Electric vehicle

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An **electric vehicle** (**EV**), also referred to as an **electric drive vehicle**, uses one or more electric motors or traction motors for propulsion. An electric vehicle may be powered through a collector system by electricity from off-vehicle sources, or may be self-contained with a battery or generator to convert fuel to electricity.[1] EVs include road and rail vehicles, surface and underwater vessels, electric aircraft and electric spacecraft.

Electric vehicles around the world *(from top left)*:

- Electric car. Top-selling Nissan Leaf in Amsterdam
- High-speed rail. China's CRH5 in Beijing
- Electric trolleybus in São Paulo, Brazil
- Electric tram in Vienna, Austria
- U.S. manufactured electric truck, Australia
- BYD K9, a battery electric bus with onboard $LiFePO_4$ battery

EVs first came into existence in the mid-19th century, when electricity was among the preferred methods for motor vehicle propulsion, providing a level of comfort and ease of operation that could not be achieved by the gasoline cars of the time. The internal combustion engine (ICE) has been the dominant propulsion method for motor vehicles for almost 100 years, but electric power has remained commonplace in other vehicle types, such as trains and smaller vehicles of all types.

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- Electric locomotive of the Shatabdi Express in India *(see gallery of multiple units)*
- The electric, solar-powered aircraft, Solar Impulse 2 successfully circumnavigated the globe.
- Chinese made electric scooter in the Brazilian city of Maringá, and e-Bike, in Manhattan, New York

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History

Edison and a 1914 Detroit Electric model 47 (courtesy of the National Museum of American History)

An EV and an antique car on display at a 1912 auto show

Electric motive power started in 1827, when Slovak-Hungarian priest Ányos Jedlik built the first crude but viable electric motor, provided with stator, rotor and commutator, and the year after he used it to power a tiny car.[2] A few years later, in 1835, professor Sibrandus Stratingh of University of Groningen, the Netherlands, built a small scale electric car and a Robert Anderson of Scotland is reported to have made a crude electric carriage sometime between the years of 1832 and 1839. Around the same period, early experimental electrical cars were moving on rails, too. American blacksmith and inventor Thomas Davenport built a toy electric locomotive, powered by a primitive electric motor, in 1835. In 1838, a Scotsman named Robert Davidson built an electric locomotive that attained a speed of four miles per hour (6 km/h). In England a patent was granted in 1840 for the use of rails as conductors of electric current, and similar American patents were issued to Lilley and Colten in 1847.[3]

Between 1832 and 1839 (the exact year is uncertain), Robert Anderson of Scotland invented the first crude electric carriage, powered by non-rechargeable primary cells.[4]

By the 20th century, electric cars and rail transport were commonplace, with commercial electric automobiles having the majority of the market. Over time their general-purpose commercial use reduced to specialist roles, as platform trucks, forklift trucks, ambulances,[5] tow tractors and urban delivery vehicles, such as the iconic British milk float; for most of the 20th century, the UK was the world's largest user of electric road vehicles.[6]

Electrified trains were used for coal transport, as the motors did not use precious oxygen in the mines. Switzerland's lack of natural fossil resources forced the rapid electrification of their rail network. One of the earliest rechargeable batteries - the nickel-iron battery - was favored by Edison for use in electric cars.

EVs were among the earliest automobiles, and before the preeminence of light, powerful internal combustion engines, electric automobiles held many vehicle land speed and distance records in the early 1900s. They were produced by Baker Electric, Columbia Electric, Detroit Electric, and others, and at one point in history out-sold gasoline-powered vehicles. In fact, in 1900, 28 percent of the cars on the road in the USA were electric. EVs were so popular that even President Woodrow Wilson and his secret service agents toured Washington DC in their Milburn Electrics, which covered 60–70 mi (100–110 km) per charge.[7]

A number of developments contributed to decline of electric cars.[8] Improved road infrastructure required a greater range than that offered by electric cars, and the discovery of large reserves of petroleum in Texas, Oklahoma, and California led to the wide availability of affordable gasoline/petrol, making internal combustion powered cars cheaper to operate over long distances.[9] Also internal combustion powered cars became ever easier to operate thanks to the invention of the electric starter by Charles Kettering in 1912,[10] which eliminated the need of a hand crank for starting a gasoline engine, and the noise emitted by ICE cars became more bearable thanks to the use of the muffler, which Hiram Percy Maxim had invented in 1897. As roads were improved outside urban areas electric vehicle range could not compete with the ICE. Finally, the initiation of mass production of gasoline-powered vehicles by Henry Ford in 1913 reduced significantly the cost of gasoline cars as compared to electric cars.[11]

In the 1930s, National City Lines, which was a partnership of General Motors, Firestone, and Standard Oil of California purchased many electric tram networks across the country to dismantle them and replace them with GM buses. The partnership was convicted of conspiring to monopolize the sale of equipment and supplies to their subsidiary companies, but were acquitted of conspiring to monopolize the provision of transportation services.

Experimentation

In January 1990, General Motors' President introduced its EV concept two-seater, the "Impact", at the Los Angeles Auto Show. That September, the California Air Resources Board mandated major-automaker sales of EVs, in phases starting in 1998. From 1996 to 1998 GM produced 1117 EV1s, 800 of which were made available through three-year leases.

Chrysler, Ford, GM, Honda, Nissan and Toyota also produced limited numbers of EVs for California drivers. In 2003, upon the expiration of GM's EV1 leases, GM crushed them. The crushing has variously been attributed to:

- the auto industry's successful federal court challenge to California's zero-emissions vehicle mandate,
- a federal regulation requiring GM to produce and maintain spare parts for the few thousands EV1s and
- the success of the oil and auto industries' media campaign to reduce public acceptance of EVs.

A movie made on the subject in 2005-2006 was titled *Who Killed the Electric Car?* and released theatrically by Sony Pictures Classics in 2006. The film explores the roles of automobile manufacturers, oil industry, the U.S. government, batteries, hydrogen vehicles, and consumers, and each of their roles in limiting the deployment and adoption of this technology.

General Motors EV1 electric car (1996-1998), story told in movie Who Killed the Electric Car?

Ford released a number of their Ford Ecostar delivery vans into the market. Honda, Nissan and Toyota also repossessed and crushed most of their EVs, which, like the GM EV1s, had been available only by closed-end lease. After public protests, Toyota sold 200 of its RAV EVs to eager buyers; they later sold at over their original forty-thousand-dollar price. This lesson did not go unlearned; BMW of Canada sold off a number of Mini EV's when their Canadian testing ended.

The production of the Citroën Berlingo Electrique stopped in September 2005.

Reintroduction

During the last few decades, environmental impact of the petroleum-based transportation infrastructure, along with the fear of peak oil, has led to renewed interest in an electric transportation infrastructure.[12] EVs differ from fossil fuel-powered vehicles in that the electricity they consume can be generated from a wide range of sources, including fossil fuels, nuclear power, and renewable sources such as tidal power, solar power, and wind power or any combination of those. The carbon footprint and other emissions of electric vehicles varies depending on the fuel and technology used for electricity generation.[13][14] The electricity may then be stored on board the vehicle using a battery, flywheel, or supercapacitors. Vehicles making use of engines working on the principle of combustion can usually only derive their energy from a single or a few sources, usually non-renewable fossil fuels. A key advantage of hybrid or plug-in electric vehicles is regenerative braking due to their capability to recover energy normally lost during braking as electricity is stored in the on-board battery.

The world's two best selling all-electric cars in history are the Nissan Leaf (left), with 240,000 global sales through September 2016, and the Tesla Model S (right), with over 150,000 units delivered through November 2016.[15]

As of September 2016, series production highway-capable all-electric cars available in some countries for retail customers released to the market since 2010 include the Mitsubishi i-MiEV, Nissan Leaf, Ford Focus Electric, Tesla Model S, BMW ActiveE, Coda, Renault Fluence Z.E., 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, Venucia e30, BAIC E150 EV, Denza EV, Zotye Zhidou E20, BYD e5, Tesla Model X, Detroit Electric SP.01, BYD Qin EV300, and Hyundai Ioniq Electric. As of early December 2015, the Leaf, with 200,000 units sold worldwide, is the world's top-selling highway-capable all-electric car in history, followed by the Tesla Model S with global deliveries of about 100,000 units.[16]

As of May 2015, more than 500,000 highway-capable all-electric passenger cars and light utility vehicles have been sold worldwide since 2008, out of total global sales of about 850,000 light-duty plug-in electric vehicles.[17][18] As of May 2015, the United States had the largest fleet of highway-capable plug-in electric vehicles in the world, with about 335,000 highway legal plug-in electric cars sold in the country since 2008, and representing about 40% of the global stock.[19][20] California is the largest plug-in car regional market in the country, with almost 143,000 units sold between December 2010 and March 2015, representing over 46% of all plug-in cars sold in the U.S.[21][22][23][24] Cumulative global sales of all-electric cars and vans passed the 1 million unit milestone in September 2016.[25]

Norway is the country with the highest market penetration per capita in the world, with four plug-in electric vehicles per 1000 inhabitants in 2013.[26] In March 2014, Norway became the first country where over 1 in every 100 passenger cars on the roads is a plug-in electric.[27][28] Norway also has the world's largest plug-in electric segment market share of total new car sales, 13.8% in 2014, up from 5.6% in 2013.[19][29] In June 2016, Andorra became the second country in this list, with a 6% of market share combining electric vehicles and plug-in hybrids[30] due to a strong public policy providing multiple advantages.[31] As of May 2015, there were 58,989 plug-in electric vehicles registered in Norway, consisting of 54,160 all-electric vehicles and 4,829 plug-in hybrids.[32]

Electricity sources

There are many ways to generate electricity, of varying costs, efficiency and ecological desirability.

Connection to generator plants

- direct connection to generation plants as is common among electric trains, trolley buses, and trolley trucks (See also : overhead lines, third rail and conduit current collection)
- Online Electric Vehicle collects power from electric power strips buried under the road surface through electromagnetic induction

Onboard generators and hybrid EVs

(See articles on diesel-electric and gasoline-electric hybrid locomotion for information on EVs using also combustion engines).

- generated on-board using a diesel engine: diesel-electric locomotive
- generated on-board using a fuel cell: fuel cell vehicle
- generated on-board using nuclear energy: nuclear submarines and aircraft carriers
- renewable sources such as solar power: solar vehicle

It is also possible to have hybrid EVs that derive electricity from multiple sources. Such as:

- on-board rechargeable electricity storage system (RESS) and a direct continuous connection to land-based generation plants for purposes of on-highway recharging with unrestricted highway range

- on-board rechargeable electricity storage system and a fueled propulsion power source (internal combustion engine): plug-in hybrid

A passenger train, taking power through a third rail with return through the traction rails

An electric locomotive at Brig, Switzerland

Electric bus in Santa Barbara, California

Another form of chemical to electrical conversion is fuel cells, projected for future use.

For especially large EVs, such as submarines, the chemical energy of the diesel-electric can be replaced by a nuclear reactor. The nuclear reactor usually provides heat, which drives a steam turbine, which drives a generator, which is then fed to the propulsion. *See Nuclear Power*

A few experimental vehicles, such as some cars and a handful of aircraft use solar panels for electricity.

Onboard storage

These systems are powered from an external generator plant (nearly always when stationary), and then disconnected before motion occurs, and the electricity is stored in the vehicle until needed.

- on-board rechargeable electricity storage system (RESS), called Full Electric Vehicles (FEV). Power storage methods include:
  - chemical energy stored on the vehicle in on-board batteries: Battery electric vehicle (BEV)
  - kinetic energy storage: flywheels
  - static energy stored on the vehicle in on-board electric double-layer capacitors

Batteries, electric double-layer capacitors and flywheel energy storage are forms of rechargeable on-board electrical storage. By avoiding an intermediate mechanical step, the energy conversion efficiency can be improved over the hybrids already discussed, by avoiding unnecessary energy conversions. Furthermore, electro-chemical batteries conversions are easy to reverse, allowing electrical energy to be stored in chemical form.

Lithium-ion battery

Most electric vehicles use lithium ion batteries. Lithium ion batteries have higher energy density, longer life span and higher power density than most other practical batteries. Complicating factors include safety, durability, thermal breakdown and cost. Li-ion batteries should be used within safe temperature and voltage ranges in order to operate safely and efficiently.[33]

Increasing the battery's lifespan decreases effective costs. One technique is to operate a subset of the battery cells at a time and switching these subsets.[34]


Battery electric bus powered with lithium-ion batteries

Electric motor

The power of a vehicle electric motor, as in other vehicles, is measured in kilowatts (kW). 100 kW is roughly equivalent to 134 horsepower, although electric motors can deliver their full torque over a wide RPM range, so the performance is not equivalent, and far exceeds a 134 horsepower (100 kW) fuel-powered motor, which has a limited torque curve.

Electric truck e-Force One

Usually, direct current (DC) electricity is fed into a DC/AC inverter where it is converted to alternating current (AC) electricity and this AC electricity is connected to a 3-phase AC motor.

For electric trains, forklift trucks, and some electric cars, DC motors are often used. In some cases, universal motors are used, and then AC or DC may be employed. In recent production vehicles, various motor types have been implemented, for instance: Induction motors within Tesla Motor vehicles and permanent magnet machines in the Nissan Leaf.[35]

Vehicle types

It is generally possible to equip any kind of vehicle with an electric powertrain.


The Chevrolet Volt is the world's top selling plug-in hybrid of all time. Global Volt/Ampera family sales passed the 100,000 unit milestone in October 2015.[36]

Ground vehicles

Plug-in electric vehicle

A plug-in electric vehicle (PEV) is any motor vehicle that can be recharged from any external source of electricity, such as wall sockets, and the electricity stored in the rechargeable battery packs drives or contributes to drive the wheels. PEV is a subcategory of electric vehicles that includes all-electric or battery electric vehicles (BEVs), plug-in hybrid vehicles, (PHEVs), and electric vehicle conversions of hybrid electric vehicles and conventional internal combustion engine vehicles.[37][38][39]

Cumulative global sales totaled over 1.5 million plug-in cars and utility vans by the end of May 2016.[40] As of June 2016, the world's top selling plug-in electric cars are the Nissan Leaf, with global sales of more than 228,000 units, followed by the all-electric Tesla Model S with about 129,400 units sold worldwide, the Chevrolet Volt plug-in hybrid, which together with its sibling the Opel/Vauxhall Ampera has combined global sales of about 117,300 units, the Mitsubishi Outlander P-HEV with about 107,400 units, and the Prius Plug-in Hybrid with over 75,400 units.[41]

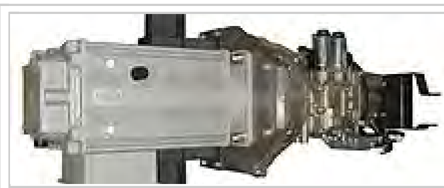
Hybrid EVs

A hybrid electric vehicle combines a conventional (usually fossil fuel-powered) powertrain with some form of electric propulsion. As of April 2016, over 11 million hybrid electric vehicles have been sold worldwide since their inception in 1997. Japan is the market leader with more than 5 million hybrids sold, followed by the United States with cumulative sales of over 4 million units since 1999, and Europe with about 1.5 million hybrids delivered since 2000.[42] Japan has the world's highest hybrid market penetration. By 2013 the hybrid market share accounted for more than 30% of new standard passenger car sold, and about 20% new passenger vehicle sales including kei cars.[43] Norway ranks second with a hybrid market share of 6.9% of new car sales in 2014, followed by the Netherlands with 3.7%[44]

Global hybrid sales are by Toyota Motor Company with more than 9 million Lexus and Toyota hybrids sold as of April 2016,[45] followed by Honda Motor Co., Ltd. with cumulative global sales of more than 1.35 million hybrids as of June 2014,[46][47][48] Ford Motor Corporation with over 424,000 hybrids sold in the United States through June 2015,[49][50][51][52][53] and the Hyundai Group with cumulative global sales of 200,000 hybrids as of March 2014, including both Hyundai Motor Company and Kia Motors hybrid models.[54] As of April 2016, worldwide hybrid sales are led by the Toyota Prius liftback, with cumulative sales of over 3.7 million units. The Prius nameplate has sold more than 5.7 million hybrids up to April 2016.[55]

On- and off-road EVs

EVs are on the road in many functions, including electric cars, electric trolleybuses, electric buses, battery electric buses, electric trucks, electric bicycles, electric motorcycles and scooters, neighborhood electric vehicles, golf carts, milk floats, and forklifts. Off-road vehicles include electrified all-terrain vehicles and tractors.



An electric powertrain used by Power Vehicle Innovation for trucks or buses[56]

Railborne EVs

The fixed nature of a rail line makes it relatively easy to power EVs through permanent overhead lines or electrified third rails, eliminating the need for heavy onboard batteries. Electric locomotives, electric trams/streetcars/trolleys, electric light rail systems, and electric rapid transit are all in common use today, especially in Europe and Asia.

Since electric trains do not need to carry a heavy internal combustion engine or large batteries, they can have very good power-to-weight ratios. This allows high speed trains such as France's double-deck TGVs to operate at speeds of 320 km/h (200 mph) or higher, and electric locomotives to have a much higher power output than diesel locomotives. In addition, they have higher short-term surge power for fast acceleration, and using regenerative brakes can put braking power back into the electrical grid rather than wasting it.

A streetcar (or Tram) drawing current from a single overhead wire through a pantograph.

Maglev trains are also nearly always EVs.

Space rover vehicles

Manned and unmanned vehicles have been used to explore the Moon and other planets in the solar system. On the last three missions of the Apollo program in 1971 and 1972, astronauts drove silver-oxide battery-powered Lunar Roving Vehicles distances up to 35.7 kilometers (22.2 mi) on the lunar surface. Unmanned, solar-powered rovers have explored the Moon and Mars.

Airborne EVs

Since the beginning of the era of aviation, electric power for aircraft has received a great deal of experimentation. Currently flying electric aircraft include manned and unmanned aerial vehicles.

Seaborne EVs

Electric boats were popular around the turn of the 20th century. Interest in quiet and potentially renewable marine transportation has steadily increased since the late 20th century, as solar cells have given motorboats the infinite range of sailboats. Electric motors can and have also been used in sailboats instead of traditional diesel engines.[57] Electric ferries operate routinely.[58] Submarines use batteries (charged by diesel or gasoline engines at the surface), nuclear power, fuel cells[59] or Stirling engines to run electric motor-driven propellers.

Oceanvolt SD8.6 electric saildrive motor

Electrically powered spacecraft

Electric power has a long history of use in spacecraft.[60][61] The power sources used for spacecraft are batteries, solar panels and nuclear power. Current methods of propelling a spacecraft with electricity include the arcjet rocket, the electrostatic ion thruster, the Hall effect thruster, and Field Emission Electric Propulsion. A number of other methods have been proposed, with varying levels of feasibility.

Energy and motors


A trolleybus uses two overhead wires to provide electric current supply and return to the power source

Most large electric transport systems are powered by stationary sources of electricity that are directly connected to the vehicles through wires. Electric traction allows the use of regenerative braking, in which the motors are used as brakes and become generators that transform the motion of, usually, a train into electrical power that is then fed back into the lines. This system is particularly advantageous in mountainous operations, as descending vehicles can produce a large portion of the power required for those ascending. This regenerative system is only viable if the system is large enough to utilise the power generated by descending vehicles.


An electric bus at Lucerne

In the systems above motion is provided by a rotary electric motor. However, it is possible to "unroll" the motor to drive directly against a special matched track. These linear motors are used in maglev trains which float above the rails supported by magnetic levitation. This allows for almost no rolling resistance of the vehicle and no mechanical wear and tear of the train or track. In addition to the high-performance control systems needed, switching and curving of the tracks becomes difficult with linear motors, which to date has restricted their operations to high-speed point to point services.

Properties of EVs

Components


Battery electric bus by BYD in the Netherlands

The type of battery, the type of traction motor and the motor controller design vary according to the size, power and proposed application, which can be as small as a motorized shopping cart or wheelchair, through pedelecs, electric motorcycles and scooters, neighborhood electric vehicles, industrial fork-lift trucks and including many hybrid vehicles.

Energy sources

Although EVs have few direct emissions, all rely on energy created through electricity generation, and will usually emit pollution and generate waste, unless it is generated by renewable source power plants. Since EVs use whatever electricity is delivered by their electrical utility/grid operator, EVs can be made more or less efficient, polluting and expensive to run, by modifying the electrical generating stations. This would be done by an electrical utility under a government energy policy, in a timescale negotiated between utilities and government.

Fossil fuel vehicle efficiency and pollution standards take years to filter through a nation's fleet of vehicles. New efficiency and pollution standards rely on the purchase of new vehicles, often as the current vehicles already on the road reach their end-of-life. Only a few nations set a retirement age for old vehicles, such as Japan or Singapore, forcing periodic upgrading of all vehicles already on the road.

EVs will take advantage of whatever environmental gains happen when a renewable energy generation station comes online, a fossil-fuel power station is decommissioned or upgraded. Conversely, if government policy or economic conditions shifts generators back to use more polluting fossil fuels and internal combustion engine vehicles (ICEVs), or more inefficient sources, the reverse can happen. Even in such a situation, electrical vehicles are still more efficient than a comparable amount of fossil fuel vehicles. In areas with a deregulated electrical energy market, an electrical vehicle owner can choose whether to run his electrical vehicle off conventional electrical energy sources, or strictly from renewable electrical energy sources (presumably at an additional cost), pushing other consumers onto conventional sources, and switch at any time between the two.

Issues with batteries

Efficiency

Old: Banks of conventional lead-acid car batteries are still commonly used for EV propulsion

Because of the different methods of charging possible, the emissions produced have been quantified in different ways.[62] Plug-in all-electric and hybrid vehicles also have different consumption characteristics.[63]

Electromagnetic radiation

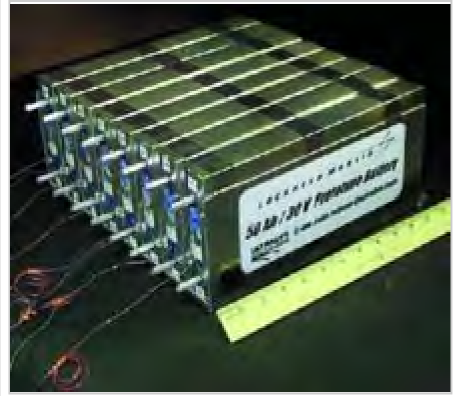
Electromagnetic radiation from high performance electrical motors has been claimed to be associated with some human ailments, but such claims are largely unsubstantiated except for extremely high exposures.[64] Electric motors can be shielded within a metallic Faraday cage, but this reduces efficiency by adding weight to the vehicle, while it is not conclusive that all electromagnetic radiation can be contained.

Charging

Grid capacity

If a large proportion of private vehicles were to convert to grid electricity it would increase the demand for generation and transmission, and consequent emissions. However, overall energy consumption and emissions would diminish because of the higher efficiency of EVs over the entire cycle. In the USA it has been estimated there is already nearly sufficient existing power plant and transmission infrastructure, assuming that most charging would occur overnight, using the most efficient off-peak base load sources.[65]

In the UK however, things are different. While National Grid's high-voltage electricity transmission system can currently manage the demand of 1 million electric cars, Steve Holliday (CEO National Grid PLC) said, "penetration up and above that becomes a real issue. Local distribution networks in cities like London may struggle to balance their grids if drivers choose to all plug in their cars at the same time."



75 watt-hour/kilogram lithium ion polymer battery prototypes. Newer Li-poly cells provide up to 130 Wh/kg and last through thousands of charging cycles.

Charging stations

EVs typically charge from conventional power outlets or dedicated charging stations, a process that typically takes hours, but can be done overnight and often gives a charge that is sufficient for normal everyday usage.

However, with the widespread implementation of electric vehicle networks within large cities, such as those provided by POD Point [1] (http://www.pod-point.com/) in the UK and Europe, EV users can plug in their cars whilst at work and leave them to charge throughout the day, extending the possible range of commutes and eliminating range anxiety.

BYD e6 taxi in Shenzhen, China. Recharging in 15 Minutes to 80 Percent

A recharging system that avoids the need for a cable is Curb Connect, patented in 2012[66] by Dr Gordon Dower. In this system, electrical contacts are fitted into curbs, such as angle parking spaces on city streets. When a suitably authorized vehicle is parked so that its front end overhangs the curb, the curb contacts become energized and charging occurs.

Another proposed solution for daily recharging is a standardized inductive charging system such as Evatran's Plugless Power. Benefits are the convenience of parking over the charge station and minimized cabling and connection infrastructure.[67][68][69] Qualcomm is trialling such a system in London in early 2012.[70][71]

A BYD electric bus in Shanghai at a charging station

Yet another proposed solution for the typically less frequent, long distance travel is "rapid charging", such as the Aerovironment PosiCharge line (up to 250 kW) and the Norvik MinitCharge line (up to 300 kW). Ecotality is a manufacturer of Charging Stations and has partnered with Nissan on several installations. Battery replacement is also proposed as an alternative, although no OEMs including Nissan/Renault have any production vehicle plans. Swapping requires standardization across platforms, models and manufacturers. Swapping also requires many times more battery packs to be in the system.

One type of battery "replacement" proposed, vanadium redox battery, is much simpler: while the latest generation of vanadium redox battery only has an energy density similar to lead-acid, the charge is stored solely in a vanadium-based electrolyte, which can be pumped out and replaced with charged fluid. The vanadium battery system is also a potential candidate for intermediate energy storage in quick charging stations because of its high power density and extremely good endurance in daily use. System cost however, is still prohibitive. As vanadium battery systems are estimated to range between $350–$600 per kWh, a battery that can service one hundred customers in a 24-hour period at 50 kWh per charge would cost $1.8-$3 million.


A battery electric bus charging station in Geneva, Swiss

According to Department of Energy research conducted at Pacific Northwest National Laboratory, 84% of existing vehicles could be switched over to plug-in hybrids without requiring any new grid infrastructure.[72] In terms of transportation, the net result would be a 27% total reduction in emissions of the greenhouse gases carbon dioxide, methane, and nitrous oxide, a 31% total reduction in nitrogen oxides, a slight reduction in nitrous oxide emissions, an increase in particulate matter emissions, the same sulfur dioxide emissions, and the near elimination of carbon monoxide and volatile organic compound emissions (a 98% decrease in carbon monoxide and a 93% decrease in volatile organic compounds).[73] The emissions would be displaced away from street level, where they have "high human-health implications."[74]

Battery swapping

Instead of recharging EVs from electric socket, batteries could be mechanically replaced on special stations in a couple of minutes (battery swapping).

Batteries with greatest energy density such as metal-air fuel cells usually cannot be recharged in purely electric way. Instead, some kind of metallurgical process is needed, such as aluminum smelting and similar.

Silicon-air, aluminum-air and other metal-air fuel cells look promising candidates for swap batteries.[75][76] Any source of energy, renewable or non-renewable, could be used to remake used metal-air fuel cells with relatively high efficiency. Investment in infrastructure will be needed. The cost of such batteries could be an issue, although they could be made with replaceable anodes and electrolyte.

Chassis swapping

Instead of replacing batteries, it is possible to replace the entire chassis (including the batteries, electric motor and wheels) of an electric Modular vehicle.

Such a system was patented in 2000[77] by Dr Gordon Dower and three road-licensed prototypes have been built by the Ridek Corporation (http://ridek.com) in Point Roberts, Washington.

Dr Dower has proposed that an individual might own only the body (or perhaps a few different style bodies) for their vehicle, and would lease the chassis from a pool, thereby reducing the depreciation costs associated with vehicle ownership.

Other in-development technologies

Conventional electric double-layer capacitors are being worked to achieve the energy density of lithium ion batteries, offering almost unlimited lifespans and no environmental issues. High-K electric double-layer capacitors, such as EEStor's EESU, could improve lithium ion energy density several times over if they can be produced. Lithium-sulphur batteries offer 250 Wh/kg.[78] Sodium-ion batteries promise 400 Wh/kg with only minimal expansion/contraction during charge/discharge and a very high surface area.[79] Researchers from one of the Ukrainian state universities claim that they have manufactured samples of pseudocapacitor based on Li-ion intercalation process with 318 Wh/kg specific energy, which seem to be at least two times improvement in comparison to typical Li-ion batteries.[80]

Safety

The United Nations in Geneva (UNECE) has adopted the first international regulation (Regulation 100) on safety of both fully electric and hybrid electric cars, with the intent of ensuring that cars with a high voltage electric power train, such as hybrid and fully EVs, are as safe as combustion-powered cars. The EU and Japan have already indicated that they intend to incorporate the new UNECE Regulation in their respective rules on technical standards for vehicles[81]

There is a growing concern about the safety of EVs, given the demonstrated tendency of the Lithium-ion battery, most promising for EV use because of its high energy density, to overheat, possibly leading to fire or explosion, especially when damaged in a crash. The U.S. National Highway Traffic Safety Administration opened a defect investigation of the Chevy Volt on November 25, 2011 amid concerns over the risk of battery fires in a crash. At that time, automotive consulting firm CNW Marketing Research reported a decline in consumer interest in the Volt, citing the fires as having made an impact on consumer perception.[82] Consumer response impelled GM to make safety enhancements to the battery system in December, and the NHTSA closed its investigation on January 20, 2012, finding the matter satisfactorily resolved with "no discernible defect trend" remaining. The agency also announced it has developed interim guidance to increase awareness and identify appropriate safety measures regarding electric vehicles for the emergency response community, law enforcement officers, tow truck operators, storage facilities and consumers.[83][84]

Advantages and disadvantages of EVs

Environmental

EVs release no tail pipe air pollutants at the place where they are operated. They also typically generate less noise pollution than an internal combustion engine vehicle, whether at rest or in motion.[85] The energy that electric and hybrid cars consume is usually generated by means that have environmental impacts. Nevertheless, adaptation of EVs would have a significant net environmental benefit, except in a few countries that continue to rely on older coal fired power plants for the bulk of their electricity generation throughout the life of the car.[86][87][88]

There are special kind of electric vehicles named SAFA TEMPO in Nepal that help lower the pollution created by vehicles.[89] These vehicles are powered by electricity - usually charged batteries - rather than oil or gas and currently heavily promoted by the government to facilitate environmental and vehicle management issues.. Electric motors don't require oxygen, unlike internal combustion engines; this is useful for submarines and for space rovers.

Mechanical

Tesla Model S chassis with drive motor

Cutaway view of a Tesla Model S drive motor

Electric motors are mechanically very simple and often achieve 90% energy conversion efficiency[90] over the full range of speeds and power output and can be precisely controlled. They can also be combined with regenerative braking systems that have the ability to convert movement energy back into stored electricity. This can be used to reduce the wear on brake systems (and consequent brake pad dust) and reduce the total energy requirement of a trip. Regenerative braking is especially effective for start-and-stop city use.

They can be finely controlled and provide high torque from rest, unlike internal combustion engines, and do not need multiple gears to match power curves. This removes the need for gearboxes and torque converters.

EVs provide quiet and smooth operation and consequently have less noise and vibration than internal combustion engines.[85] While this is a desirable attribute, it has also evoked concern that the absence of the usual sounds of an approaching vehicle poses a danger to blind, elderly and very young pedestrians. To mitigate this situation, automakers and individual companies are developing systems that produce warning sounds when EVs are moving slowly, up to a speed when normal motion and rotation (road, suspension, electric motor, etc.) noises become audible.[91]

Energy resilience

Electricity can be produced from a variety of sources, therefore it gives the greatest degree of energy resilience.[92]

Energy efficiency

EV 'tank-to-wheels' efficiency is about a factor of 3 higher than internal combustion engine vehicles.[85] Energy is not consumed while the vehicle is stationary, unlike internal combustion engines which consume fuel while idling. However, looking at the well-to-wheel efficiency of EVs, their total emissions, while still lower, are closer to an efficient gasoline or diesel in most countries where electricity generation relies on fossil fuels.[93][94][95]

Well-to-wheel efficiency of an EV has less to do with the vehicle itself and more to do with the method of electricity production. A particular EV would instantly become twice as efficient if electricity production were switched from fossil fuel to a wind or tidal primary source of energy. Thus, when "well-to-wheels" is cited, one should keep in mind that the discussion is no longer about the vehicle, but rather about the entire energy supply infrastructure - in the case of fossil fuels this should also include energy spent on exploration, mining, refining, and distribution.

Cost of recharge

According to General Motors, as reported by CNN Money, the GM Volt will cost "less than purchasing a cup of your favorite coffee" to recharge. The Volt should cost less than 2 cents per mile to drive on electricity, compared with 12 cents a mile on gasoline at a price of $3.60 a gallon. This means a trip from Los Angeles to New York would cost $56 on electricity, and $336 with gasoline. This would be the equivalent to paying 60 cents a gallon of gas.[96]

The reality is that the cost of operating an EV varies wildly depending on the part of the world in which the owner lives. In some locations an EV costs less to drive than a comparable gas-powered vehicle, as long as the higher initial purchase-price is not factored in (i.e. a pure comparison of gasoline cost to electricity cost). In the USA, however, in states which have a tiered electricity rate schedule, "fuel" for EVs today costs owners significantly more than fuel for a comparable gas-powered vehicle. A study done by Purdue University found that in California most users already reach the third pricing tier for electricity each month, and adding an EV could push them into the fourth or fifth (highest, most expensive) tier, meaning that they will be paying in excess of $.45 cents per KWH for electricity to recharge their vehicle. At this price, which is higher than the average electricity price in the US, it is dramatically more expensive to drive a pure-EV than it is to drive a traditional pure-gas powered vehicle. "The objective of a tiered pricing system is to discourage consumption. It's meant to get you to think about turning off your lights and conserving electricity. In California, the unintended consequence is that plug-in hybrid cars won't be economical under this system," said Tyner (the author), whose findings were published in the online version of the journal Energy Policy.[97]

Stabilization of the grid

Since EVs can be plugged into the electric grid when not in use, there is a potential for battery powered vehicles to even cut the demand for electricity by feeding electricity *into* the grid from their batteries during peak use periods (such as midafternoon air conditioning use) while doing most of their charging at night, when there is unused generating capacity.[98] This vehicle-to-grid (V2G) connection has the potential to reduce the need for new power plants, as long as vehicle owners do not mind reducing the life of their batteries, by being drained by the power company during peak demand.

Furthermore, our current electricity infrastructure may need to cope with increasing shares of variable-output power sources such as windmills and PV solar panels. This variability could be addressed by adjusting the speed at which EV batteries are charged, or possibly even discharged.

Some concepts see battery exchanges and battery charging stations, much like gas/petrol stations today. Clearly these will require enormous storage and charging potentials, which could be manipulated to vary the rate of charging, and to output power during shortage periods, much as diesel generators are used for short periods to stabilize some national grids.[99][100]

Range

Many electric designs have limited range, due to the low energy density of batteries compared to the fuel of internal combustion engined vehicles. EVs also often have long recharge times compared to the relatively fast process of refueling a tank. This is further complicated by the current scarcity of public charging stations. "Range anxiety" is a label for consumer concern about EV range.

Heating of EVs

In cold climates, considerable energy is needed to heat the interior of a vehicle and to defrost the windows. With internal combustion engines, this heat already exists as waste combustion heat diverted from the engine cooling circuit. This process offsets the greenhouse gases' external costs. If this is done with battery EVs, the interior heating requires extra energy from the vehicles' batteries. Although some heat could be harvested from the motor or motors and battery, their greater efficiency means there is not as much waste heat available as from a combustion engine.

However, for vehicles which are connected to the grid, battery EVs can be preheated, or cooled, with little or no need for battery energy, especially for short trips.

Newer designs are focused on using super-insulated cabins which can heat the vehicle using the body heat of the passengers. This is not enough, however, in colder climates as a driver delivers only about 100 W of heating power. A heat pump system, capable of cooling the cabin during summer and heating it during winter, seems to be the most practical and promising way of solving the thermal management of the EV. Ricardo Arboix[101] introduced (2008) a new concept based on the principle of combining the thermal-management of the EV-battery with the thermal-management of the cabin using a heat pump system. This is done by adding a third heat-exchanger, thermally connected with the battery-core, to the traditional heat pump/air conditioning system used in previous EV-models like the GM EV1 and Toyota RAV4 EV. The concept has proven to bring several benefits, such as prolonging the life-span of the battery as well as improving the performance and overall energy-efficiency of the EV.[102][103][104][105]

Electric public transit efficiency

Shifts from private to public transport (train, trolleybus, personal rapid transit or tram) have the potential for large gains in efficiency in terms of individual miles per kWh.

Research shows people do prefer trams,[106] because they are quieter and more comfortable and perceived as having higher status.[107] Therefore, it may be possible to cut liquid fossil fuel consumption in cities through the use of electric trams. Trams may be the most energy-efficient form of public transportation, with rubber wheeled vehicles using 2/3 more energy than the equivalent tram, and run on electricity rather than fossil fuels.

In terms of net present value, they are also the cheapest—Blackpool trams are still running after 100-years, but combustion buses only last about 15-years.

Incentives and promotion

Many governments offer incentives to promote the use of electric vehicles, with the goals of reducing air pollution and oil consumption. Some incentives intend to increase purchases of electric vehicles by offsetting the purchase price with a grant. Other incentives include lower tax rates or exemption from certain taxes, and investment in charging infrastructure.

Future

Ferdinand Dudenhoeffer, head of the Centre of Automotive Research at the Gelsenkirchen University of Applied Sciences in Germany, said that "by 2025, all passenger cars sold in Europe will be electric or hybrid electric".[108]

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

Improved batteries

First, advances in lithium ion batteries, in large part driven by the consumer electronics industry, allow full-sized, highway-capable EVs to be propelled as far on a single charge as conventional cars go on a single tank of gasoline. Lithium batteries have been made safe, can be recharged in minutes instead of hours (see recharging time), and now last longer than the typical vehicle (see lifespan). The production cost of these lighter, higher-capacity lithium batteries is gradually decreasing as the technology matures and production volumes increase (see price history).

Tesla Model S, since 2012. 0 to 100 km/h in 2.5 seconds, recharging in 30 minutes to 80 percent, range 600 km

Toyota Motors Corporation is trying to replace the current lithium ion battery with solid-state battery technology by 2020. The solid-state battery replaces the liquid electrolyte with a solid electrolyte.[109][110]

Rechargeable lithium-air batteries potentially offer increased range over other types and are a current topic of research.[111]

Battery management and intermediate storage

Another improvement is to decouple the electric motor from the battery through electronic control, employing supercapacitors to buffer large but short power demands and regenerative braking energy. The development of new cell types combined with intelligent cell management improved both weak points mentioned above. The cell management involves not only monitoring the health of the cells but also a redundant cell configuration (one more cell than needed). With sophisticated switched wiring it is possible to condition one cell while the rest are on duty.

EV organizations

Worldwide

- The World Electric Vehicle Association (WEVA), chairman Hisashi Ishitani, formed by:
- Electric Drive Transportation Association (EDTA)
- Electric Vehicle Association of Asia Pacific (EVAAP)
- European Association for Battery, Hybrid and Fuel Cell Electric Vehicles (AVERE)
- Multilateral Cooperation to Advance Electric Vehicles
- The Implementing Agreement for co-operation on Hybrid and Electric Vehicle Technologies and Programmes (A-HEV) - IA-HEV was formed in 1993 to produce and disseminate balanced, objective information about advanced electric, hybrid, and fuel cell vehicles. IA-HEV is an international membership group collaborating under the International Energy Agency (IEA) framework.

Europe

- ECars-Now!
- EV Cup
- Avere-France
- Electric Vehicles Industrial Cluster - Bulgaria

North America

- Alternative Technologies Institute
- Big Island EV Association
- Drive Oregon
- East Coast Electric Drag Racing Association
- Electric Auto Association (EAA) (North America) and its chapter Plug In America.
- Vancouver Electric Vehicle Association founded 1998 and chapter of Electric Auto Association.
- Inno-VÉ
- National Electric Drag Racing Association
- Project EVIE

Asia

- Charged Hong Kong
- Society of Manufacturers of Electric Vehicles (SMEV), India www.smev.in (http://www.smev.in)
- Australian Electric Vehicle Association (AEVA) [2] (http://www.aeva.asn.au)

See also

- Battery electric vehicle
- Battery swapping
- Bumper cars
- Dual-mode vehicle
- Electrathon
- Electric bicycle
- Electric car use by country
- Electric go-kart
- Electric rickshaw
- Electric-steam locomotive
- Electric Vehicle Company
- Electric vehicle conversion
- Electric vehicle production
- Electric Vehicle Technical Center
- Electric vehicle industry in India
- Electrocar
- Electromote
- European Electric Motor Show
- FIA Formula E Championship
- Human-electric hybrid vehicle
- Hybrid electric vehicle
- List of production battery electric vehicles
- Motorized bicycle
- Neighborhood electric vehicle (NEV)
- Online Electric Vehicle
- Plug-in electric vehicle:
- Plug-in electric vehicle fire incidents
- Plug-in hybrid
- Project Get Ready
- Renewable energy by country
- Superbus (transport)
- Traction motor
- Tribrid vehicle
- Trolley bus
- Trolleytruck
- Vehicle glider

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External links

Wikimedia Commons has media related to ***Electrically powered vehicles***.

- Alternative Fueling Station Locator (http://www.eere.energy.gov/afdc/fuels/stations_locator.html), charging stations (EERE).

- Fleet Test and Evaluation Project (http://www.nrel.gov/transportation/fleettest.html) – Electric and Plug-In Hybrid Electric Fleet Vehicle Testing (http://www.nrel.gov/transportation/fleettest_electric.html) (National Renewable Energy Laboratory (http://www.nrel.gov/))
- European strategy on clean and energy efficient vehicles (http://ec.europa.eu/enterprise/sectors/automotive/competitiveness-cars21/energy-efficient/index_en.htm) (European Commission)
- Transport Action Plan: Urban Electric Mobility Initiative (http://www.un.org/climatechange/summit/wp-content/uploads/sites/2/2014/09/TRANSPORT-Action-Plan-UEMI.pdf), United Nations, Climate Summit 2014, September 2014

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