significant technical differences between charging electric cars and refueling gasoline cars that make charging behavior different from traditional refueling behavior:

- **Charging speed.** Refueling an ICE car at a petrol station only takes a few minutes, and the infrastructure already exists. For full battery EVs, even fast-charging a battery to 80% will require 20-30 minutes (depending on battery size and fast-charging speed), and slow-charging a BEV usually takes multiple hours.

- **Charging frequency.** Current BEV models also lack the range that gasoline cars have. The 2013 Nissan LEAF has a nominal maximum range of 200 km, and the Tesla Model S with 85 kWh battery has a nominal maximum range of 426 km. This reduced range capacity compared to traditional ICE vehicles means that "plugging" in to charge will need to happen more frequently than refueling. However, an European driver of a BEV with a range of 150 km who has the opportunity to recharge at home or at work will have a limited need for additional recharging most of the time, since average trips are quite short. In most European countries, passenger vehicle driving distances average 40-80 km per day, with 2-3 trips per day. So most drivers would have an occasional need for additional charging outside of their homes or workplaces.

Initial evidence shows that most of the early adopters of BEVs and PHEVs have the opportunity to charge at home, and this is their primary charging location. In Norway, for example, 95% of BEV and PHEV owners have charging access at their homes (either personal or shared within apartment complexes). For those who own a garage, home-charging an electric car can be done using either a household plug or a relatively cheap residential charger ("wall box").

Secondary to charging at home, this first group of EV drivers charges at work. Research by the Norwegian Vehicle Association (November 2013[4]) indicates that almost 60% of the country's BEV and PHEV drivers have access to charging stations at their places of work.

Public charging stations (at either retail locations or fast-charging stations) are the third most popular charging locations after home and office. When asked about their use of public charging stations during the last month, 11% of BEV and PHEV Norwegian owners said they used public charging on a daily basis, 28% – on a weekly basis, and 35% – less frequently than that, 26% reported not using public charging at all in the last month.

Since fast-charging stations have been introduced fairly recently, only very preliminary conclusions can be drawn about their use. From the Norwegian survey, 62% of respondents indicated they did not use fast chargers at all in the last month, compared to 9% that used fast chargers at least once a week. It should be noted, however, that the current number of fast-charging stations in Norway is still quite limited (67 as of June 2013) and the three most popular fast-charging stations in Norway (located centrally and offering free electricity) have had 10,000 charging sessions in one year, averaging approximately 9 charging sessions per day for each of the three chargers.

4 Haugneland, Kuisle (Norwegian Electric Vehicle Association), "Norwegian electric car user experiences", November 2013

In the future, charging behavior – and in particular the use of public charging infrastructure, both slow and fast – is likely to change, influenced by multiple factors:

- **Need for public charging stations for EV drivers without access to garages.** The need for public charging stations will increase if consumers who do not have access to a garage or other private or semiprivate residential parking – a large share of people living in cities – also adopt EVs. For instance, in Germany almost two-thirds of all households have a garage or parking space. Looking at the urban metropolis of London, however, two-thirds of homes have neither a garage nor off-street parking.

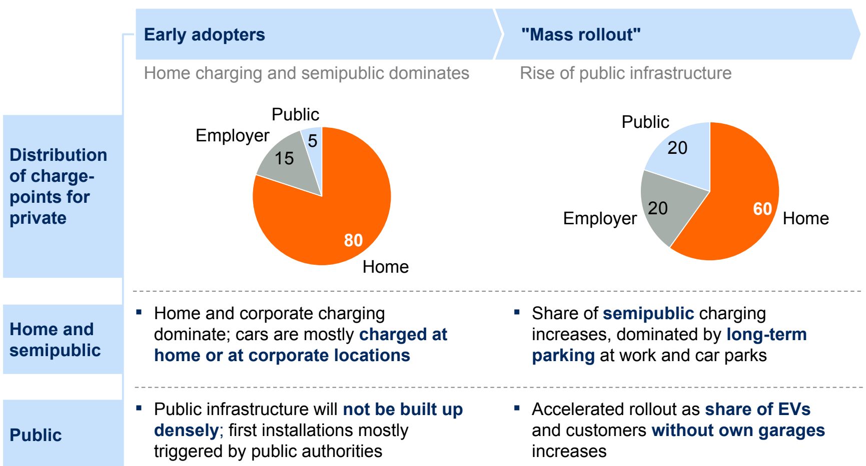
- **Battery size.** Conversely, the need for public slow-charging stations would decrease if the average battery size and range of BEVs increases. With less frequent charging required, drivers who rely solely on public stations will use them less, and those with access to stations at home and work may stop using public stations altogether.

- **Use of the car.** When it comes to slow- vs. fast-charging stations, the potentially changing role of the BEV may shift the ratio required. Experience from Norway shows that currently BEVs are often purchased as a second car for households and used primarily for daily commuting purposes. If the adoption of BEVs grows and more people want to use their BEV for long-distance trips (between cities or even countries), the demand for fast-charging stations will increase.

Exhibit 3.4

Implications for charging infrastructure: Basic belief from interviews and pilot results: In the first years, home charging will dominate

Sales in %



SOURCE: McKinsey

Introduction of targets and standards by the EU

The EU's Clean Fuel Directive, as proposed in January 2013 and being discussed in EU Parliament in March 2014, sets a target of 800,000 publicly accessible EV charging stations to be installed throughout Europe by 2020 – with individual targets being set for each member state. This requirement for publicly available charging infrastructure recognizes that many EV owners, especially in cities, will need to rely on access to charging stations in collective parking lots, at apartment blocks, offices, or business locations, and suggests that member states focus on charging station density in urban areas.

Vehicle-charging station (in)compatibility

Dense charging station coverage alone will not ensure driver access to charging infrastructure. Currently, due to a variety of plugs and outlets (and related communication systems between the car and charging station), not all EV models can plug in at all stations (as explained at the start of this chapter). Moreover, charging stations are often associated with specific charging network with unique identification and payment systems accessible to its members only. The Clean Fuel Directive is addressing this issue by proposing two pathways to standardization.

The first approach prioritizes certain charger types and standardizes them, setting the "Type 2" (Mennekes) plug as the standard for slow-charging EVs throughout Europe. The Japanese CHAdeMO 50 kW fast charger (compatible with Nissan LEAF and Mitsubishi i-MiEV, among others) is already deployed in Europe (more than 1,000 stations today). However, the Clean Fuel Directive proposes CCS (Combo) as the standard for fast-charging, following the adoption of this standard by German and US car makers. The Directive proposes a transition period through 2019 during which installing CHAdeMO for new fast-charging stations would still be allowed. In the meantime, CCS standard is now starting to be adopted in new charging stations and car models.

As fast-charging standardization is not yet achieved, industry is providing an interim solution – multistandard fast-charging stations, which allow CHAdeMO, CCS Combo, and AC fast-charging, similar to the gasoline-diesel-CNG offering at petrol stations.

Another compatibility challenge is caused by multiple networks of charging stations and the related services systems they operate, namely the billing, identification, and communication systems. There are efforts to promote interoperability and to allow EV drivers to freely use all charging stations available. In the Netherlands, for example, all parties involved in the EV charging infrastructure rollout agreed early on to use the same identification and communication systems for charging stations based upon open-source protocols, so that inter-operability at a national level is ensured. In addition to this, proposed EU regulation would promote "free choice of provider" at any charge point, which would make "roaming" for EV charging points possible – in a similar way as for mobile phone providers and local telecoms networks.

Commercial EV charging business models

Though a growing EV charging station infrastructure seems inevitable, the entire EV ecosystem faces a funding dilemma. The installation of a public charging infrastructure at the scale required by the EU comes at a cost too high for governments to bear alone. At the same time, the economics of both public (slow) and highway (fast) charging stations make commercial exploitation of public charging stations currently quite challenging.

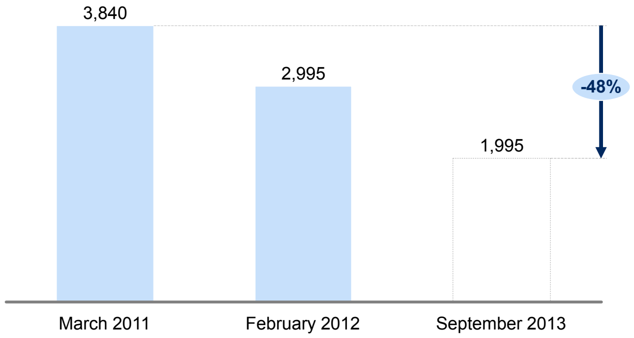
There are two important developments that may facilitate further rollout of charging infrastructure. First, the cost of charging stations – both hardware and installation – have decreased significantly already (Exhibit 3.5). Second, there is an interest in the new business segments that are related to charging of EVs, and some companies from different backgrounds and industries are entering this space. For example, ChargePoint in the US, which operates 70% of the charging locations in the country, has discovered a viable business model by exploiting the adjacent business segments of EV charging – e.g., billing and payments (Exhibit 3.5).

Exhibit 3.5

Hardware costs of a standard charging station has dropped by ~50% between 2011 and 2013

LOCAL NETHERLANDS EXAMPLE

Hardware costs for 2-plug public slow charging station in the Netherlands (excluding installation), EUR



CHARGING STATION TYPE:

- Pole-mounted, with two Type 2 “Mennekes” sockets
- 3.7 kW power level, using single-phase AC current of 16A-230V
- RFID/GSM controller for identification purposes

SOURCE: EV Box; The New Motion; Press search

BUSINESS MODELS OF CHARGING SERVICE PROVIDERS

As many players in the EV charging infrastructure have experienced, it is difficult to generate sufficient revenue solely from the power sales to EV drivers that charge their vehicles, in order to recoup the investment in the infrastructure.

Some charging services providers, such as ChargePoint in the US and The New Motion in Europe, have followed a different approach. They provide both the hardware (i.e., actual charging stations) and back-office services (such as payment and billing services) as a turnkey solution for customers who want to have charging stations installed, such as retailers, municipalities, and businesses with parking lots for their guests and employees. EV drivers pay for a subscription with the service provider and – with the use of an RFID identification card – can get access to the network of all publicly accessible stations connected to the network.

Municipalities and businesses are paying for hardware and installation of charge points. As a result, the actual infrastructure is funded by numerous parties, which have the freedom to set their own pricing scheme for the charging stations that are installed, and to decide whether it is public or private. Some retailers might want to attract extra additional customers by offering two hours of free charging and then charging a high premium for any additional charging time. Businesses might want to offer completely free charging to their employees. Given that some customers might receive additional benefits from setting up the charging stations, they do not necessarily need to recoup the complete investment from the power sales to EV drivers. For the charging services provider, revenues are generated by the hardware sales and the subscription fees from EV drivers, as well as the fees for the back-office services delivered to customers.

Chapter 4
Distribution and delivery

The emergence of electric mobility is an important development for the power sector. While the adoption of EVs can provide new opportunities – such as creating additional electricity sales for utilities and a demand for charging infrastructure and related services – the charging of EVs at a large scale can also create challenges for local distribution grids and their operators, if not properly managed.

A growing adoption of electric mobility would coincide with other trends that put higher requirements on the grid and power system, such as the increasing share of renewables and distributed generation, as well as demands for increasing energy efficiency. Together these trends – with the grid functionality requirements inherent in them – will drive the transition from traditional to smarter grids.

The challenge posed by the increasing use of electricity by EVs lies not so much in the volume of the associated power demand, but rather in the potential increase in peak demand, which is determined by the speed, moment, and location of EV charging. In general, a growing number of EVs will cause a higher demand for electricity. Taking the Netherlands as an example, driving an EV 15,000 km per year and charging it solely at home would roughly double the household's electricity demand, taking it from about 3,500 kWh to about 6,500 kWh per year. Despite this marked volume increase at the household level, significant EV penetration would only lead to a moderate rise in total demand – estimates suggest that even if EVs comprised 20% of all cars on the road in Europe by 2020, associated incremental electricity demand would be 3-4% of base case without large-scale EV adoption. From a volume perspective, this additional electricity demand could be accommodated by the power sector without additional significant investments.

Rather than a significant impact on the overall electricity demand, the key challenge of large-scale EV adoption will be the potential increase in peak demand caused by the charging of EVs. The impact is determined by characteristics such as speed, time, and location of EV charging. Fast-charging (i.e., charging at a higher voltage) will have a more significant impact on the grid then slow-charging. The moment of charging (i.e., when charging happens) also impacts the grid: throughout the day, electricity demand follows a load curve; when exactly EV drivers charge their cars can either intensify peaks or level them out. Finally, where the charging takes place (cluster of EVs charging or lot of grid capacity available) can also have implications for the power infrastructure.

Over time, the growth of EVs can lead to a significant increase in the load requirements put on distribution grids, depending on whether the charging is unconstrained or controlled

Unrestrained EV charging at home can significantly increase residential peaks, especially since charging when returning home would increase the common “afternoon peak” in household electricity consumption. The combined impact of several such residential peaks on the distribution grid would be particularly high in neighborhoods with a high penetration of EVs, and would affect lower-voltage distribution grids the most, ultimately requiring expensive grid upgrades.

In addition to load demand potentially caused by large-scale EV charging, renewable energy sources are impacting the power infrastructure. The share of renewable energy sources in the EU power generation mix has grown from 13% in 1990 to about 20% by 2010, and will continue to increase towards EU’s 20-20-20 targets, which include a target of 20% of renewable energy in the EU’s gross final energy consumption by 2020 (~9% in 2010).
This increase has two distinct effects that exert stress on the grid (and related systems):

- **Supply volatility.** The growth in renewable energies creates more intermittency and volatility in the power supply, as wind and solar energy are not consistent in terms of production over time.

- **Distributed generation.** Mostly due to the installation of solar PV by individual homes and businesses, consumers of electricity are becoming small-scale producers. If the electricity generated by distributed generation is not consumed locally, it can flow back into the distribution grid, causing reverse flows, which the grid and metering system may not be able to accommodate.

Of the two grid-related effects of renewable energy, distributed generation is likely to have the more significant impact. In Europe, the total installed capacity of solar PV systems reached 69 GW in 2012, ~80% of which is connected to low-voltage grids.
This solar capacity impact on the electricity infrastructure is already reaching significant scale, with examples of “grid stress” being felt throughout Europe. The grid challenges in accommodating significant reverse flows from distributed generation are already apparent today (Exhibit 4.1).

- In certain locations in Italy, 20% of distributed production is reversed into the distribution grid. In this situation, distribution substations can struggle to actively manage reverse flows (and ensure overall grid stability).

- In Germany, for example, solar and wind generation has to be disconnected from the grid at times because these sources produce a level of power that the grid cannot accommodate.

- In Belgium, the electricity grid has had trouble accommodating the production of renewable energy on sunny and windy days in which there was not much industrial demand.

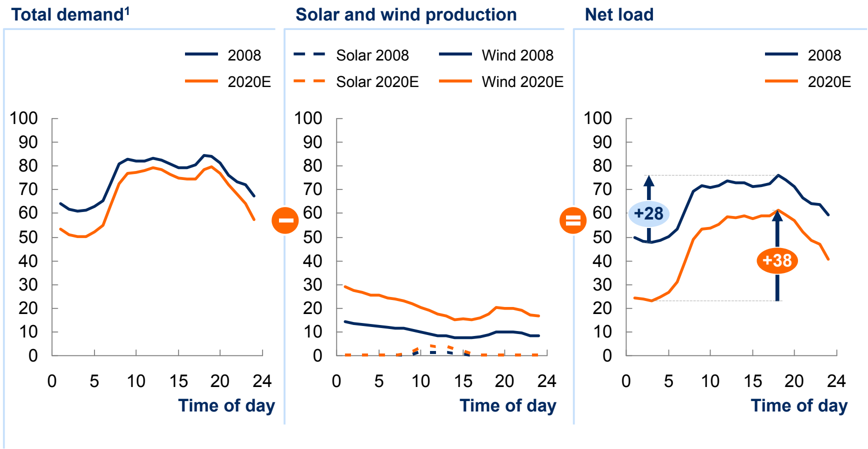
- In Northern Ireland, the uptake of small-scale renewable energy has been so quick (due to strong government incentives), that the grid is reaching a saturation point. As a result, some projects are not able to go ahead unless substations and lines are upgraded.

Exhibit 4.1

The increasing share of renewables exacerbates peak/load differential, creating challenges for grid operators

GERMAN EXAMPLE FOR JANUARY 16 IN YEAR INDICATED

GW



1 Total demand expected to decline over the next decade, in part, due to less industrial demand, which again makes the load profile more spiky

SOURCE: McKinsey analysis

Not anticipating future load requirements on existing grid infrastructure could result in costly grid upgrades in future. Such grid upgrades would consist of replacing existing cables with thicker versions and upgrading the transformers feeding into the distribution networks. Without smart systems, investments in the grid to integrate demand from a large population of EVs will be larger than the base case without EVs and, in certain areas of high EV penetration, may be as high as double.

To avoid these investments, grid operators are interested in new solutions that could help balance the grid, and chief among these today are energy efficiency targets. In particular, the EU has set the target of achieving a 20% energy efficiency improvement, as part of its 20-20-20 climate and energy goal set. As part of the Energy Efficiency Directive, member states are required to drive energy efficiency improvements in households, industries, and transport sectors. Home energy management systems can play a role in reducing energy demand and increasing energy efficiency – some pilots in Europe achieved energy demand reductions of 4-10%. Apart from achieving energy savings, such home energy management systems can be used for intelligent demand-side management, which will become a critical feature in stabilizing the grid in future. Early pilots have shown that peak demand reductions of 12-20% are possible, when combined with (and reacting to) critical peak pricing tariffs.

Outlook on grid intelligence

As a result of the need and demand for more functionalities of both distribution grids and home energy management systems, the traditional electricity grid is changing to a more complex and intelligent system.

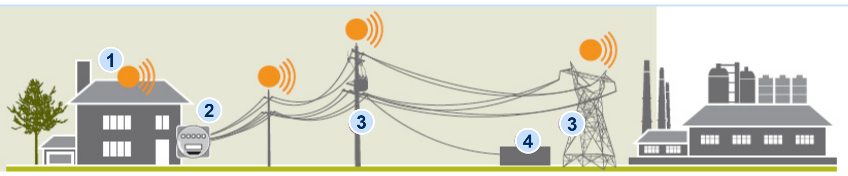
Overall, the traditional "one-way" model for the distribution and delivery of electricity – one in which power flows from large centralized power plants to individual consumers – is gradually changing. Renewable energy generation feeds multiple sources of electricity production into the grid, and the intermittent nature of this production introduces more volatility. Together, these factors can lead to a misalignment of power supply and demand. Therefore, more intelligent systems are required to restore and maintain the balance of the grid (Exhibit 4.2).

Exhibit 4.2

Emerging smart grid requires new applications, infrastructure and support services

Key smart grid component

Transmission and distribution environment



1 Customer applications support
- In-home display with real-time usage and pricing statistics
- Usage-aware appliances, e.g. smart charging of electric vehicles
- Home automation

2 Advanced Metering Infrastructure (AMI) allows
- Report usage by time and outages in real time
- Remote disconnect
- Operational improvements for distribution/retail companies

3 Grid applications drive
- Automation of the grid
- Reduction in losses
- Remote monitoring
- More accurate balancing

4 Integration of distributed generation and aggregated demand-side management
- Integration of back-up generators, storage, distributed solar
- Aggregation of demand-side response (e.g. clusters of EVs)
- Disconnection in case of network overload

SOURCE: McKinsey Quarterly, "The smart grid opportunity for solutions providers", Summer 2010; McKinsey analysis

To deliver the intelligence required, smart grid applications are emerging, which can be categorized in four groups, each with different functionalities:

Customer applications. Advanced demand-side management or home energy management services that shift demand, reduce overall energy consumption, and increase information flow to and awareness of customers

Advanced metering infrastructure (AMI). E.g., smart meters that read and send usage data over a network and allow for basic demand-side management or that can identify the location and assess extent of outages

Grid automation. Fault detection, isolation and restoration that can isolate transmission and distribution network faults to smaller sections and reroute power; voltage and volt-ampere reactive control that can manage voltage level and power factor real-time; monitoring and diagnostics to address impending failures and optimize inspections and maintenance.

Integration of distributed generation and aggregated demand-side management. Managing large-scale distributed generation and EV charging at an aggregated level (e.g., by combining the demand response of multiple clustered EVs), providing additional services (e.g., payment or consumption control) and integrating back-up generators and storage; enabling remote connect and disconnect.

The first steps towards a smarter grid are being taken, with various pilots taking place across Europe – driven by regulation and recognition that implementation can avoid costly grid upgrades. The implementation of smart meters in households is moving forward, facilitated by an EU target that states that 80% of households should have a smart meter installed by 2020. While the exact functionalities of smart meters vary across Europe, the intent is that in due course, such devices can enable demand-side management that would include smart charging of EV.

EVs' evolution from managed problem to active solution

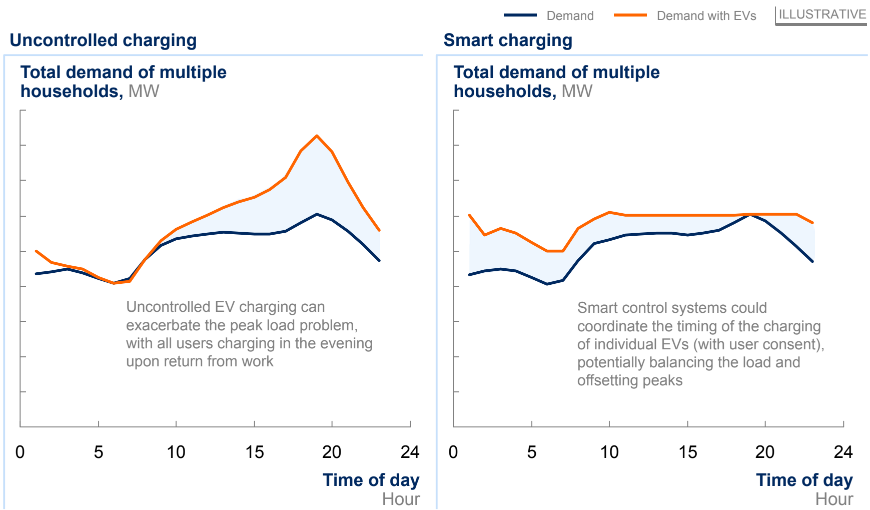
Over the longer term, if EVs reach large-scale market penetration and smart grid systems become more commonplace, EVs could become part of the solution – load-shifting and supplying power can be a part of EVs' future role in the new grid.

- **Load-shifting.** I.e., shifting demand from peak moment (e.g., working day afternoon) to lower-demand periods (e.g., night) could be accomplished by instituting controlled charging of EVs and could be an important step in minimizing the impact or even improving management of existing peak demand for electricity (Exhibit 4.3).

- **Vehicle to Grid (V2G).** One step further than controlling their demand for electricity, EVs could be equipped to actually provide electricity to the grid. This functionality can be even more effective for balancing purposes and managing the electricity load. Volkswagen and Lichtblick announced a pilot in Berlin that has 20 VW e-Ups that are able to charge back to the grid. In the US, a collaborative V2G pilot between BMW and the University of Delaware, has 15 (stationary) Mini-E's coupled to the grid in which bidirectional flows are being managed.

Exhibit 4.3

Smart charging of EVs can avoid the peak load problem and become a key balancing component in demand side management



SOURCE: McKinsey

- **Vehicle to Building (V2B).** The storage capacity of the batteries in EVs can also be utilized to arbitrage between different electricity tariffs throughout the day. This is relevant, as one fully-charged BEV could theoretically power a household for one or more days depending on its battery size. For example, with typical European household demand of ~10 kWh per day, a fully-charged battery of a Nissan LEAF (24 kWh) would be able to deliver power for 1-2 days. Nissan is piloting this V2B approach in Japan, with the idea that it will allow companies to regulate their electricity bills using the batteries of the EVs of their staff. It has carried out an initial pilot at its own Advanced Technology Center in Atsugi City, Japan, using 6 Nissan LEAFs, which according to Nissan led to a 2.5% reduction of electrical power use during peak hours, yielding electricity cost savings.

Further, the decrease in Li-ion battery prices has led to growing interest in using automotive battery technology (or even second-hand EV batteries) as local stationary electricity storage solutions, for households, buildings, or grid nodes – providing a potential solution for storage for distributed renewable generation.

Exhibit 4.4

EVs can be part of the smart grid solution: Price arbitrage and control reserve

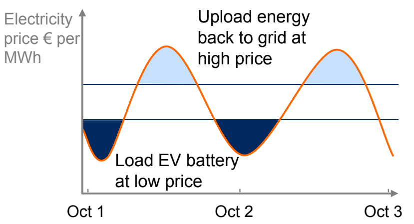
ASSUMING BI-DIRECTIONAL CHARGING

ILLUSTRATIVE

A Price arbitrage

Description

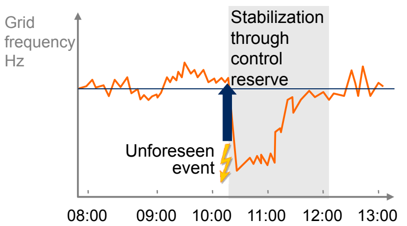
- Taking advantage of electricity price differences in time
- Electricity is traded on a per minute basis at energy exchanges
- Risk due to battery aging and customer acceptance



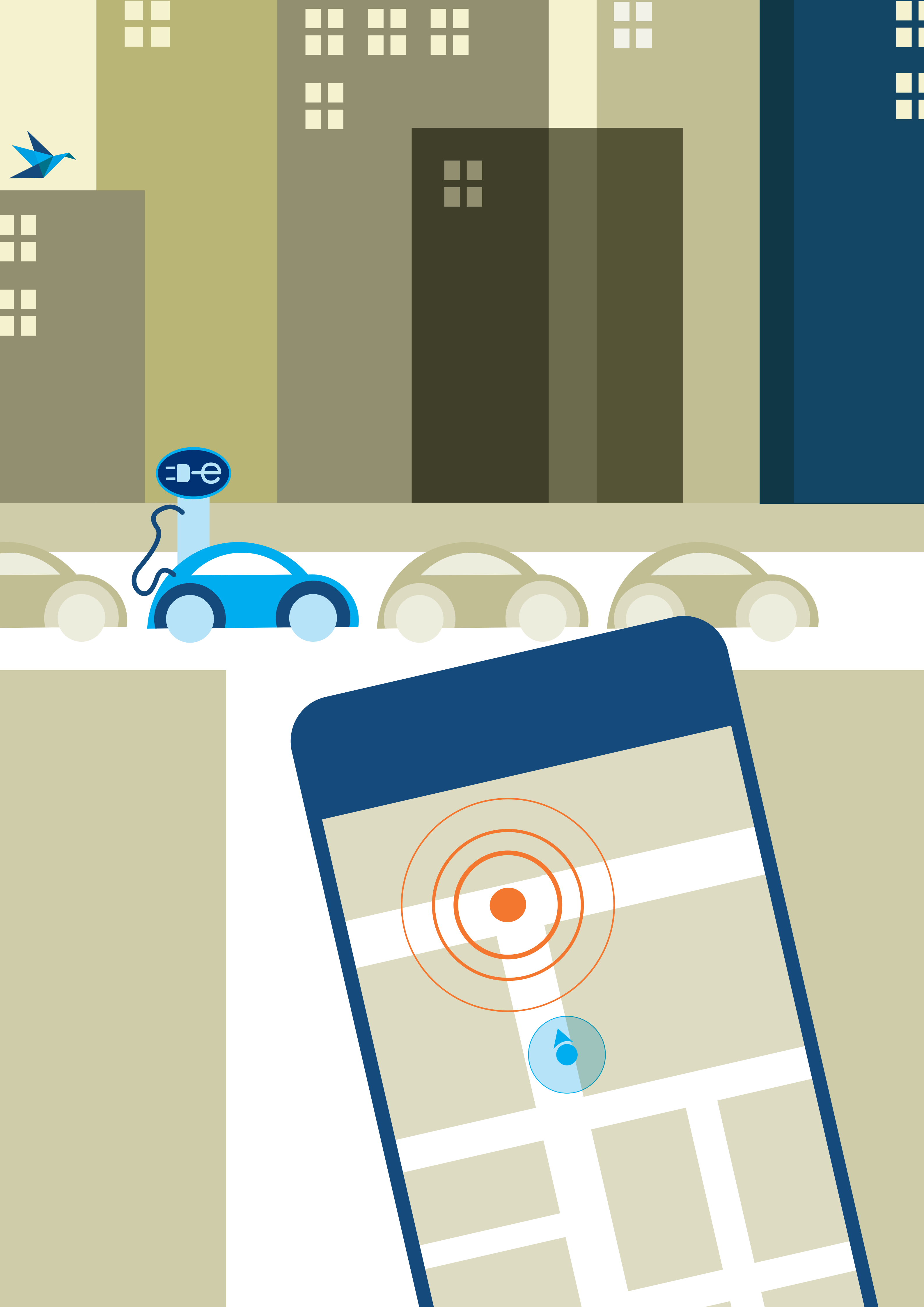
B Control reserve

Description

- In case of unplanned grid fluctuations, positive or negative control reserve must be activated to stabilize the grid
- Triggered charging or vehicle-to-grid upload can be used as such control reserve
- High prices are paid for provisioning of such systems



SOURCE: McKinsey



Chapter 5
Innovative businessmodels

In this report, we have described the status and developments of the electric mobility space in EU. As a new technology with its own ecosystem, the rise of EVs is challenging business models and spawning new ones – from infrastructure to charging service solutions, from OEM offerings to grid management applications. These business models help the industry to mature and provide the foundation (and sometimes impulse) for further EV adoption.

In addition, broader trends such as the emergence of "mobility as a service," embraced by both consumers and OEMs, could significantly boost EV adoption in the coming years.

The shift towards electric mobility introduces a novel end-to-end value chain, and in this report, we have discussed its various elements. For every challenge and new consideration that arises from this technology there is an opportunity for the creation of new (or enhancement of existing) business models along this new value chain (Exhibit 5.1).

Exhibit 5.1
Impact of powertrain transformation on value chain

EXAMPLES

Raw materials / Manufacturing equipment	Carmaker / Automotive supplier	Changing infrastructure	Maintenance	2nd use / Recycling
▪ Growing demand for copper and rare earth, e.g. neodymium ▪ High investments in EV production equipment, while machinery demand mechanic operations will drop	▪ Carmaker and suppliers will enter into e-motor production to tap high growth potential ▪ Turbocharger manufacturers will benefit from down-sizing trend, but will get under pressure in the long run	▪ Utilities and infrastructure providers can benefit from investments to build up charging stations for EVs and new business models to provide ancillary services	▪ Negative impact on after sales service providers: BEVs require less effort for maintenance than today's ICEs	▪ New businesses around 2nd use and recycling of EV components will arise driven by increasing prices for raw materials

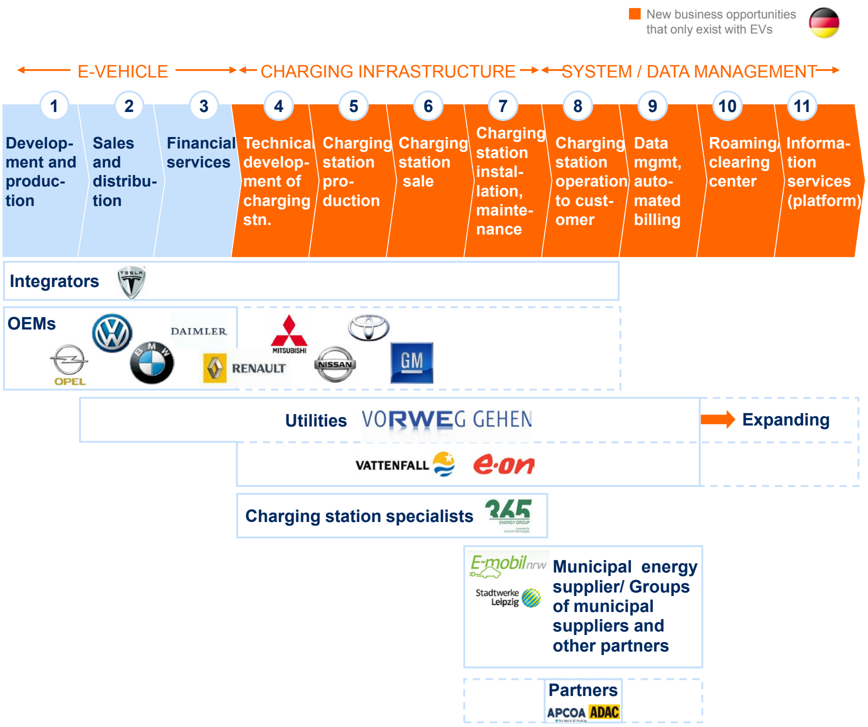
SOURCE: McKinsey – Boost! Powertrain KIP

Incumbents of the traditional automotive value chain as well as new entrants are testing new approaches and models to meet the needs of the new value chain and take advantage of the emerging markets for new applications and services.

Exhibit 5.2

Incumbents and new entrants are trying to capture new opportunities along the EV value chain that did not exist with ICE

OUTSIDE-IN



SOURCE: McKinsey

This evolving electric mobility ecosystem is spawning a number of innovative business models. Emerging markets for products and services on the one hand are a result of EV adoption, and on the other hand enable and facilitate further EV scale-up.

We started this report by looking at **cars, components, and costs** – development of alternative powertrains themselves and the associated battery packs. Beyond their obvious roles as manufacturers, incumbent OEMs and new entrants are working on new business models in this space:

- **Vertical OEM offerings.** Some car manufacturers are looking into playing a role beyond car production and becoming active on the infrastructure side. Tesla, for example, offers exclusive access to the Supercharger stations – which are compatible only with Tesla models – and is rolling them out across the US and Europe.

- **Battery leasing.** In order to lower the hurdle of a higher purchase price of EVs for potential buyers, some OEMs are experimenting with the concept of battery leasing, separate from the purchase of the EV itself. The additional benefit to consumers is that they can replace batteries when needed and not have to worry about its durability and long-term performance.

A critical enabler of the scale-up of EV adoption is the improvement of the **charging infrastructure**. Here we see companies experimenting with several services and business models:

- **Navigation software and apps related to charging infrastructure.** Since EV infrastructure is still not widely available, EV drivers need to actively seek out not just the location of charging stations but also the type of station compatible with their vehicle. Currently, many separate maps are available, but there are limited integrated offerings. In the future, making a reservation for a charging station spot might be an additional functionality.

- **Charging services (payment, access, and registration).** In order to charge at a charging station, it is currently often necessary to have an account with an EV charging service provider. This service provides customers with an RFID pass for identification and operates a back-office with payment and billing systems, so that the customer gets billed for the electricity that is being charged into the car.

- **Charging point services (installation and maintenance).** There is an increasing number of companies on the market that provide charging point services for private charging. They install charge points at home or at the office and provide maintenance services.

- **Operating charging infrastructure.** Similar to operating petrol stations, there might be a business case in operating charging infrastructure – for example, operating a fast-charger highway network in combination with retail activities.

- **Battery swapping.** As a potential solution to infrastructure and charging time issues, battery swapping could be a quick recharge alternative for EV drivers.

From electricity distribution and delivery perspective – the link between electric mobility and the power sector – three new business models are emerging:

- **Smart grid applications.** While the current power infrastructure can accommodate the rise in volume that would accompany greater EV penetration, a spike in peak demand could be overwhelming. In order to manage the charging of an increasing number of EVs, there is a need for applications that can coordinate the smart charging of EVs and reduce the impact of EV charging on the grid.

- **Aggregating demand-side response and monetizing flexibility.** As we discussed earlier, any demand volatility created by EVs will be occurring alongside the shifts in supply that come from renewable energies and distributed generation. Given the increasing challenges of balancing electricity grids with more fluctuations in supply and demand, it is expected that demand-side response systems will gain in importance. Flexible demand could represent economic value – especially if parties take an "aggregator" role and pull together the individual small-scale demand-side response opportunities into large volumes. In the case of a high penetration of EVs, regulating their charging behavior – and possibly using the option to provide power back to the grid using Vehicle-to-Grid technology – could provide value to energy companies and grid operators that need to match supply and demand and balance the grid.

- **Stationary storage using EV batteries.** EV batteries – either new or second-hand – could potentially provide a cost-effective option for stationary electricity storage solutions, for instance in households or at grid nodes.

New business models such as those described above help the industry to mature, and provide the foundation for further EV adoption. As is often the case with emerging technologies, the growth of the EV sector from niche towards a larger scale has not been without its ups and downs. Recent years have seen prominent failures, such as BetterPlace, which went bankrupt with its business model based on battery swapping. However, there are also opportunities provided by this growing market. In the current emerging playing field, both incumbents as well as new entrants are trying to find a profitable position.

Shift towards "mobility as a service"

"Mobility as a service" is changing the traditional model of car ownership (and the related value chain) with an objective of meeting consumer mobility needs in the most efficient way. Getting from Point A to Point B can be done in a multitude of ways and may mean using a privately owned vehicle for only part of the journey or not owning a car at all (especially in dense urban areas).

From an OEM perspective, the shift towards mobility as a service has important implications. After outsourcing most parts of production to individual specialized suppliers, automotive players are now transitioning even further away from being classic car manufacturers and venturing out in multiple directions to become "providers of mobility." One example is BMW moving into parking and payment services with ParkNow. ParkNow, is an app- and web-based service provides a clear overview of the parking situation in a city allows it filtering of partner car parks by price, distance or even availability of services, makes a confirmed booking, guides directly to selected garage, and manages electronic check-in, check-out, and paperless payment.

Car sharing is another major example of the mobility-as-a-service space into which OEM's are moving. Daimler and its Car2Go car-sharing service is just one example of this important and potentially disruptive business model that is already seeing rapid growth in Europe. Despite currently low usage rates, a market survey by McKinsey found that a third of Germany's urban population is a prospective user of car-sharing services. Nearly 40% of young Germans (18- to 39-year olds) living in cities with more than 100,000 inhabitants indicated that ten years from now they "will use car sharing more." This data support supports industry analyst forecasts that the number of car-sharing customers in Europe might increase to 15 million by 2020, up from 1 million today.

Full mobility solutions complement the use of car sharing by integrating it with other mobility offerings. From a consumer demand perspective, mobility solutions such as the Moovel app, which offers journey advice based on integrated mobility, combining public and private transport, are gaining ground.

To the degree that mobility as a service, and specifically car-sharing as an important new model, can integrate the usage of EVs, it offers new opportunities for EV adoption by removing some of the barriers. First, on the user side, these models eliminate the hurdle of high initial purchase price, because users do not have to buy the cars they are driving. Mobility as a service can also alleviate the "range anxiety" that makes some consumers reluctant to purchase an EV by allowing them to opt for BEV usage only for driving distances that they're comfortable with. Car-sharing fleet operators could possibly benefit from lower fuel and maintenance costs, because they should be able to realize higher utilization rates (especially in dense, urban areas) as compared to private car use.

Car2Go, DriveNow, Flinkster and Autolib' are some of the car-sharing services that have already included EVs in their fleets. As the share of EVs in car-sharing fleets grows, more customers can get familiar with the new technology – potentially leading to an increase in the proportion of prospective car buyers that is open to buying an EV.

WHAT'S MINE IS YOURS: THE FUNDAMENTALS OF CAR SHARING

Car sharing is a mobility-as-a-service solution and an innovation on the traditional car rental business. At its heart, car sharing allows members to access a fleet of vehicles for their individual, short-term usage, but this is being done through three distinct service and business models:

Station based. In this model, cars can be picked up at one of a set of designated locations and need to be returned to one of those locations (sometimes the exact location from which it was picked up).

Free float car sharing operates without the use of set stations and allows users to pick up a car from ever-changing locations and park them anywhere (within certain geographical limits) when they are done.

Peer-to-peer cars are part of a car-sharing fleet with a unique business model. Unlike with other models, these cars are not owned by any organization. Instead, individual owners can rent out their own cars when not in use through an online, third-party platform.

One of the largest car-sharing programs is the **'Autolib'** program in Paris, which was launched in 2011 and now includes over 2,000 full electric BlueCars, over 4,000 charging stations, and more than 100,000 registered users. The Bolloré BlueCar uses a 30kWh lithium metal polymer battery and has a nominal range of 250 kilometers.

Car2Go (Daimler) now has more than 600,000 customers and 10,000 vehicles worldwide, operating in 7 countries and 25 cities, with the first few cities being profitably operated. In some of the cities in which Car2Go operates, such as Amsterdam, San Diego, and Stuttgart, it has a fleet fully comprised of BEVs (300-500 EVs in each).

DriveNow is a car-sharing venture set up by BMW and the European rental company Sixt. It is now active in 5 cities in Germany and operates a fleet of ~890 BMW and MINIs, including 40 electric Active E (Mini) models in Berlin and 20 in Munich. DriveNow is also operating in San Diego and Oakland.

On the peer-to-peer side, **WhipCar** in the UK stopped its operations in 2013, but the start-up **SnappCar** (currently active in the Netherlands and Germany) has plans to expand further across Europe. **Getaround** in the US (with cars available in the Bay Area, as well as Portland, Chicago, Austin, and San Diego) has been growing since 2009, with peer-to-peer on-demand car rental by the hour, day, week, or month seeing so much demand that the start-up has recently entered into a partnership with Smart car dealership in its San Francisco location to increase available supply.

DOOR-TO-DOOR: THE EMERGENCE OF FULL MOBILITY SOLUTIONS

Mobility tends to be more complicated than just getting from Point A to Point B. When you consider all of the intermediary steps involved in getting from your home to your final destination (e.g., the bus to the train station, the taxi from the train station, or the endless search for an empty parking space) the overall journey ends up using a few more letters of the alphabet. “Full mobility” describes the set of solutions either focused on the complete journey – from start to finish – or on the parts of the journey not addressed by the first wave of mobility-as-a-service solutions.

Flinkster. In Germany, Deutsche Bahn has initiated the Flinkster car-sharing service, which is available in over 140 towns and cities in Germany, with over 800 stations. With Flinkster, Deutsche Bahn aims to facilitate the onward journey for train travelers. Vehicles can be booked via smartphone for the duration that customers need them.

Moovel is an app for smartphones, introduced by Daimler, which offers complete travel routes from one address to another, combining the real-time availability of Car2Go cars, public transport, taxi, ride-sharing, and bike-sharing concepts.

ParkNow is BMW’s offering that focuses on the last piece of the journey by car: parking. This service eases the burden of finding parking by highlighting real-time availability in a given geography and facilitating the payment of parking fees.

Conclusion

We appear to be entering a new phase for EV in Europe, with opportunities becoming ripe in select market clusters. As a result, there will be opportunities throughout the value chain for incumbents and new entrants. In the longer term, large-scale EV adoption will be conditional on regulation and TCO evolution compared to ICE alternatives.

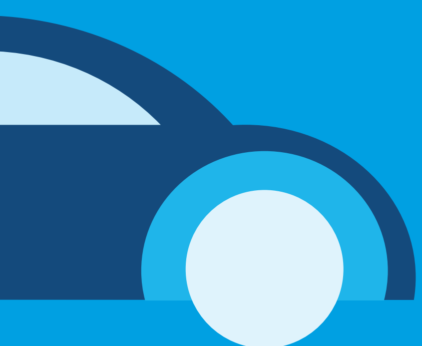
Implications for OEMs and suppliers: While ICE will dominate EU's powertrain portfolio for the coming years, EVs are likely to claim a substantial share of this portfolio in the long run. Cost competitiveness with ICE on a TCO basis is critical for large-scale adoption of EVs. TCO reduction is contingent on further evolution of battery pack costs, the pathway of which remains unclear.

Implications for charging infrastructure: Wired charging infrastructure has now clearly gained momentum ahead of other alternatives. The initial rollout is largely supported by the public sector, with selected OEM's, utilities and other private sector players starting to enter the space. Achieving a further significant scale-up will require standardization, economies of scale, and commercial business models.

Implications for the grid: EV's impact on power infrastructure and electricity demand today remains manageable. However, large scale adoption of EVs and charging behavior evolution will have implications for infrastructure investments in the near term. Proactive consideration of potential impact of scale-up and role of EVs in emerging smart grid can result in potential savings for utilities and grid operators.

New business models and market opportunities: Current levels and further adoption of EVs creates demand for new applications and services along the value chain including charging infrastructure (charging hardware, charging services, navigation); power sector (smart charging/smart grid applications, aggregated demand-side management); cars and components (e.g., battery leasing); recycling services. New mobility business models, especially those centered on carsharing, can already in the short term remove barriers for adoption of EVs at scale as privately owned vehicles (e.g., range limitations, high purchase price).

The trajectory and ultimate scale of adoption of EVs in Europe remains uncertain. However, the developments to date and some indicators looking forward suggest significant potential. Incumbents in the traditional automotive value chain and players with competencies to meet the demands of the new emerging ecosystems can benefit from a deeper understanding of the key drivers of EV adoption and the characteristics of opportunities it creates.



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