Electric car

For hybrid cars, see Hybrid vehicle and Plug-in hybrid.

An **electric car** is an automobile that is propelled by one or more electric motors, using electrical energy stored in rechargeable batteries or another energy storage device. Electric motors give electric cars instant torque, creating strong and smooth acceleration. They are also around three times as efficient as cars with an Internal combustion engine.

Two electric cars charging on street in Amsterdam: Tesla Model S (left) and Smart ED (right).

The first electric cars were produced in the 1880s.*[1] Electric cars were popular in the late 19th century and early 20th century, until advances in internal combustion engines and mass production of cheaper gasoline vehicles led to a decline in the use of electric drive vehicles. The energy crises of the 1970s and 1980s brought a short-lived interest in electric cars; although, those cars did not reach the mass marketing stage, as is the case in the 21st century. Since 2008, a renaissance in electric vehicle manufacturing has occurred due to advances in batteries and energy management, concerns about increasing oil prices, and the need to reduce greenhouse gas emissions.*[2]*[3] Several national and local governments have established tax credits, subsidies, and other incentives to promote the introduction and adoption in the mass market of new electric vehicles depending on battery size and their all-electric range.

Electric cars are significantly quieter than conventional internal combustion engine automobiles. They also do not emit tailpipe pollutants,*[4] giving a large reduction of local air pollution, and, in many cases, a large reduction in total greenhouse gas and other emissions (dependent on the method used for electricity generation*[2]*[3]). They also provide for independence from foreign oil, which in several countries is cause for concern about vulnerability to oil price volatility and supply disruption.*[2]*[5]*[6] But widespread adoption of electric cars faces several hurdles and limitations, including their current higher purchase cost, patchy recharging infrastructure (other than home charging) and range anxiety (drivers' fear that electric energy stored in the batteries will run out before reaching their destination, due to limited range of most existing electric cars).*[2]*[3] Recharging can take a long time; however, for long distance driving, many cars support fast charging that can give around 80% charge in half an hour, using public fast chargers.*[7]*[8]*[9]

As of September 2015, there are over 30 models of highway legal all-electric passenger cars and utility vans available for retail sales, mainly in the United States, China, Japan, Western European countries. By mid-September 2015, about 620,000 light-duty electric vehicles have been sold worldwide out of total global sales of one million plug-in electric cars sold since 2008.*[10] The world's top selling highway-capable electric car is the Nissan Leaf, released in December 2010 and sold in 46 countries. As of early December 2015, global Leaf sales passed the 200,000 unit milestone, and the Tesla Model S, released in June 2012, ranks second with about 100,000 units sold worldwide.*[11]

1 Terminology

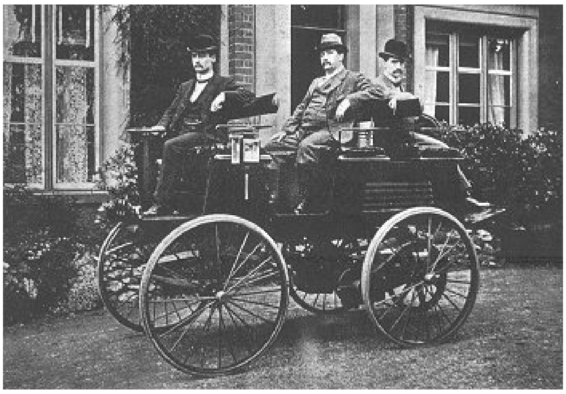
Electric cars are a variety of electric vehicle (EV). The term “electric vehicle” refers to any vehicle that uses electric motors for propulsion, while “electric car” generally refers to highway-capable automobiles powered by electricity. Low-speed electric vehicles, classified as neighborhood electric vehicles (NEVs) in the United States,*[12] and as electric motorised quadricycles in Europe,*[13] are plug-in electric-powered microcars or city cars with limitations in terms of weight, power and maximum speed that are allowed to travel on public roads and city streets up to a certain posted speed limit, which varies by country.

While an electric car's power source is not explicitly an on-board battery, electric cars with motors powered by other energy sources are generally referred to by a different name: an electric car carrying solar panels to power it is a solar car, and an electric car powered by a gasoline generator is a form of hybrid car. Thus, an electric car that derives its power from an on-board battery pack is a form of battery electric vehicle (BEV). Most often, the term “electric car” is used to refer to battery electric vehicles.

2 History

Main article: History of the electric vehicle

2.1 Invention



First practical electric car, built by Thomas Parker in 1884

Rechargeable batteries that provided a viable means for storing electricity on board a vehicle did not come into being until 1859, with the invention of the lead-acid battery by French physicist Gaston Planté.*[14]*[15]*[16]

Thomas Parker, responsible for innovations such as electrifying the London Underground, overhead tramways in Liverpool and Birmingham, built the first practical production electric car in London in 1884, using his own specially designed high-capacity rechargeable batteries.*[17]*[18] Parker's long-held interest in the construction of more fuel-efficient vehicles led him to experiment with electric vehicles. He also may have been concerned about the malign effects smoke and pollution were having in London.*[19]

An alternative contender as the world's first electric car was the German *Flocken Elektrowagen*, built in 1888.*[1]

2.2 Golden age

German electric car, 1904

1911 Ideal Electric car ad

Electric cars were reasonably popular in the late 19th century and early 20th century, when electricity was among the preferred methods for automobile propulsion, providing a level of comfort and ease of operation that could not be achieved by the gasoline cars of the time.*[20] In 1900, 40% of American automobiles were powered by steam, 38% by electricity, and 22% by gasoline.*[21] The electric vehicle stock peaked at approximately 30,000 vehicles at the turn of the 20th century.*[22]

Advances in internal combustion engines – especially the adoption of the electric starter motor which replaced other, often laborious, methods of starting the ICE engine, such as hand-cranking – soon lessened the relative advantages of the electric car. The greater range of gasoline cars, and their much quicker refueling times, encouraged a rapid expansion of petroleum infrastructure, which quickly proved decisive. The mass production of gasoline-powered vehicles, by companies such as Ford, reduced prices of gasoline-engined cars to less than half that of equivalent electric cars, and that inevitably led to a decline in the use of electric propulsion, effectively removing it from the automobile market by the early 1930s.*[21] Out of the 568,000 vehicles produced by American automobile manufacturers in 1914, 99% were powered by internal combustion engines.*[23] Electric cars went out of production in the U.S. in 1920.*[21]

Electric battery-powered taxis became available at the end of the 19th century. In London, Walter C. Bersey designed a fleet of such cabs and introduced them to the streets of London in 1897. They were soon nicknamed "Hummingbirds" due to the idiosyncratic noise they made.*[24] In the same year in New York City, the Samuel's Electric Carriage and Wagon Company began running 12 electric hansom cabs.*[25] The company operated until 1898 with up to 62 cabs in service, until it was reformed by its financiers to form the Electric Vehicle Company.*[26]

In 1911, the *New York Times* stated that the electric car has long been recognized as "ideal" because it was cleaner, quieter and much more economical than gasoline-powered cars.*[27] However an article in the *Washington Post* in 2010, quoting that comment, asserted that "the same unreliability of electric car batteries that flummoxed Thomas Edison persists today." *[28]

2.3 Mid to late 20th century: stops and starts

The Story, a Dutch electric car made during World War II

1961 Henney Kilowatt electric car based on the Renault Dauphine

Some European nations during World War II experimented with electric cars, but the technology stagnated. Several ventures were established to build electric cars, such as the Henney Kilowatt. In 1955, the U.S. Air Pollution Control Act helped address the growing emissions problems and this law was later amended to establish regulatory standards for automobiles.*[29] In 1959, American Motors Corporation (AMC) and Sonotone Corporation planned a car to be powered by a "self-charging" battery.*[30] It was to have sintered plate nickel-cadmium batteries.*[31] Nu-Way Industries also showed an experimental electric car with a one-piece plastic body that was to begin production in early 1960.*[30]

Concerns with rapidly decreasing air quality caused by automobiles prompted the U.S. Congress to pass the Electric Vehicle Development Act of 1966 that provided for electric car research by universities and laboratories.*[29] Meanwhile, the Enfield Thunderbolt, an electric car produced after a competition run by the Electrical Board, was won by Enfield Auto, and 100 cars were produced at their factory on the Isle of Wight.*[32] By the late-1960s, the U.S. and Canada Big Three automakers each had electric car development programs. The much smaller AMC partnered with Gulton Industries to develop a new battery based on lithium and use an advanced speed controller.*[33] Although a nickel-cadmium battery was used for an all-electric 1969 Rambler American station wagon, other "plug-in" vehicles were developed with Gulton that included the Amitron and the similar Electron.

The energy crises of the 1970s and 80s brought about renewed interest in the perceived independence that electric cars had from the fluctuations of the hydrocarbon energy market. In the early 1990s, the California Air Resources Board (CARB) began a push for more fuel-efficient, lower-emissions vehicles, with the ultimate goal being a move to zero-emissions vehicles such as electric vehicles.*[2]*[34] In response, automakers developed electric models, including the Chrysler TEVan, Ford Ranger EV pickup truck, GM EV1, and S10 EV pickup, Honda EV Plus hatchback, Nissan Altra EV miniwagon, and Toyota RAV4 EV. These cars were eventually withdrawn from the U.S. market.*[35]

2.4 1990s to present: Revival of interest

Main article: History of the electric vehicle: Revival of interest

The global economic recession in the late 2000s led to increased calls for automakers to abandon fuel-inefficient SUVs, which were seen as a symbol of the excess that caused the recession, in favor of small cars, hybrid cars, and electric cars. California electric automaker Tesla Motors began development in 2004 on the Tesla Roadster, which was first delivered to customers in 2008. As of March 2012, Tesla had sold more than 2,250 Roadsters in at least 31 countries.*[36] The

The Mitsubishi i-MiEV was released for fleet customers in Japan in 2009.

First Nissan Leaf delivered in the U.S. in December 2010.

First deliveries of the Tesla Model S took place in the U.S. in June 2012.

Mitsubishi i MiEV was launched for fleet customers in Japan in July 2009, and for individual customers in April 2010,*[37]*[38]*[39] followed by sales to the public in Hong Kong in May 2010,*[40] and Australia in July 2010 via leasing.*[41] Retail customer deliveries of the Nissan Leaf in Japan and the United States began in December 2010,*[42]*[43] followed in 2011 by several European countries and Canada.*[44]*[45]

In the 2011 State of the Union address, U.S. President Barack Obama expressed an ambitious goal of putting one million plug-in electric vehicles on the roads in the U.S. by 2015.*[46] The objectives include "reducing dependence on oil and ensuring that America leads in the growing electric vehicle manufacturing industry." *[47]

The Smart electric drive, Wheego Whip LiFe, Mia electric, Volvo C30 Electric, and the Ford Focus Electric were launched for retail customers during 2011. The BYD e6, released initially for fleet customers in 2010, began retail sales in Shenzhen, China in October, 2011.*[48] The Bolloré Bluecar was released in December 2011 and deployed for use in the Autolib' carsharing service in Paris.*[49] Leasing to individual and corporate customers began in October 2012 and is limited to the Île-de-France area.*[50]

In February 2011, the Mitsubishi i MiEV became the first electric car to sell more than 10,000 units, including the models badged in Europe as the Citroën C-Zero and Peugeot iOn. Several months later, the Nissan Leaf overtook the i MiEV as the best selling all-electric car ever.*[51]

Models released to the market between 2012 and 2014 include the BMW ActiveE, Coda, Renault Fluence Z.E., Tesla Model S, Honda Fit EV, Toyota RAV4 EV, Renault Zoe, Roewe E50, Mahindra e2o, Chevrolet Spark EV, Fiat 500e, Volkswagen e-Up!, BMW i3, BMW Brilliance Zinoro 1E, Kia Soul EV, Volkswagen e-Golf, Mercedes-Benz B-Class Electric Drive, and Venucia e30. The Nissan Leaf passed the milestone of 50,000 units sold worldwide in February 2013,*[52] and the 100,000 unit mark in mid January 2014.*[53] In June 2014 Tesla Motors announced it was making its patents open source freely available to speed up production of electric cars and spur competition, at a time that electric cars comprised less than 1% of all automobiles sold in the United States.*[54] By early June 2015, the Renault-Nissan Alliance, passed the milestone of 250,000 electric vehicles sold worldwide.*[55]

3 Economics

3.1 Price

Main article: electric vehicle battery § Battery cost and parity

An important goal for electric vehicles is overcoming the disparity between their costs of development, production, and operation, with respect to those of equivalent internal combustion engine vehicles (ICEVs). As of 2013, electric cars are significantly more expensive than conventional internal combustion engine vehicles and hybrid electric vehicles due to the cost of their lithium-ion battery pack.*[56] However, battery prices are coming down about 8% per annum with mass production, and are expected to drop further.*[57]*[58]

Not only the high purchase price is hindering the mass transition from gasoline cars to electric cars, but also the continued subsidization of fossil fuels, such as huge tax breaks and financial help in finding and developing oil fields for oil companies, higher allowed pollution for coal-fired power stations owned by oil refineries, as well as unpriced harm resulting for tailpipe emissions. According to a survey taken by Nielsen for the Financial Times in 2010, around three quarters of American and British car buyers have or would consider buying an electric car, but they are unwilling to pay more for an electric car. The survey showed that 65% of Americans and 76% of Britons are not willing to pay more for an electric car than the price of a conventional car.*[59]

The electric car company Tesla Motors uses laptop -size cells for the battery packs of its electric cars, which are 3 to 4 times cheaper than dedicated electric car battery packs of other auto makers. Dedicated battery packs cost $700–$800 per kilowatt hour, while battery packs using small laptop cells cost about $200. This could drive down the cost of electric cars that use Tesla's battery technology such as the Toyota RAV4 EV, Smart ED and Tesla Model X which announced for 2014.*[60]*[61]*[62] As of June 2012, and based on the three battery size options offered for the Tesla Model S, the New York Times estimated the cost of automotive battery packs between US$400 to US$500 per kilowatt-hour.*[63]

A 2013 study, by the American Council for an Energy-Efficient Economy reported that battery costs came down from US$1,300 per kilowatt hour in 2007 to US$500 per kilowatt hour in 2012. The U.S. Department of Energy has set cost targets for its sponsored battery research of US$300 per kilowatt hour in 2015 and US$125 per kilowatt hour by 2022. Cost reductions of batteries and higher production volumes will allow plug-in electric vehicles to be more competitive with conventional internal combustion engine vehicles.*[64] However, in 2014 manufacturers were already offering battery packs for about $300/kWh.*[65]

Several governments have established policies and economic incentives to overcome existing barriers, promote the sales of electric cars, and fund further development of electric vehicles, batteries and components. Several national and local governments have established tax credits, subsidies, and other incentives to reduce the net purchase price of electric cars and other plug-ins.*[66]*[67]*[68]*[69]

3.2 Maintenance

Electric cars have expensive batteries that must be replaced if they become defective, however the lifetime of said batteries can be very long (many years). Otherwise, electric cars incur very low maintenance costs, particularly in the case of current lithium-based designs. The documentary film *Who Killed the Electric Car?**[70] shows a comparison between the parts that require replacement in gasoline powered cars and EV1s, with the garages stating that they bring the electric cars in every 5,000 mi (8,000 km), rotate the tires, fill the windshield washer fluid and send them back out again.

The Tesla Roadster, launched in 2008, has a range of 244 mi (393 km) and ended production in 2011.

3.3 Running costs

The cost of charging the battery depends on the price paid per kWh of electricity - which varies with location. As of November 2012, a Nissan Leaf driving 500 miles (800 km) per week is estimated to cost US$600 per year in charging costs in Illinois, U.S.,*[71] as compared to US$2,300 per year in fuel costs for an average new car using regular gasoline.*[72]*[73]

The EV1 energy use at 60 mph (97 km/h) was about 16.8 kW-hrs/100 mi (10.4 kW·h/100 km; 205 mpg-e).*[74] The 2011/12 Nissan Leaf uses 21.25 kW·h/100 km (34.20 kW-hrs/100 mi; 100.6 mpg-e) according to the US Environmental Protection Agency.*[75] These differences reflect the different design and utility targets for the vehicles, and the varying testing standards. The energy use greatly depends on the driving conditions and driving style. Nissan estimates that the Leaf's 5-year operating cost will be US$1,800 versus US$6,000 for a gasoline car in the US.*[76] According to Nissan, the operating cost of the Leaf in the UK is 1.75 pence per mile (1.09p per km) when charging at an off-peak electricity rate, while a conventional petrol-powered car costs more than 10 pence per mile (6.25p per km). These estimates are based on a national average of British Petrol Economy 7 rates as of January 2012, and assumed 7 hours of charging overnight at the night rate and one hour in the daytime charged at the Tier-2 daytime rate.*[77]

The following table compares out-of-pocket fuel costs estimated by the U.S. Environmental Protection Agency according to its official ratings for fuel economy (miles per gallon gasoline equivalent in the case of plug-in electric vehicles) for series production all-electric passenger vehicles rated by the EPA as of November 2015,*[78] versus EPA rated most fuel efficient plug-in hybrid with long distance range (second generation Chevrolet Volt), gasoline-electric hybrid car (third generation Toyota Prius),*[79]*[80]*[81] and EPA's average new 2016 vehicle, which has a fuel economy of 25 $\text{mpg}_{\text{-US}}$ (9.4 L/100 km; 30 $\text{mpg}_{\text{-imp}}$).*[78]*[79]

3.4 Mileage costs

Most of the mileage-related cost of an electric vehicle can be attributed to electricity costs of charging the battery pack, and its potential replacement with age, because an electric vehicle has only around five moving parts in its motor, compared to a gasoline car that has hundreds of parts in its internal combustion engine.*[108] To calculate the cost per kilometer of an electric vehicle it is therefore necessary to assign a monetary value to the wear incurred on the battery. With use, the capacity of a battery decreases. However, even an 'end of life' battery which has insufficient capacity has market value as it can be repurposed, recycled or used as a spare.

The Tesla Roadster's very large battery pack is expected to last seven years with typical driving and costs US$12,000 when pre-purchased today.*[109]*[110] Driving 40 miles (64 km) per day for seven years or 102,200 miles (164,500 km) leads to a battery consumption cost of US$0.1174 per 1 mile (1.6 km) or US$4.70 per 40 miles (64 km). The now-defunct company Better Place provided another cost comparison when it anticipated meeting contractual obligations to deliver batteries, as well as clean electricity to recharge the batteries, at a total cost of US$0.08 per 1 mile (1.6 km) in 2010, US$0.04 per mile by 2015 and US$0.02 per mile by 2020.*[111] 40 miles (64 km) of driving would initially cost US$3.20 and fall over time to US$0.80.

3.5 Total cost of ownership

A 2010 report, by J.D. Power and Associates states that it is not entirely clear to consumers the total cost of ownership of battery electric vehicles over the life of the vehicle, and "*there is still much confusion about how long one would have to own such a vehicle to realize cost savings on fuel, compared with a vehicle powered by a conventional internal combustion engine (ICE). The resale value of HEVs and BEVs, as well as the cost of replacing depleted battery packs, are other financial considerations that weigh heavily on consumers' minds.*" *[112]

A study published in 2011, by the Belfer Center, Harvard University, found that the gasoline costs savings of plug-in electric cars over their lifetimes do not offset their higher purchase prices. The study compared the lifetime net present value at 2010 purchase and operating costs for the US market with no government subsidies.*[113]*[114] The study estimated that a PHEV−40 is US$5,377 more expensive than a conventional internal combustion engine, while a battery electric vehicle is US$4,819 more expensive. But assuming that battery costs will decrease and gasoline prices increase over the next 10 to 20 years, the study found that BEVs will be significantly cheaper than conventional cars (US$1,155 to US$7,181 cheaper). PHEVs, will be more expensive than BEVs in almost all comparison scenarios, and more expensive than conventional cars unless battery costs are very low and gasoline prices high. Savings differ because BEVs are simpler to build and do not use liquid fuel, while PHEVs have more complicated power trains and still have gasoline-powered engines.*[113]

3.6 Dealerships reluctance to sell

With the exception of Tesla Motors, almost all new cars in the United States are sold through dealerships, so they play a crucial role in the sales of electric vehicles, and negative attitudes can hinder early adoption of plug-in electric vehicles.*[115]*[116] Dealers decide which cars they want to stock, and a salesperson can have a big impact on how someone feels about a prospective purchase. Sales people have ample knowledge of internal combustion cars while they do not have time to learn about a technology that represents a fraction of overall sales.*[115] As with any new technology, and in the particular case of advanced technology vehicles, retailers are central to ensuring that buyers, especially those switching to a new technology, have the information and support they need to gain the full benefits of adopting this new technology.*[116]

There are several reasons for the reluctance of some dealers to sell plug-in electric vehicles. PEVs do not offer car dealers the same profits as gasoline-powered car. Plug-in electric vehicles take more time to sell because of the explaining required, which hurts overall sales and sales people commissions. Electric vehicles also may require less maintenance, resulting in loss of service revenue, and thus undermining the biggest source of dealer profits, their service departments. According to the National Automobile Dealers Association (NADS), dealers on average make three times as much profit from service as they do from new car sales. However, a NADS spokesman said there was not sufficient data to prove that electric cars would require less maintenance.*[115] According to the New York Times, BMW and Nissan are among the companies whose dealers tend to be more enthusiastic and informed, but only about 10% of dealers are knowledgeable on the new technology.*[115]

A study conducted at the Institute of Transportation Studies (ITS), at the University of California, Davis (UC Davis) published in 2014 found that many car dealers are less than enthusiastic about plug-in vehicles. ITS conducted 43 interviews with six automakers and 20 new car dealers selling plug-in vehicles in California's major metro markets. The study also analyzed national and state-level J.D. Power 2013 Sales Satisfaction Index (SSI) study data on customer satisfaction with new car dealerships and Tesla retail stores. The researchers found that buyers of plug-in electric vehicles were significantly less satisfied and rated the dealer purchase experience much lower than buyers of non-premium conventional cars, while Tesla Motors earned industry-high scores. According to the findings, plug-in buyers expect more from dealers than conventional buyers, including product knowl-

Car dealerships play a crucial role in the sales of plug-in electric vehicles. Shown a Tesla Motors retail store in Washington, D.C.

edge and support that extends beyond traditional offerings.*[116]*[117]

In 2014 Consumer Reports published results from a survey conducted with 19 secret shoppers that went to 85 dealerships in four states, making anonymous visits between December 2013 and March 2014. The secret shoppers asked a number of specific questions about cars to test the salespeople's knowledge about electric cars. The consumer magazine decided to conduct the survey after several consumers who wanted to buy a plug-in car reported to the organization that some dealerships were steering them toward gasoline-powered models. The survey found that not all sales people seemed enthusiastic about making PEV sales; a few outright discouraged it, and even one dealer was reluctant to even show a plug-in model despite having one in stock. And many sales people seemed not to have a good understanding of electric-car tax breaks and other incentives or of charging needs and costs. Consumer Reports also found that when it came to answering basic questions, sales people at Chevrolet, Ford, and Nissan dealerships tended to be better informed than those at Honda and Toyota. The survey found that most of the Toyota dealerships visited recommended against buying a Prius Plug-in and suggested buying a standard Prius hybrid instead. Overall, the secret shoppers reported that only 13 dealers "discouraged sale of EV," with seven of them being in New York. However, at 35 of the 85 dealerships visited, the secret shoppers said sales people recommended buying a gasoline-powered car instead.*[118]

The ITS-Davis study also found that a small but influential minority of dealers have introduced new approaches to better meet the needs of plug-in customers. Examples include marketing carpool lane stickers, enrolling buyers in charging networks, and preparing incentive paperwork for customers. Some dealers assign seasoned sales people as plug-in experts, many of whom drive plug-ins themselves to learn and be familiar with the technology and relate the car's benefits to potential buyers. The study concluded also that carmakers could do much more to support dealers selling PEVs.*[116]

4 Environmental aspects

4.1 Electricity generation for electric cars

A solar energy charging station in North America

Electric cars usually also show significantly reduced greenhouse gas emissions, depending on the method used for electricity generation to charge the batteries.*[2]*[3]

Even when the power is generated using fossil fuels, electric vehicles usually, compared to gasoline vehicles, show significant reductions in overall well-wheel global carbon emissions due to the highly carbon intensive production in mining, pumping, refining, transportation and the efficiencies obtained with gasoline.*[119] Researchers in Germany have claimed that while there is some technical superiority of electric propulsion compared with conventional technology that in many countries the effect of electrification of vehicles' fleet emissions will predominantly be due to regulation rather than technology.*[120] Indeed, electricity production is submitted to emission quotas, while vehicles' fuel propulsion is not, thus electrification shifts demand from a non-capped sector to a capped sector. This means that the emissions of electrical grids can be expected to improve over time as more wind and solar generation is deployed.

Many countries are introducing CO_2 average emissions targets across all cars sold by a manufacturer, with financial penalties on manufacturers that fail to meet these targets. This has created an incentive for manufacturers, especially those selling many heavy or high-performance cars, to introduce electric cars as a means of reducing average fleet CO_2 emissions.*[121]

4.2 Air pollution and carbon emissions

See also: Greenhouse gas emissions in plug-in electric vehicles and Greenhouse gas emissions in plug-in hybrids

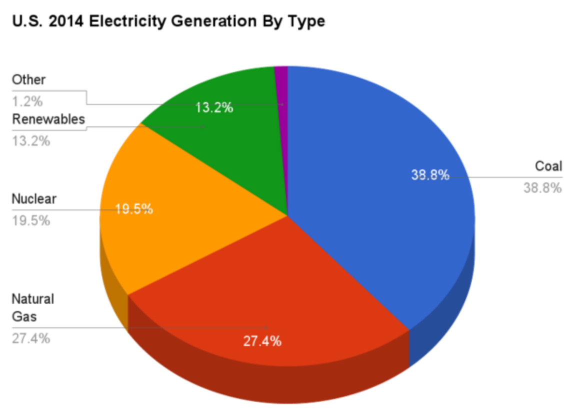
Electric cars have several benefits over conventional internal combustion engine automobiles, including a significant reduction of local air pollution, especially in cities, as they do not emit harmful tailpipe pollutants such as particulates (soot), volatile organic compounds, hydrocarbons, carbon monoxide, ozone, lead, and various oxides of nitrogen.*[122]*[123]*[124] The clean air benefit may only be local because, depending on the source of the electricity used to recharge the batteries, air pollutant emissions may be shifted to the location of the generation plants.*[2] This is referred to as the long tailpipe of electric vehicles.

Nevertheless, introducing EV would come with a major environmental benefits in most (EU) countries, except those relying on old coal fired power plants.*[125] So for example the part of electricity, which is produced with renewable energy is (2014) in Norway 99 percent and in Germany 30 percent.

The amount of carbon dioxide emitted depends on the emission intensity of the power source used to charge the vehicle, the efficiency of the said vehicle and the energy wasted in the charging process. For mains electricity the emission intensity varies significantly per country and within a particular country it will vary depending on demand,*[126] the availability of renewable sources and the efficiency of the fossil fuel-based generation used at a given time.*[125]*[127]

Charging a vehicle using renewable energy (e.g., wind power or solar panels) yields very low carbon footprint-only that to produce and install the generation system (see Energy Returned On Energy Invested.) Even on a fossil-fueled grid, it's quite feasible for a household with a solar panel to produce enough energy to account for their electric car usage, thus (on average) cancelling out the emissions of charging the vehicle, whether or not the panel directly charges it.*[128]

United States



U.S. 2014 electricity generation by type[129]*

The following table compares tailpipe and upstream CO_2 emissions estimated by the U.S. Environmental Protection Agency for all series production model year 2014 all-electric passenger vehicles available in the U.S. market. Since all-electric cars do not produce tailpipe emissions, for comparison purposes the two most fuel efficient plug-in hybrids and the typical gasoline-powered car are included in the table. Total emissions include the emissions associated with the production and distribution of electricity used to charge the vehicle, and for plug-in hybrid electric vehicles, it also includes emissions associated with tailpipe emissions produced from the internal combustion engine. These figures were published by the EPA in October in its 2014 report "*Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends.*" *[130]

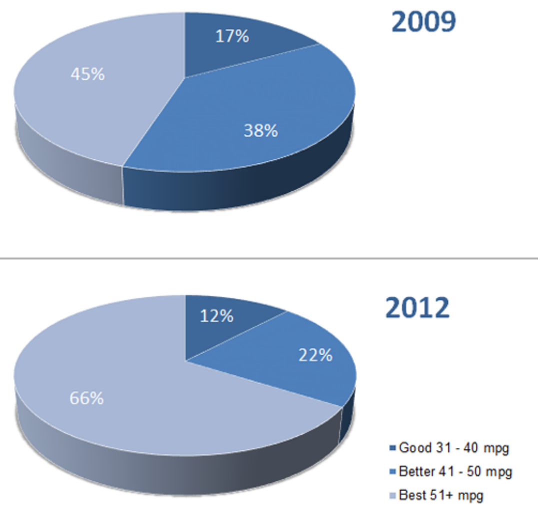
In order to account for the upstream CO_2 emissions associated with the production and distribution of electricity, and since electricity production in the United States varies significantly from region to region, the EPA considered three scenarios/ranges with the low end scenario corresponding to the California powerplant emissions factor, the middle of the range represented by the national average powerplant emissions factor, and the upper end of the range corresponding to the powerplant emissions factor for the Rocky Mountains. The EPA estimates that the electricity GHG emission factors for various regions of the country vary from 346 g CO_2/kWh in California to 986 g CO_2/kWh in the Rockies, with a national average of 648 g CO_2/kWh.*[130] In the case of plug-in hybrids, and since their all-electric range depends on the size of the battery pack, the analysis introduced a utility factor as a projection of the share of miles that will be driven using electricity by an average driver.*[130]

The Union of Concerned Scientists (UCS) published in 2012, a report with an assessment of average greenhouse gas emissions resulting from charging plug-in car batteries considering the full life-cycle (well-to-wheel analysis) and the fuel used to generate electric power by region in the U.S. The study used the Nissan Leaf all-electric car to establish the analysis's baseline. The UCS study expressed the results in terms of miles per gallon instead of the conventional unit of grams of carbon dioxide emissions per year. The study found that in areas where electricity is generated from natural gas, nuclear, or renewable resources such as hydroelectric, the potential of plug-in electric cars to reduce greenhouse emissions is significant. On the other hand, in regions where a high proportion of power is generated from coal, hybrid electric cars produce less CO_2 emissions than plug-in electric cars, and the best fuel efficient gasoline-powered subcompact car produces slightly less emissions than a plug-in car. In the worst-case scenario, the study estimated that for a region where all energy is generated from coal, a plug-in electric car would emit greenhouse gas emissions equivalent to a gasoline car rated at a combined city/highway fuel economy of 30 $\text{mpg}_{\text{-US}}$ (7.8 L/100 km; 36 $\text{mpg}_{\text{-imp}}$). In contrast, in a region that is completely reliant on natural gas, the plug-in would be equivalent to a gasoline-powered car rated at 50 mpg-US (4.7 L/100 km; 60 mpg-imp) combined.*[131]*[132]

The study found that for 45% of the U.S. population, a plug-in electric car will generate lower CO_2 emissions than a gasoline-powered car capable of a combined fuel economy of 50 mpg-US (4.7 L/100 km; 60 mpg-imp), such as the Toyota Prius. Cities in this group included Portland, Oregon, San Francisco, Los Angeles, New York City, and Salt Lake City, and the cleanest cities achieved well-to-wheel emissions equivalent to a fuel economy of 79 mpg-US (3.0 L/100 km; 95 mpg-imp). The study also found that for 37% of the population, the electric car emissions will fall in the range of a gasoline-powered car rated at a combined fuel economy between 41 to 50 mpg-US (5.7 to 4.7 L/100 km; 49 to 60 mpg-imp), such as the Honda Civic Hybrid and the Lexus CT200h. Cities in this group include Phoenix, Arizona, Houston, Miami, Columbus, Ohio and Atlanta, Georgia. An 18% of the population lives in areas where the power supply is more dependent on burning carbon, and emissions will be equivalent to a car rated at a combined fuel economy between 31 to 40 mpg-US (7.6 to 5.9 L/100 km; 37 to 48 mpg-imp), such as the Chevrolet Cruze and Ford Focus. This group includes Denver, Minneapolis, Saint Louis, Missouri, Detroit, and Oklahoma City.*[132]*[133]*[134] The study found that there are no regions in the U.S. where plug-in electric cars will have higher greenhouse gas emissions than the average new compact gasoline engine automobile, and the area with the dirtiest power supply produces CO_2 emissions equivalent to a gasoline-powered car rated 33 mpg-US (7.1 L/100 km; 40 mpg-imp).*[131]

In September 2014, the UCS published an updated analysis of its 2012 report. The 2014 analysis found that 60% of Americans, up from 45% in 2009, live in regions where an all-electric car produce fewer CO_2 equivalent emissions per mile than the most efficient hybrid. The UCS study found two reasons for the improvement. First, electric utilities have adopted cleaner sources of electricity to their mix between the two analysis. Second, electric vehicles have become more efficient, as the average 2013 all-electric vehicle used 0.33 kWh per mile, representing a 5% improvement over 2011 models. Also, some new models are cleaner than the average, such as the BMW i3, which is rated at 0.27 kWh by the EPA. In states with a cleaner mix generation, the gains were larger. The average all-electric car in California went up to 95 mpg-US (2.5 L/100 km) equivalent from 78 mpg-US (3.0 L/100 km) in the 2012 study. States with dirtier generation that rely heavily on coal still lag, such as Colorado, where the average BEV only achieves the same emissions as a 34 mpg-US (6.9 L/100 km; 41 mpg-imp) gasoline-powered car. The author of the 2014 analysis noted that the benefits are not distributed evenly across the U.S. because electric car adoptions is concentrated in the states with cleaner power.*[135]*[136]

One criticism to the UCS analysis and several other that have analyze the benefits of PEVs is that these analysis were made using average emissions rates across regions instead of marginal generation at different times of the day. The former approach does not take into account the generation mix within interconnected electricity markets and shifting load profiles throughout the day.*[137]*[138] An analysis by three economist affiliated with the National Bureau of Economic Research (NBER), published in November 2014, developed a methodology to estimate marginal emissions of electricity demand that vary by location and time of day across the United States. The marginal analysis, applied to plug-in electric vehicles, found that the emissions of charging PEVs vary by region and hours of the day. In some regions, such as the Western U.S. and Texas, CO_2 emissions per mile from driving PEVs are less than those from driving a hybrid car. However, in other regions, such as the Upper Midwest, charging during the recommended hours of midnight to 4 a.m. implies that PEVs generate more emissions per mile than the average car currently on the road.



Change from 2009 to 2012 of the percentage of Americans that live in regions where powering an electric vehicle on the regional electricity grid produces lower global warming emissions than a gasoline car expressed in terms of combined cith/highway fuel economy rating. Source: Union of Concerned Scientists.[139]*

The results show a fundamental tension between electricity load management and environmental goals as the hours when electricity is the least expensive to produce tend to be the hours with the greatest emissions. This occurs because coal-fired units, which have higher emission rates, are most commonly used to meet base-level and off-peak electricity demand; while natural gas units, which have relatively low emissions rates, are often brought on-line to meet peak demand.*[138]

In November 2015, the Union of Concerned Scientists published a new report comparing two battery electric vehicles (BEVs) with similar gasoline vehicles by examining their global warming emissions over their full life-cycle, craddle-to-grave analysis. The two BEVs modeled, midsize and full-size, are based on the two most popular BEV models sold in the United States in 2015, the Nissan LEAF and the Tesla Model S. The study found that all-electric cars representative of those sold today, on average produce less than half the global warming emissions of comparable gasoline-powered vehicles, despite taken into account the higher emissions associated with BEV manufacturing. Considering the regions where the two most popular electric cars are being sold, excess manufacturing emissions are offset within 6 to 16 months of average driving. The study also concluded that driving an average EV results in lower global warming emissions than driving a gasoline car that gets 50 $mpg_{\text{-US}}$ (4.7 L/100 km) in regions covering two-thirds of the U.S. population, up from 45% in 2009. Based on where EVs are being sold in the United States in 2015, the average EV produces global warming emissions equal to a gasoline vehicle with a 68 $mpg_{\text{-US}}$ (3.5 L/100 km) fuel economy rating. The authors identified two main reason for the fact that EV-related emissions have become even lower in many parts of the country since the first study was conducted in 2012. Electricity generation has been getting cleaner, as coal-fired generation has declined while lower-carbon alternatives have increased. In addition, electric cars are becoming more efficient. For example, the Nissan Leaf and the Chevrolet Volt, have undergone improvements to increase their efficiencies compared to the original models launched in 2010, and other even more efficient BEV models, such as the most lightweight and efficient BMW i3, have entered the market.*[139]*[140]

United Kingdom

A study made in the UK in 2008, concluded that electric vehicles had the potential to cut down carbon dioxide and greenhouse gas emissions by at least 40%, even taking into account the emissions due to current electricity generation in the UK and emissions relating to the production and disposal of electric vehicles.*[141]

The savings are questionable relative to hybrid or diesel cars (according to official British government testing, the most efficient European market cars are well below 115 grams of CO_2 per kilometer driven, although a study in Scotland gave 149.5 gCO_2/km as the average for new cars in the UK*[142]), but since UK consumers can select their energy suppliers, it also will depend on how 'green' their chosen supplier is in providing energy into the grid. In contrast to other countries, in the UK a stable part of the electricity is produced by nuclear, coal and gas plants. Therefore, there are only minor differences in the environmental impact over the year.*[125]

Germany

In a worst-case scenario where incremental electricity demand would be met exclusively with coal, a 2009 study conducted by the World Wide Fund for Nature and IZES found that a mid-size EV would emit roughly 200 $g(CO_2)$/km (11 $oz(CO_2)$/mi), compared with an average of 170 $g(CO_2)$/km (9.7 $oz(CO_2)$/mi) for a gasoline-powered compact car.*[143] This study concluded that introducing 1 million EV cars to Germany would, in the best-case scenario, only reduce CO_2 emissions by 0.1%, if nothing is done to upgrade the electricity infrastructure or manage demand.*[143] A more reasonable estimate, relaxing the coal assumption, was provided by Massiani and Weinmann taking into account that the source of energy used for electricity generation would be determined based on the temporal pattern of the additional electricity demand (in other words an increase in electricity consumption at peak hour will activate the marginal technology, while an off peak increase would typically activate other technologies). Their conclusion is that natural gas will provide most of the energy used to reload EV, while renewable energy will not represent more than a few percent of the energy used.*[144]

Volkswagen conducted a life-cycle assessment of its electric vehicles certified by an independent inspection agency. The study found that CO_2 emissions during the use phase of its all-electric VW e-Golf are 99% lower than those of the Golf 1.2 TSI when powers comes from exclusively hydroelectricity generated in Germany, Austria and Switzerland. Accounting for the electric car entire life-cycle, the e-Golf reduces emissions by 61%. When the actual EU-27 electricity mix is considered, the e-Golf emissions are still 26% lower than those of the conventional Golf 1.2 TSI.*[145]

In 2014 in Germany, 28 percent of whole electricity was renewable energy produced in Germany.

France and Belgium

In France and Belgium, which have many nuclear power plants, CO_2 emissions from electric car use would be about 12 g per km (19.2 g per US mile).*[146] Because of the stable nuclear production, the timing of charging electric cars has almost no impact on their environmental footprint.*[125]

Emissions during production

Several reports have found that hybrid electric vehicles, plug-in hybrids and all-electric cars generate more carbon emissions during their production than current conventional vehicles, but still have a lower overall carbon footprint over the full life cycle. The initial higher carbon footprint is due mainly to battery production.*[125] As an example, the Ricardo study estimated that 43 percent of production emissions for a mid-size electric car are generated from the battery production.*[147]

4.3 Environmental impact of manufacturing

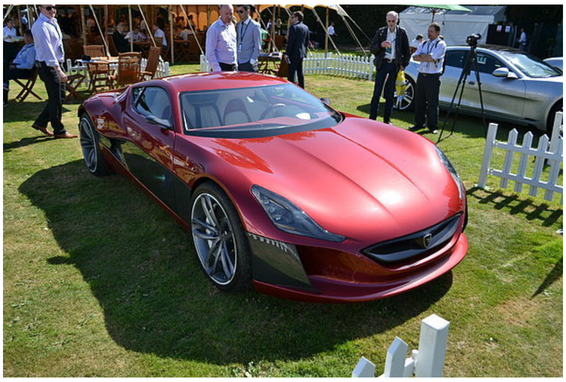
Electric cars are not completely environmentally friendly, and have impacts arising from manufacturing the vehicle. Since battery packs are heavy, manufacturers work to lighten the rest of the vehicle. As a result, electric car components contain many lightweight materials that require a lot of energy to produce and process, such as aluminium and carbon-fiber-reinforced polymers. Electric motors and batteries also add to the energy of electric-car manufacture.*[148] Additionally, the magnets in the motors of many electric vehicles contain rare earth metals. In a study released in 2012, a group of MIT researchers calculated that global mining of two rare Earth metals, neodymium and dysprosium, would need to increase 700% and 2600%, respectively, over the next 25 years to keep pace with various green-tech plans.*[149] Substitute strategies do exist, but deploying them introduces trade-offs in efficiency and cost.*[148] The same MIT study noted that the materials used in batteries are also harmful to the environment.*[150] Compounds such as lithium, copper, and nickel are mined from the Earth and processed in a manner that demands energy and can release toxic components. In regions with poor legislature, mineral exploitation can even further extend risks. The local population may be exposed to toxic substances through air and groundwater contamination.*[148]

A paper published in the Journal of Industrial Ecology named *"Comparative environmental life cycle assessment of conventional and electric vehicles"* begins by stating that it is important to address concerns of problem-shifting.*[151] The study highlighted in particular the toxicity of the electric car's manufacturing process compared to conventional petrol/diesel cars. It concludes that the global warming potential of the process used to make electric cars is twice that of conventional cars. The study also finds that electric cars do not make sense if the electricity they consume is produced predominately by coal-fired power plants.*[152] However, the study was later corrected by the authors due to them overstating the environmental damage of electric vehicles in the first paper; many of the components of electric vehicles had been incorrectly modelled, and the European power grids were cleaner in many respects than their paper had assumed.*[153]

5 Performance

5.1 Acceleration and drivetrain design

Electric motors can provide high power-to-weight ratios, and batteries can be designed to supply the large currents to support these motors. Electric motors have very flat torque curves down to zero speed. For simplicity and reliability, many electric cars use fixed-ratio gearboxes and have no clutch.



Rimac Concept One, electric supercar, since 2013. 0 to 100 km/h in 2.8 seconds, 1088 hp

Although some electric vehicles have very small motors, 15 kW (20 hp) or less and therefore have modest acceleration, many electric cars have large motors and brisk acceleration. In addition, the relatively constant torque of an electric motor, even at very low speeds tends to increase the acceleration performance of an electric vehicle relative to that of the same rated motor power internal combustion engine.

Electric vehicles can also use a direct motor-to-wheel configuration which increases the amount of available power. Having multiple motors connected directly to the wheels allows for each of the wheels to be used for both propulsion and as braking systems, thereby increasing traction.*[154]*[155]*[156] When not fitted with an axle, differential, or transmission, electric vehicles have less drivetrain rotational inertia.

For example, the Venturi Fetish delivers supercar acceleration despite a relatively modest 220 kW (295 hp), and top speed of around 160 km/h (100 mph). Some DC-motor-equipped drag racer EVs have simple two-speed manual transmissions to improve top speed.*[157] The Tesla Roadster 2.5 Sport can accelerate from 0 to 97 km/h (0 to 60 mph) in 3.7 seconds with a motor rated at 215 kW (288 hp).*[158] The Tesla Model S P90D currently holds the world record for the quickest production electric car to do 402 m (1⁄4 mi), which it did in 10.9 seconds.*[159] And the Wrightspeed X1 prototype created by Wrightspeed Inc is the worlds fastest street legal electric car to accelerate from 0 to 97 km/h (0 to 60 mph), which it does in 2.9 seconds.*[160]*[161] The electric supercar Rimac Concept One can go from 0–100 km/h (0–62 mph) in 2.8 seconds using 811 kW (1,088 hp).

6 Energy efficiency

Main articles: Fuel efficiency, Electrical efficiency, Thermal efficiency and Energy conversion efficiency

Internal combustion engines are relatively inefficient at converting on-board fuel energy to propulsion as most of the energy is wasted as heat. On the other hand, electric motors are more efficient in converting stored energy into driving a vehicle, and electric drive vehicles do not consume energy while at rest or coasting, and some of the energy lost when braking is captured and reused through regenerative braking, which captures as much as one fifth of the energy normally lost during braking.*[2]*[162] Typically, conventional gasoline engines effectively use only 15% of the fuel energy content to move the vehicle or to power accessories, and diesel engines can reach on-board efficiencies of 20%, while electric drive vehicles have on-board efficiency of around 80%.*[162]

Production and conversion electric cars typically use 10 to 23 kW·h/100 km (0.17 to 0.37 kW·h/mi).*[74]*[163] Approximately 20% of this power consumption is due to inefficiencies in charging the batteries. Tesla Motors indicates that the vehicle efficiency (including charging inefficiencies) of their lithium-ion battery powered vehicle is 12.7 kW·h/100 km (0.21 kW·h/mi) and the well-to-wheels efficiency (assuming the electricity is generated from natural gas) is 24.4 kW·h/100 km (0.39 kW·h/mi).*[164]

6.1 Cabin heating and cooling

Electric vehicles generate very little waste heat and resistance electric heat may have to be used to heat the interior of the vehicle if heat generated from battery charging/discharging cannot be used to heat the interior.

While heating can be simply provided with an electric resistance heater, higher efficiency and integral cooling can be obtained with a reversible heat pump (this is currently implemented in the hybrid Toyota Prius). Positive Temperature Coefficient (PTC) junction cooling*[165] is also attractive for its simplicity —this kind of system is used for example in the Tesla Roadster.

To avoid draining the battery and thus reducing the range, some models allow the cabin to heated while the car is plugged in. For example, the Nissan Leaf, the Mitsubishi i-MiEV and the Tesla Model S can be pre-heated while the vehicle is plugged in.*[166]*[167]*[168]

Some electric cars, for example the Citroën Berlingo Electrique, use an auxiliary heating system (for example gasoline-fueled units manufactured by Webasto or Eberspächer) but sacrifice "green" and "Zero emissions" credentials. Cabin cooling can be augmented with solar power, most simply and effectively by inducting outside air to avoid extreme heat buildup when the vehicle is closed and parked in the sunlight (such cooling mechanisms are available for conventional vehicles, in some cases as aftermarket kits). Two models of the 2010 Toyota Prius include this feature as an option.*[169]

7 Safety

The safety issues of BEVs are largely dealt with by the international standard ISO 6469. This document is divided in three parts dealing with specific issues:

- On-board electrical energy storage, i.e. the battery
- Functional safety means and protection against failures
- Protection of persons against electrical hazards.

7.1 Risk of fire

Main article: Plug-in electric vehicle fire incidents

Lithium-ion batteries may suffer thermal runaway and

Frontal crash test of a Volvo C30 DRIVe Electric to assess the safety of the battery pack

cell rupture if overheated or overcharged, and in extreme cases this can lead to combustion.*[170] Several plug-in electric vehicle fire incidents have taken place since the introduction of mass-production plug-in electric vehicles in 2008. Most of them have been thermal runaway incidents related to their lithium-ion battery packs, and have involved the Zotye M300 EV, Chevrolet Volt, Fisker Karma, BYD e6, Dodge Ram 1500 Plug-in Hybrid, Toyota Prius Plug-in Hybrid, Mitsubishi i-MiEV and Outlander P-HEV. As of November 2013, four post-crash fires associated with the batteries of all-electric cars —involving one BYD e6 and three Tesla Model S cars— have been reported.

The first modern crash-related fire was reported in China in May 2012, after a high-speed car crashed into a BYD e6 taxi in Shenzhen.*[171] The second reported incident occurred in the United States in October 1, 2013, when a Tesla Model S caught fire after the electric car hit metal debris on a highway in Kent, Washington state, and the debris punctured one of 16 modules within the battery pack.*[172]*[173] A second reported fire occurred on October 18, 2013 in Merida, Mexico. In this case the vehicle was being driven at high speed through a roundabout and crashed through a wall and into a tree. On November 6, 2013, a Tesla Model S being driven on Interstate 24 near Murfreesboro, Tennessee caught fire after it struck a tow hitch on the roadway, causing damage beneath the vehicle.*[174]

In the United States, General Motors ran in several cities a training program for firefighters and first responders to demonstrate the sequence of tasks required to safely disable the Chevrolet Volt's powertrain and its 12 volt electrical system, which controls its high-voltage components, and then proceed to extricate injured occupants. The Volt's high-voltage system is designed to shut down automatically in the event of an airbag deployment, and to detect a loss of communication from an airbag control module.*[175]*[176] GM also made available an Emergency Response Guide for the 2011 Volt for use by emergency responders. The guide also describes methods of disabling the high voltage system and identifies cut zone information.*[177] Nissan also published a guide for first responders that details procedures for handling a damaged 2011 Leaf at the scene of an accident, including a manual high-voltage system shutdown, rather than the automatic process built-in the car's safety systems.*[178]*[179]

7.2 Vehicle safety

Great effort is taken to keep the mass of an electric vehicle as low as possible to improve its range and endurance. However, the weight and bulk of the batteries themselves usually makes an EV heavier than a comparable gasoline vehicle, reducing range and leading to longer braking distances. However, in a collision, the occupants of a heavy vehicle will, on average, suffer fewer and less serious injuries than the occupants of a lighter vehicle; therefore, the additional weight brings safety benefits*[180] despite having a negative effect on the car's performance. *[181] They also use up interior space if packaged ineffectively. If stored under the passenger cell, not only is this not the case, they also lower the vehicles's center of gravity, increasing driving stability, thereby lowering the risk of an accident through loss of control. An accident in a 2,000 lb (900 kg) vehicle will on average cause about 50% more injuries to its occupants than a 3,000 lb (1,400 kg) vehicle.*[182] In a single car accident, and for the other car in a two car accident, the increased mass causes an increase in accelerations and hence an increase in the severity of the accident.

Some electric cars use low rolling resistance tires, which typically offer less grip than normal tires.*[183]*[184]*[185] Many electric cars have a small, light and fragile body, though, and therefore offer inadequate safety protection. The Insurance Institute for Highway Safety in America had condemned the use of low speed vehicles and "mini trucks," referred to as neighborhood electric vehicles (NEVs) when powered by electric motors, on public roads.*[186] Mindful of this, several companies (Tesla Motors, BMW) have succeeded in keeping the body light, while making it very strong.

7.3 Hazard to pedestrians

See also: Electric vehicle warning sounds

At low speeds, electric cars produced less roadway noise as compared to vehicles propelled by internal combustion engines. Blind people or the visually impaired consider the noise of combustion engines a helpful aid while crossing streets, hence electric cars and hybrids could pose an unexpected hazard.*[187]*[188] Tests have shown that this is a valid concern, as vehicles operating in electric mode can be particularly hard to hear below 20 mph (30 km/h) for all types of road users and not only the visually impaired. At higher speeds, the sound created by tire friction and the air displaced by the vehicle start to make sufficient audible noise.*[188]

The Government of Japan, the U.S. Congress, and the European Parliament passed legislation to regulate the minimum level of sound for hybrids and plug-in electric vehicles when operating in electric mode, so that blind people and other pedestrians and cyclists can hear them coming and detect from which direction they are approaching.*[188]*[189]*[190]*[191] The Nissan Leaf was the first electric car to use Nissan's Vehicle Sound for Pedestrians system, which includes one sound for forward motion and another for reverse.*[192]*[193] As of January 2014, most of the hybrids and plug-in electric and hybrids available in the United States, Japan and Europe make warning noises using a speaker system. The Tesla Model S is one of the few electric cars without warning sounds, because Tesla Motors will await until regulations are enacted.*[194] Volkswagen and BMW also decided to add artificial sounds to their electric drive cars only when required by regulation.*[195]

Several anti-noise and electric car advocates have opposed the introduction of artificial sounds as warning for pedestrians, as they argue that the proposed system will only increase noise pollution.

8 Controls

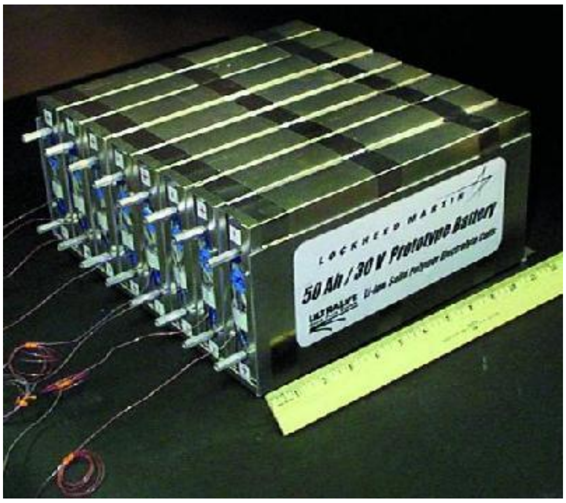
Presently most EV manufacturers do their best to emulate the driving experience as closely as possible to that of a car with a conventional automatic transmission that motorists are familiar with. Most models therefore have a PRNDL selector traditionally found in cars with automatic transmission despite the underlying mechanical differences. Push buttons are the easiest to implement as all modes are implemented through software on the vehicle's controller.

Even though the motor may be permanently connected to the wheels through a fixed-ratio gear and no parking pawl may be present the modes "P" and "N" will still be provided on the selector. In this case the motor is disabled in "N" and an electrically actuated hand brake provides the "P" mode.

In some cars the motor will spin slowly to provide a small amount of creep in "D", similar to a traditional automatic.*[196]

When the foot is lifted from the accelerator of an ICE, engine braking causes the car to slow. An EV would coast under these conditions, but applying mild regenerative braking instead provides a more familiar response and recharges the battery somewhat. Selecting the L mode will increase this effect for sustained downhill driving, analogous to selecting a lower gear. These features also reduce the use of the conventional brakes, significantly reducing wear and tear and maintenance costs as well as improving vehicle range.

9 Batteries



Prototypes of 75 watt-hour/kilogram lithium-ion polymer battery. Newer lithium-ion cells can provide up to 130 W·h/kg and last through thousands of charging cycles.

Main article: Electric vehicle battery

While most current highway-speed electric vehicle designs focus on lithium-ion and other lithium-based variants a variety of alternative batteries can also be used. Lithium-based batteries are often chosen for their high power and energy density but have a limited shelf life and cycle lifetime which can significantly increase the running costs of the vehicle. Variants such as Lithium iron phosphate and Lithium-titanate attempt to solve the durability issues with traditional lithium-ion batteries.

Other battery types include lead acid batteries which are still the most used form of power for most of the electric vehicles used today. The initial construction costs are significantly lower than for other battery types, but the power to weight ratio is poorer than other designs,*[197] Nickel metal hydride (NiMH) which are somewhat heavier and less efficient than lithium ion, but also cheaper. Several other battery chemistries are in development such as zinc-air battery which could be much lighter, and liquid batteries that might be rapidly refilled, rather than recharged, are also under development.

9.1 Range

The range of an electric car depends on the number and type of batteries used. The weight and type of vehicle, and the performance demands of the driver, also have an impact just as they do on the range of traditional vehicles. Range may also significantly be reduced in cold weather. The List of electric cars currently available has a column with range information for electric cars sold worldwide.

The Tesla Roadster can travel 245 miles (394 km) per charge;*[200] more than double that of prototypes and evaluation fleet cars currently on the roads.*[201]

Electric cars are virtually universally fitted with an expected range display. This may take into account many factors, including battery charge, the recent average power use, the ambient temperature, driving style, air conditioning system, route topography etc. to come up with an estimated driving range. However, since factors can vary over the route, the estimate can vary from the actual achieved range. People can thus be concerned that they would run out of energy from their battery before reaching their destination, a worry known as range anxiety.

The display allows the driver able to make informed choices about driving speed and whether to, perhaps briefly, stop at a charging point en route to ensure that they have enough charge that they arrive at their destination successfully.

9.2 Charging

Home charging

Most cars with internal combustion engines can be considered to have indefinite range, as they can be refueled very quickly. Electric cars typically have less maximum range on one charge than cars powered directly by fossil fuels, and they can take considerable time to recharge. However, they can be charged at home overnight, which fossil fueled cars cannot. 71% of all car drivers in America drive less than 40 miles (64 km) per day, and require only a relatively quick topping up.*[202]

Fast charging

However, most vehicles also support much faster charging, where a suitable power supply is available. Therefore, for long distance travel, in the US and elsewhere, there has been the installation of DC Fast Charging stations with high-speed charging capability from three-phase industrial outlets so that consumers could recharge the 100-200+ mile battery of their electric vehicle to 80 percent in about 30 minutes.*[7]*[8]*[9] Although charging at these stations is still relatively time consuming compared to refueling, in practice it often meshes well with a normal driving pattern, where driving is usually done for a few hours before stopping and resting and drinking or eating; this gives the car a chance to be charged.*[203]

The Tesla Roadster can be fully recharged in about 3.5 hours from a 220-volt, 70-amp outlet which can be installed in a home.*[204] But using a European standard 220-volt, 16-amp outlet a full charge will take more than 15 hours. However, the more common Tesla Model S can be fast charged from a proprietary DC rapid-charging station that provides up to 135 kW of power, giving 85 kWh vehicles an additional 180 mi (290 km) of range in about 30 minutes.

As of December 2013, Estonia is the first and only country that had deployed an EV charging network with nationwide coverage, with fast chargers available along highways at a minimum distance of between 40 to 60 km (25 to 37 mi), and a higher density in urban areas.*[205]*[206]*[207] DC Fast Chargers are going to be installed at 45 BP and ARCO locations and will be made available to the public as early as March 2011.*[208] The EV Project will deploy charge infrastructure in 16 cities and major metropolitan areas in six states.*[209]*[210] Nissan has announced that 200 of its dealers in Japan will install fast chargers for the December 2010 launch of its Leaf EV, with the goal of having fast chargers everywhere in Japan within a 25-mile radius.*[211]

Battery swapping

The BMW i3 has an optional gasoline-powered range extender engine

Further information: Battery swapping

Another way to extend the limited range of electric vehicles is by battery swapping. An EV can go to a battery switch station and swap a depleted battery with a fully charged one in a few minutes. In 2011, Better Place deployed the first modern commercial application of the battery switching model, but due to financial difficulties, the company filed for bankruptcy in May 2013.*[212]*[213]*[214]*[215]

Tesla Motors designed its Model S to allow fast battery swapping.*[216] In June 2013, Tesla announced their goal to deploy a battery swapping station in each of its supercharging stations. At a demonstration event Tesla showed that a battery swap operation with the Model S takes just over 90 seconds, about half the time it takes to refill a gasoline-powered car.*[217]*[218] The first stations are planned to be deployed along Interstate 5 in California where, according to Tesla, a large number of Model S sedans make the San Francisco-Los Angeles trip regularly. These will be followed by the Washington, DC to Boston corridor. Each swapping station will cost US$500,000 and will have about 50 batteries available without requiring reservations. The service would be offered for the price of about 15 US gallons (57 l; 12 imp gal) of gasoline at the current local rate, around US$60 to US$80 at June 2013 prices.*[217]

Range extension

A similar idea is that of the range-extension trailer which is attached only when going on long trips. The trailers can either be owned or rented only when necessary.*[219]

BMW i is offering a built-in gasoline-powered range extender engine as an option for its BMW i3 all-electric car.*[220] The range-extender option will cost an additional US$3,850 in the United States,*[221] an additional €4,710 (~ US$6,300) in France,*[222] and €4,490 (~ US$6,000) in the Netherlands.*[223]

Panoramic view of Tesla supercharger rapid charging station in Tejon Ranch, California

9.3 Lifespan

Battery life should be considered when calculating the extended cost of ownership, as all batteries eventually wear out and must be replaced. The rate at which they expire depends on the type of battery and how they are used —many types of batteries are damaged by depleting them beyond a certain level. Lithium-ion batteries degrade faster when stored at higher temperatures.

A full replacement battery is relatively costly. With technological advances there are now recycle options available

(“Maintenance and Safety of Electric Vehicles”), and a battery that is no longer capable of delivering sufficient range nevertheless has significant trade-in value.

Although there are times when batteries do fail the electric vehicles batteries are designed to last for the expected life of the vehicle. Failure rate of some electric vehicles batteries already on the road are as low as 0.003%. There is also high mileage warranties on the electric vehicle batteries. Several manufactures offer up to eight year and one hundred thousand mile warranties on the batteries alone.*[224]

9.4 Future

Lithium availability

The Salar de Uyuni in Bolivia is one of the largest known lithium reserves in the world.[225]*[226]*

See also: Rare earth metals availability and supply security

Many electric cars use a lithium-ion battery and an electric motor which uses rare earth elements. The demand for lithium, heavy metals, and other specific elements (such as neodymium, boron and cobalt) required for the batteries and powertrain is expected to grow significantly due to the future sales increase of plug-in electric vehicles in the mid and long term.*[227]*[228] Some of the largest world reserves of lithium and other rare metals are located in countries with strong resource nationalism, unstable governments or hostility to U.S. interests, raising concerns about the risk of replacing dependence on foreign oil with a new dependence on hostile countries to supply strategic materials.*[225]*[227]*[228]*[229] It is estimated that there are sufficient lithium reserves to power 4 billion electric cars.*[230]*[231]

Other methods of energy storage

Experimental supercapacitors and flywheel energy storage devices offer comparable storage capacity, faster charging, and lower volatility. They have the potential to overtake batteries as the preferred rechargeable storage for EVs.*[232]*[233] The FIA included their use in its sporting regulations of energy systems for Formula One race vehicles in 2007 (for supercapacitors) and 2009 (for flywheel energy storage devices).

Solar cars

Main article: Solar vehicle

Solar cars are electric vehicles powered completely or significantly by direct solar energy, usually, through photovoltaic (PV) cells contained in solar panels that convert the sun's energy directly into electric energy.

10 Infrastructure

10.1 Charging station

Charging station at Rio de Janeiro, Brazil. This station is run by Petrobras and uses solar energy.

Main article: Charging station

Batteries in BEVs must be periodically recharged (see also Replacing, above).

Unlike vehicles powered directly by fossil fuels, BEVs are most commonly and conveniently charged from the power grid overnight at home, without the inconvenience of having to go to a filling station. Charging can also be done using a street or shop charging station.

The electricity on the grid is in turn generated from a variety of sources; such as coal, hydroelectricity, nuclear and others. Power sources such as roof top photovoltaic solar cell panels, micro hydro or wind may also be used and are promoted because of concerns regarding global warming.

As part of its commitment to environmental sustainability, the Dutch government initiated a plan to establish over 200 recharging stations for electric vehicles across the country by 2015. The rollout will be undertaken by Switzerland-based power and automation company ABB and Dutch startup Fastned, and will aim to provide at least one station every 50 kilometres (31 miles) for the Netherlands' 16 million residents.*[234]

Reports emerged in late July 2013 of a significant conflict between the companies responsible for the two types of charging machines. The Japanese-developed CHAdeMO standard is favored by Nissan, Mitsubishi, and Toyota, while the Society of Automotive Engineers' (SAE) International J1772 Combo standard is backed by GM, Ford, Volkswagen, and BMW. Both are direct-current quick-charging systems designed to charge the battery of an electric vehicle to 80 percent in approximately 20 minutes, but the two systems are completely incompatible. In light of an ongoing feud between the two companies, experts in the field warned that the momentum of the electric vehicle market will be severely affected.*[235]*[236] Richard Martin, editorial director for clean technology marketing and consultant firm Navigant Research, stated:

> Fast charging, however and whenever it gets built out, is going to be key for the development of a mainstream market for plug-in electric vehicles. The broader conflict between the CHAdeMO and SAE Combo connectors, we see that as a hindrance to the market over the next several years that needs to be worked out.*[236]

Newer cars and prototypes are looking at ways of dramatically reducing the charging times for electric cars. The BMW i3 for example, can charge 0-80% of the battery in under 30 minutes in rapid charging mode.*[237] The superchargers developed by Tesla Motors provided up to 130 kW of charging, allowing a 50% charge in 20 minutes. Considering the size of the battery, that translated to approx. 212 km of range.

10.1.1 US charging standards

Around 1998 the California Air Resources Board classified levels of charging power that have been codified in title 13 of the California Code of Regulations, the U.S. 1999 National Electrical Code section 625 and SAE International standards. Four standards were developed, termed AC Level 1, AC Level 2, AC Level 3 charging, and Combo Charging System (CCS).

> * or potentially 208 V × 37 A, out of the strict specification but within circuit breaker and connector/cable power limits. Alternatively, this voltage would impose a lower power rating of 6.7 kW at 32 A.

More recently the term "Level 3" has also been used by the SAE J1772 Standard Committee for a possible future higher-power AC fast charging standard.*[240] To distinguish from Level 3 DC fast charging, this would-be standard is written as "Level 3 AC". SAE has not yet approved standards for either AC or DC Level 3 charging.*[241]

As of June 2012, some electric cars provide charging options that do not fit within the older California "Level 1, 2, and 3 charging" standard, with its top charging rate of 40 A. For example, the Tesla Roadster may be charged at a rate up to 70 A (16.8 kW) with a wall-mounted charger.*[242]

For comparison in Europe the IEC 61851-1 charging modes are used to classify charging equipment. The provisions of IEC 62196 charging modes for conductive charging of electric vehicles include Mode 1 (max. 16 A / max. 250 V AC. or 480 V three-phase), Mode 2 (max. 32 A / max. 250 V AC or 480 V three-phase), Mode 3 (max. 63 A (70 A U.S.) / max. 690 V AC or three-phase) and Mode 4 (max. 400 A / max. 600 V DC).*[243]

10.1.2 Connectors

Most electric cars have used conductive coupling to supply electricity for recharging after the California Air Resources Board settled on the SAE J1772−2001 standard*[244] as the charging interface for electric vehicles in California in June 2001.*[245] In Europe, the ACEA has decided to use the Type 2 connector from the range of IEC_62196 plug types for conductive charging of electric vehicles in the European Union as the Type 1 connector (SAE J1772-2009) does not provide for three-phase charging.*[246]

Another approach is inductive charging using a non-conducting "paddle" inserted into a slot in the car. Delco Electronics developed the Magne Charge inductive charging system around 1998 for the General Motors EV1 and it was also used for the Chevrolet S-10 EV and Toyota RAV4 EV vehicles.

10.1.3 Charging time

More electrical power to the car reduces charging time. Power is limited by the capacity of the grid connection, and, for level 1 and 2 charging, by the power rating of the car's on-board charger. A normal household outlet is between 1.5 kW (in the US, Canada, Japan, and other countries with 110 volt supply) to 3 kW (in countries with 230 V supply). The main connection to a house may sustain 10, 15 or even 20 kW in addition to "normal" domestic loads—although, it would be unwise to use all the apparent capability—and special wiring can be installed to use this.

As examples of on-board chargers, the Nissan Leaf at launch has a 3.3 kW charger*[247] and the Tesla Roadster can accept up to 16.8 kW (240 V at 70 A) from the

Smart ED charging from a Level 2 station

High Power Wall Connector.*[242] These power numbers are small compared to the effective power delivery rate of an average petrol pump, about 5,000 kW.

10.2 Vehicle-to-grid: uploading and grid buffering

Main article: Vehicle-to-grid
See also: Economy 7 and load balancing (electrical power)

A Smart grid allows BEVs to provide power to the grid, specifically:

- During peak load periods, when the cost of electricity can be very high. These vehicles can then be recharged during off-peak hours at cheaper rates while helping to absorb excess night time generation. Here the batteries in the vehicles serve as a distributed storage system to buffer power.
- During blackouts, as an emergency backup supply.

Eliica prototype

The full electric Formula Student car of the Eindhoven University of Technology

11 Hobbyists and conversions

Hobbyists often build their own EVs by converting existing production cars to run solely on electricity. There is a cottage industry supporting the conversion and construction of BEVs by hobbyists.*[248] Universities such as the University of California, Irvine even build their own custom electric or hybrid-electric cars from scratch.

Short-range battery electric vehicles can offer the hobbyist comfort, utility, and quickness, sacrificing only range. Short-range EVs may be built using high-performance lead–acid batteries, using about half the mass needed for a 100 to 130 km (60 to 80 mi) range. The result is a vehicle with about a 50 km (30 mi) range, which, when designed with appropriate weight distribution (40/60 front to rear), does not require power steering, offers exceptional acceleration in the lower end of its operating range, and is freeway capable and legal. But their EVs are expensive due to the higher cost for these higher-performance batteries. By including a manual transmission, short-range EVs can obtain both better performance and greater efficiency than the single-speed EVs developed by major manufacturers. Unlike the converted golf carts used for neighborhood electric vehicles, short-range EVs may be operated on typical suburban throughways (where 60–80 km/h / 35-50 mph speed limits are typical) and can keep up with traffic typical on such roads and the short "slow-lane" on-and-off segments of freeways common in suburban areas.

Faced with chronic fuel shortage on the Gaza Strip, Palestinian electrical engineer Waseem Othman al-Khozendar invented in 2008 a way to convert his car to run on 32 electric batteries. According to al-Khozendar, the batteries can be charged with US$2 worth of electricity to drive from 180 to 240 km (110 to 150 mi). After a 7-hour charge, the car should also be able to run up to a speed of 100 km/h (60 mph).*[249]*[250]

Japanese Professor Hiroshi Shimizu from Faculty of Environmental Information of the Keio University created an electric limousine: the Eliica (Electric Lithium-Ion Car) has eight wheels with electric 55 kW hub motors (8WD) with an output of 470 kW and zero emissions, a top speed of 370 km/h (230 mph), and a maximum range of 320 km (200 mi) provided by lithium-ion batteries.*[251] However, current models cost approximately US$300,000, about one third of which is the cost of the batteries.

In 2008, several Chinese manufacturers began marketing lithium iron phosphate (LiFePO
4) batteries directly to hobbyists and vehicle conversion shops. These batteries offered much better power-to-weight ratios allowing vehicle conversions to typically achieve 75 to 150 mi (120 to 240 km) per charge. Prices gradually declined to approximately US$350 per kW·h by mid-2009. As the LiFePO
4 cells feature life ratings of 3,000 cycles, compared to typical lead acid battery ratings of 300 cycles, the life expectancy of LiFePO
4 cells is around 10 years. This has led to a resurgence in the number of vehicles converted by individuals. LiFePO
4 cells do require more expensive battery management and charging systems than lead acid batteries.

12 Racing

Main article: Electric motorsport

Electric drag racing is a sport where electric vehicles start from standstill and attempt the highest possible speed over a short given distance.*[252] They sometimes race and usually beat gasoline sports cars. Organizations such as NEDRA keep track of records worldwide using certified equipment.

At the Formula Student competition at the Silverstone Circuit in July 2013, the electric powered car of the ETH Zurich won against all cars with internal combustion engines. It is believed to be the first time that an electric vehicle has beaten cars powered by combustion engines in any accredited motorsport competition.*[253]

Formula E racing car

Formula E, officially the **FIA Formula E Championship**, is a class of auto racing, sanctioned by the Fédération Internationale de l'Automobile (FIA), and is the highest class of competition for one-make, single-seater, electrically powered racing cars.*[254] The series was conceived in 2012, and the inaugural championship started in Beijing on 13 September 2014.*[255]

In 2015, an electric car won all places of the Pikes Peak International Hill Climb. Already in 2014, electric cars had won first and second place.*[256]*[257]*[258]

13 Politics

Electric vehicles provide for less dependence on foreign oil, which for the United States and other developed or emerging countries is cause for concern about vulnerability to oil price volatility and supply disruption.*[2]*[5]*[6] Also for many developing countries, and particularly for the poorest in Africa, high oil prices have an adverse impact on their balance of payments, hindering their economic growth.*[259]*[260]

14 Currently available electric cars

Main article: List of electric cars currently available

14.1 Highway capable

Main article: List of production battery electric vehicles
See also: Plug-in electric vehicle and list of modern production plug-in electric vehicles
As of September 2015, there are over 30 models of highway-capable all-electric passenger cars and utility vans available in the market for retail sales. Until the early 2010s, most electric vehicles in the world roads are low-speed, low-range neighborhood electric vehicles (NEVs) or electric quadricycles. Pike Research estimated there were almost 479,000 NEVs on the world roads in 2011.*[262] The two largest NEV markets in 2011 were the United States, with 14,737 units sold, and France, with 2,231 units.*[263] The Renault Twizy all-electric heavy quadricycle, launched in Europe in March

As of November 2015, the GEM is among the world's top selling neighborhood electric vehicle, with more than 50,000 units sold since 1998.[261]*

2012 and with global sales of 9,020 units through December 2012,*[264] became the best selling plug-in electric vehicle in Europe for 2012.*[265] As of June 2015, global Twizy sales totaled 15,786 units.*[266] Just in China, a total of 200,000 low-speed small electric cars were sold in 2013, most of which are powered by lead-acid batteries.*[267] As of October 2015, the GEM neighborhood electric vehicle was the market leader in North America, with global sales of more than 50,000 units since 1998.*[261]

The Nissan Leaf is the world's all-time best selling pure electric car. Global Leaf sales passed the 200,000 unit milestone by early December 2015, five years after its introduction.[11]*

By mid-September 2015, about 620,000 highway-capable all-electric passenger cars and light utility vehicles have been sold worldwide out of total global sales of one million plug-in electric cars.*[10] The Renault-Nissan Alliance is the leading electric vehicle manufacturer with global sales of over 274,000 all-electric vehicles delivered since December 2010, representing about half of the global light-duty all-electric market segment.*[268] Ranking second is Tesla Motors with about 96,000 electric cars sold between 2008 and October 2015.*[269]*[270]*[271]*[272] Mitsubishi Motors is the third best selling all-electric vehicle manufacturer, with global sales of over 50,000 all-electric vehicles between July 2009 and early March 2015, including the rebadged variants Peugeot iOn and Citroën C-Zero sold in Europe; and over 6,200 Mitsubishi Minicab MiEV all-electric utility vans and trucks sold in Japan through December 2014.*[273]*[274]*[275]*[276] Next is BMW with over 34,000 i3s sold through September 2015, including the REx models.*[277]*[278]*[279]

The world's top selling highway legal electric car is the Nissan Leaf, released in December 2010 and sold in 46 countries, with global sales of over 200,000 units by early December 2015.*[11]*[294] Ranking second, is the Tesla Model S, with global deliveries of about 100,000 units also by early December 2015.*[11] The Renault Kangoo Z.E. utility van is the leader of the light-duty all-electric segment with global sales of over 19,800 electric vans delivered through October 2015.*[266]

14.2 Electric cars by country

Main article: Electric car use by country
See also: Plug-in electric vehicles in the United Kingdom

As of December 2013, the United States and Japan are the world's largest highway-capable electric car markets, followed by China and several Western European countries. A total of 72,028 all-electric cars have been sold in the U.S. since December 2010,*[295] while in Japan, 43,817 all-electric cars have been sold since July 2009.*[296]*[297]*[298] Cumulative sales in China totaled 31,558 pure electric vehicles since 2011.*[267]*[299]*[300] In Western Europe, the all-electric segment is led by France with 28,560 highway-capable all-electric vehicles registered since 2010, including all-electric delivery vans, which represent almost 40% of the French segment sales.*[301] During 2012 pure electric car sales were led by Japan with a 28% market share of global sales, followed by the United States with a 26% share, China with 16%, France with 11% and Norway with 7%.*[302]

Since 2010, a total of 75,951 highway-capable all-electric passenger cars have been sold in Western European countries through December 2013, with annual sales climbing from 1,614 all-electric cars in 2010,*[303] to 11,563 electric cars during 2011.*[304] During 2012 electric car sales totaled 24,157 units, and the segment sales climbed to 38,617 units in 2013, up 60% from 2012.*[305] The market share of the electric segment rose from 0.09% of all new car sales in the region in 2011 to 0.21% in 2012, and 0.34% in 2013.*[304]*[305]*[306] Despite the region's relatively low EV market share,*[305] several countries achieved significant growth in their PEV market shares. Norwegian pure electric car sales reached 5.6% of new car sales, up from 3.1% in 2012;*[301]*[307] the Dutch plug-in electric car share was 5.37%, up from an average of 0.57% during 2011 and 2012,*[301]*[308] and the result of a surge in sales of plug-in hybrids at the end of the year, with a total of

20,164 units registered during 2013;*[309]*[310] French sales of all-electric light-duty vehicles captured a 0.65% market share, which falls to 0.49% if all-electric utility vans are excluded;*[301] and Sweden had a PEV market share of 0.57%, up from an average of 0.19% during 2011 and 2012,*[301]*[308] with plug-in hybrids representing 72% of the segment sales in 2013.*[311] During the first half of 2014, five countries achieved plug-in electric car sales with a market share higher than 1% of new car sales, Norway (14,49%), Netherlands (4,58%), Iceland (2,20%), Sweden (1,52%), and Estonia (1,05%).*[312]

The Opel Ampera was the top selling plug-in electric car in Europe for 2012.[313]*[314]*

As of December 2012, the countries with the highest EV penetration among the registered passenger car stock were Norway with four electric cars per 1,000 automobiles, Estonia with one electric car for every 1,000 cars, and the Netherlands with a penetration of 0.6 electric cars per 1,000 registered cars.*[315] During 2013 Norway kept the leadership in market penetration with 20,486 plug-in electric vehicles registered out of 2.49 million passenger cars registered through December 2013, representing an EV penetration of 8.2 plug-in electric cars per 1,000 cars registered in the country.*[301]*[316]*[317] It is expected that sometime in April 2014 Norway will become the first country with a market penetration where 1 in every 100 registered passenger cars is all-electric.*[318]

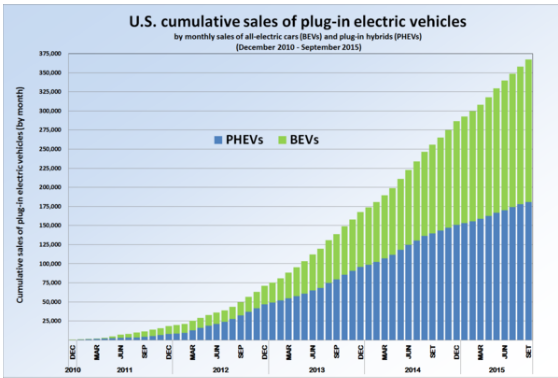
The top selling electric cars in the region in 2011 were the Mitsubishi i-MiEV (2,608) followed by its rebadged versions the Peugeot iOn (1,926) and the Citroën C-Zero (1,830).*[304]*[313] The Opel/Vauxhall Ampera was Europe's top selling plug-in electric car in 2012 with 5,268 units representing a market share of 21.5% of the region's electric passenger car segment.*[313]*[314] The Nissan Leaf ranked second with 5,210 electric cars sold 20.8.*[313] In 2013 the top selling all-electric car was the Leaf with 11,120 units sold,*[319] followed by the Renault Zoe with 8,860 units.*[266] Plug-in hybrid sales were led by the Mitsubishi Outlander P-HEV with 8,197 units.*[320] Accounting for cumulative sales since 2010, the Leaf is the top selling plug-in electric car in the European market with over 18,000 units delivered,*[313]*[319] and the Renault Kangoo Z.E. is the top selling utility van with 12,461 units.*[266]

The following table presents the top ranking countries according to market share of total new car sales in 2013 for overall plug-in electric vehicle (PEV) sales, including plug-in hybrids, and all-electric or battery electric vehicles (BEV).

14.2.1 United States

Main article: Plug-in electric vehicles in the United States

As of September 2014, the United States has the largest



U.S. plug-in electric vehicle cumulative sales by month by type of powertrain from December 2010 up to September 2015.[295]*[322]*[323] Cumulative plug-in electric car sales since 2008 passed the 300,000 unit milestone in January 2015.*[324]*

fleet of highway-capable plug-in electric vehicles in the world, with over 250,000 plug-in electric cars sold since 2008, with California accounting for 40% of nationwide total sales.*[325] As of June 2014, the U.S. is the world's leader in plug-in electric car sales with a 45% share of global sales.*[326]*[327]

Accounting for sales from December 2010 to June 2014, a total of 97,872 all-electric cars have been sold in the country, in addition to 124,718 plug-in hybrid electric cars.*[295] Plug-in car sales climbed from 17,800 units in 2011 to 53,200 during 2012, and reached 97,100 units delivered in 2013, up 83% from the previous year.*[328] During the first half of 2014 plug-in electric car sales totaled 54,973 units, up 35% year-on-year.*[329] Plug-in car sales during 2013 represented a 0.62% market share of total new car sales, up from of 0.37% in 2012, and 0.14% in 2011.*[330]*[331] During the first half of 2014 plug-in electric car sales totaled 54,973 units, representing a 0.67% market share of new car sales.*[329] The best monthly PEV sales volume on record ever was achieved in May 2014, with over 12,000 units delivered, representing a market share of 0.78% of new car sales.*[332]*[333] October 2013 achieved the best-ever market share for plug-in vehicles at 0.85% of new car sales.*[334]

The Nissan Leaf (left) and the Tesla Model S (right) are the two best selling pure electric cars in the U.S.

As of June 2014, cumulative plug-in car sales are led by the Chevrolet Volt plug-in hybrid with 63,167 units, followed by the Nissan Leaf electric car with 54,858 units. Both PEVs were released in December 2010.*[326] Launched in the U.S. market in February 2012, the Prius PHV ranks as the third top selling plug-in electric car with 34,138 units;*[329]*[330]*[335] followed by the all-electric Tesla Model S, released in June 2012, with about 27,900 units delivered;*[336]*[337]*[338] During 2013 sales were led by the Chevrolet Volt with 23,094 units, followed by the Nissan Leaf with 22,610 cars, and the Tesla Model S with almost 18,000 units.*[335]*[337] Sales during the first half of 2014 sales were led by the Nissan Leaf with 12,736 units, followed by the Prius PHEV with 9,300 units, the Volt with 8,615, the Model S with an estimated 7,400 units, and the Fusion Energi with 6,235 units.*[338]

California, the largest United States car market, is also the leading plug-in electric-drive market in the country. About 40% of the segment's nationwide sales during 2011 and 2012 were made in California, while the state represents about 10% of all new car sales in the country.*[339] As of August 2014, California still accounts for 40% of total plug-in electric car sales in the U.S. with over 100,000 plug-in cars sold.*[340] From January to May 2013, 52% of American plug-in electric car registrations were concentrated in five metropolitan areas: San Francisco, Los Angeles, Seattle, New York and Atlanta.*[341]

14.2.2 Japan

Main article: Plug-in electric vehicles in Japan

As of December 2013, a total of 43,817 all-electric cars have been sold in Japan since July 2009*[297]*[298] The Nissan Leaf is the market leader with over 34,465 units sold since December 2010,*[297] followed by the Mitsubishi i MiEV, launched for fleet customers in Japan in late July 2009, with cumulative sales of 9,402 i-MiEVs through December 2013.*[298] In addition, 5,249 all-electric light utility vehicles have sold through December 2013, including 4,695 Mitsubishi Minicab MiEV utility vans and 554 units of its all-electric mini truck

The Nissan Leaf is the top selling plug-in electric vehicle in Japan.

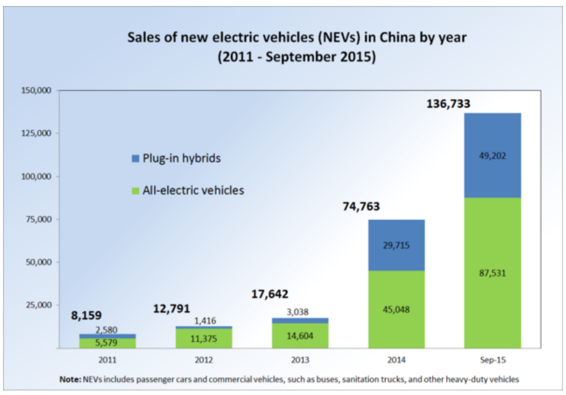
version.*[296] The Japanese plug-in electric-drive stock rises to over 74,100 plug-in electric vehicles, when accounting for 15,400 Toyota Prius PHVs*[342] and 9,608 Mitsubishi Outlander P-HEVs sold through December 2013.*[296] As of December 2013, pure electric vehicles represent 66.3% of cumulative sales of the plug-in electric vehicle segment, with 49,116 all-electric cars and light-utility vehicles sold.*[296]*[297]*[298]*[342]

During 2012, global sales of pure electric cars were led by Japan with a 28% market share of total sales, followed by the United States with a 26% share. Japan ranked second after the U.S. in terms of its share of plug-in hybrid sales in 2012, with a 12% of global sales.*[343] A total of 29,716 highway-capable plug-in electric vehicles were sold in 2013, representing a 0.55% market share of the 5.3 million new cars and kei cars sold during 2013.*[301]*[344] During 2013 sales were led by the Nissan Leaf with 13,021 units, followed by the Outlander P-HEV with 9,608 units.*[344]

14.2.3 China

See also: Electric cars in China

As of early March 2014, the new energy vehicle stock



Sales of new energy vehicles in China by year between 2011 and 2015 through September.[267]*[299]*[300]*[345]*[346]*

in China was estimated at about 50,000 units.*[347] As of March 2013, about 80% of the plug-in electric vehicles on the roads were used in public transportation, both bus and taxi services.*[348]*[349] The share of all-electric buses in the Chinese autobus market climbed from 2% in 2010 to 9.9% in 2012, and was expected to be closed to 20% for 2013.*[350] According a report by Mckinsey, electric vehicle sales between January 2009 and June 2012 represented less than 0.01% of new car sales in China.*[351] Accounting for new energy vehicle sales between January 2011 and December 2014, a total of 113,355 units have been sold in the country, of which, 76,606 units (67.6%) are all-electric vehicles, including buses.*[267]*[299]*[300]*[345]

A total of 8,159 new energy vehicles were sold in China during 2011, including passenger cars (61%) and buses (28%). Of these, 5,579 units were all-electric vehicles and 2,580 plug-in hybrids.*[300] Electric vehicle sales represented 0.04% of total new car sales in 2011.*[352] Sales of new energy vehicles in 2012 reached 12,791 units, which includes 11,375 all-electric vehicles and 1,416 plug-in hybrids.*[299] New energy vehicle sales in 2012 represented 0.07% of the country's total new car sales.*[353] During 2013 new energy vehicle sales totaled 17,642 units, up 37.9% from 2012 and representing 0.08% of the nearly 22 million new car sold in the country in 2013. Deliveries included 14,604 pure electric vehicles and 3,038 plug-in hybrids.*[267]*[354]*[355] In addition, a total of 200,000 low-speed small electric cars were sold in 2013, most of which are powered by lead-acid batteries and not accounted by the government as new energy vehicles due to safety and environmental concerns.*[267]

BYD e6 all-electric taxi in Shenzhen, China

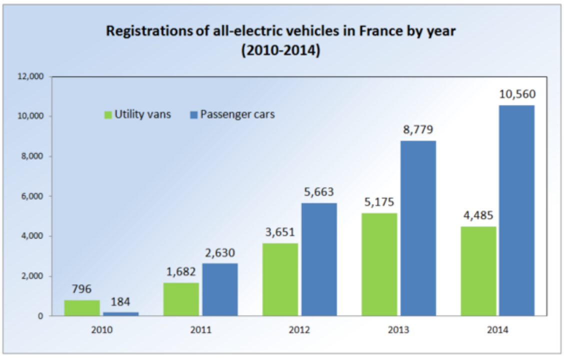
New energy vehicle sales in China during 2014 totaled 74,763 units, of which, 71% were passenger cars, 27% buses, and 1% trucks.*[356] A total of 45,048 all-electric vehicles were sold in 2014, up 210% from a year earlier, and 29,715 plug-in hybrids, up 880% from 2013. The plug-in electric segment market share reached 0.32% of the 23.5 million new car sales sold in 2014.*[345]

The Chery QQ3 EV was the top selling new energy car in China between 2011 and 2013, with 2,167 units sold in 2011, 3,129 in 2012, and 5,727 in 2013.*[284] Cumulative sales since January 2011 through March 2014 reached 13,039 units.*[284]*[357] The BYD Qin plug-in hybrid, introduced in December 2013, ranked as the top selling plug-in electric car in China in 2014, with 14,747 units sold, followed by the all-electrics Zotye Zhidou E20 with 7,341 units and BAIC E150 EV with 5,234.*[356]

14.2.4 France

See also: Electric cars in France

Since January 2010, a total of 28,560 highway-



Registration of highway capable all-electric vehicles in France by type of vehicle between 2010 and 2014[358]*[359]*[360]*[361]*

capable all-electric vehicles have been registered in France through December 2013, of which, 17,256 are electric cars and 11,304 are electric utility vans.*[358]*[359]*[360]*[362] Electric car registrations increased from 184 units in 2010 to 2,630 in 2011. Sales in 2012 increased 115% from 2011 to 5,663 cars,*[358]*[363]*[364] allowing France to rank 4th among the top selling EV countries, with an 11% market share of global all-electric car sales in 2012.*[343] Registrations reached 8,779 electric cars in 2013, up 55.0% from 2012,*[359] and the EV market share of total new car sales went up to 0.49% from 0.3% in 2012.*[364]*[365]

In addition to battery electric cars, 5,175 electric utility vans were registered in 2013, up 42% from 2012,*[359] representing a market share of 1.4% of all new light commercial vehicles sold in 2013.*[365] Sales of electric passenger cars and utility vans totaled 13,954 units in 2013,*[359] capturing a combined market share of 0.65 of these two segments new car sales.*[301] Combined sales of pure electric cars and light utility vehicles positioned France as the leading European country in the all-electric market segment in 2012 and 2013.*[301]*[359]*[362]*[366]

In the French market plug-in hybrids or rechargeable hybrids are classified and accounted together with conventional hybrid electric vehicles. Almost 1,500 plug-in hybrids were registered during 2012 and 2013.*[367]*[368]*[369] Of these, a total of 666 plug-in hybrids were registered during 2012,*[367] and 808 units in 2013.*[368]*[369] When plug-in hybrids sales in 2013 are accounted for, a total of 14,762

The Renault Zoe led electric car sales in France in 2013, and became the country's best selling all-electric car accounting for registrations since 2010.[358][359]

plug-in electric vehicles were registered in France in 2013,[359][368][369] positioning the country in 2013 as the second largest European plug-in electric market after the Netherlands, where 28,673 plug-in electric vehicles were registered during 2013.[301]

During 2012, all-electric car registrations in France were led by the Bolloré Bluecar with 1,543 units, the C-Zero with 1,409, and the iOn with 1,335, together representing 76% of all electric car sales that year.[370] The Renault Kangoo Z.E. was the top selling utility electric vehicle with 2,869 units registered in 2012, representing a market share of 82% of the segment.[362][366] The Renault Twizy electric quadricycle, launched in March 2012, sold 2,232 units during 2012, surpassing the Bolloré Bluecar, and ranking as the second best selling plug-in electric vehicle after the Kangoo Z.E.[371]

Toyota's contribution in Grenoble

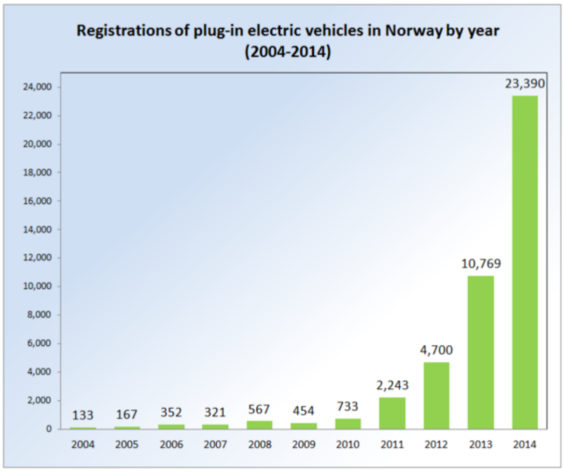
During 2013, registrations of pure electric cars were led by the Renault Zoe with 5,511 units representing 62.8% of total electric car sales, followed by the Nissan Leaf with 1,438 units.[359] Registrations of all-electric light utility vehicles were led by the Renault Kangoo Z.E. with 4,174 units, representing 80.7% of the segment sales.[359] With a total of 7,826 Kangoo ZEs registered in the country through December 2013, the electric van is the French leader in the all-electric vehicle segment accounting for sales since 2010.[359][362][372] Total registrations of all-electric cars since January 2010 through December 2013 are led by the Renault Zoe, with 5,559 units, followed by the Bolloré Bluecar, with 2,600 units, and the Peugeot iOn, with 2,256 units.[358]

During 2014, Toyota, together with several partners, is participating in a 3-year verification project involving ultra-compact EV car sharing in the city of Grenoble, France. Through this project Toyota i-Road, urban mobility is hoped to become much smoother and traffic congestion will be alleviated.[373]

14.2.5 Norway

Main article: Plug-in electric vehicles in Norway

As of December 2013, a total of 20,486 plug-in electric



Registration of plug-in electric vehicles in Norway by year between 2004 and 2014[316][374]

vehicles have been registered in Norway,[301][316] including 19,799 all-electric cars and 687 plug-in hybrids.[375] Out of the total all-electric stock, over 1,440 units are heavy quadricycles, such as the Kewet/Buddy and the REVAi.[376] Registrations include more than 2,450 used imports from neighboring countries, of which, 2,159 were imported in 2013.[307][316] The Norwegian fleet of electric cars is also one of the cleanest in the world because almost 100% of the electricity generated in the country comes from hydropower.[377] Norway is the country with the largest EV ownership per capita in the world,[378][379] reaching 4.0 plug-in electric vehicles per 1,000 people in 2013, a market penetration nine times higher than the U.S., the world's largest plug-in electric car market.[301]

Also, Norway was the first country in the world to have electric cars topping the new car sales monthly ranking. The Tesla Model S has been the top selling new car three times, twice in 2013, first in September and again in December;[380][381] and one more time in March 2014.[382] The Nissan Leaf has topped the monthly new car sales ranking twice, first in October 2013 and again in January 2014.*[383]*[384]*[385] Both the Nissan Leaf and the Tesla Model S were listed among the Norwegian top 20 best selling new cars in 2013, with the Leaf ranking third and the Model S ranking 20th.*[386] The Norwegian plug-in electric vehicle market share of new car sales is the highest in the world, its market share rose from 1.6% in 2011, to 3.1% in 2012,*[307] and reached 5.6% in 2013.*[316] Only the Netherlands has achieved a similar market share for the plug-in electric drive segment (5.37% in 2013).*[301] During the first quarter of 2014 all-electric car sales reached a record 14.5% market share of new car sales.*[382]

Electric cars have access to bus lanes in Norway. Shown a Nissan Leaf, the top selling plug-in electric car in the country since 2012.

Plug-in electric vehicle registrations totaled 10,769 units in 2013, mostly all-electric cars, and used imports represented 20% of registrations during 2013. This total includes 387 plug-in hybrids and 355 all-electric light commercial vans, together representing 6.9% of total 2013 registrations, and reflecting the continued dominance of pure electric vehicles in the Norwegian market.*[316] The plug-in electric drive segment in Norway grew 129% from 2012 to 2013, achieving one of the highest EV rates of growth in the world, second only to the Netherlands (338%).*[301]

During 2013, the Leaf continued as the top selling plug-in electric car, with 4,604 new units sold during the year, which represent 58.4% of plug-in electric car sales in 2013. The Tesla Model S ranked second with 1,986 units (25.2% share), followed by the Volkswagen e-Up! with 580 units (7.4% share).*[387] Since September 2011, a total of 7,275 new Leaf cars have been sold in the country through December 2013.*[388]*[389] Accounting for used Leafs imported from neighboring countries, of which, 1,608 units were registered during 2013, a total of 9,080 Leafs have been registered in Norway through December 2013,*[390] representing 9.4% of the 96,847 Leafs delivered worldwide through December 2013.*[391]

In March 2014, with 26,886 plug-in electric vehicles registered in the country, Norway became the first country where over one in every 100 registered passenger cars is plug-in electric,*[392] out of a fleet of over 2.52 million registered passenger cars.*[393]*[394] Also in March 2014 the Tesla Model S also broke the 28-year-old record for monthly sales of a single model regardless of its power source, with 1,493 units sold, surpassing the Ford Sierra, which sold 1,454 units in May 1986.*[382]*[395] The Model S, with 2,056 units sold during the first quarter of 2014, is Norway's best selling new car during 2014 (CYTD), capturing a 5.6% market share of new car sales during this period. During the same quarter, the Nissan Leaf ranked as the best third selling new car with 1,559 units, capturing a 4.3% market share of new car sales.*[382]*[392]*[394]

14.3 Government subsidy

See also: Government incentives for plug-in electric vehicles

Several countries have established grants and tax credits for the purchase of new electric cars depending on battery size. The U.S. offers a federal income tax credit up to US$7,500,*[69] and several states have additional incentives.*[396] The UK offers a Plug-in Car Grant up to a maximum of £5,000 (US$7,600).*[397]*[398] The U.S. government also pledged US$2.4 billion in federal grants for the development of advanced technologies for electric cars and batteries.*[399]

As of April 2011, 15 European Union member states provide economic incentives for the purchase of new electrically chargeable vehicles, which consist of tax reductions and exemptions, as well as of bonus payments for buyers of all-electric and plug-in hybrid vehicles, hybrid electric vehicles, and some alternative fuel vehicles.*[400]*[401]

15 See also

- Compressed air car
- Electric boat
- Electric bus
- Electric car use by country
- Electric motorcycles and scooters
- Electric vehicle conversion
- Government incentives for plug-in electric vehicles
- Electric vehicle industry in India
- Hybrid electric vehicle (HEV)
- List of electric cars currently available
- List of modern production plug-in electric vehicles

- List of production battery electric vehicles
- Nikola Tesla electric car hoax
- Patent encumbrance of large automotive NiMH batteries
- Plug-in electric vehicle (PEV)
- Plug-in electric vehicles in the Netherlands
- Plug-in hybrid (PHEV)
- Solar Golf Cart
- The Greenpower Challenge - EV racing for young people
- The long tailpipe
- Electric vehicle
- Battery electric vehicle
- Plug-in electric vehicle
- Green vehicle

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19.1 Text

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