

# Encyclopedia of Electric Vehicles

Seema Melvin



First Edition, 2012

ISBN 978-81-323-2749-3

WWT

© All rights reserved.

*Published by:*  
**Orange Apple**  
4735/22 Prakashdeep Bldg,  
Ansari Road, Darya Ganj,  
Delhi - 110002  
Email: [info@wtbooks.com](mailto:info@wtbooks.com)

---

WORLD TECHNOLOGIES

---

# Table of Contents

Chapter 1 - Electric Vehicle

Chapter 2 - Electric Car

Chapter 3 - Electric Locomotive

Chapter 4 - Electric Aircraft

Chapter 5 - Electric Boat

Chapter 6 - Electric Motorcycles and Scooters

WWT

## Chapter- 1

# Electric Vehicle

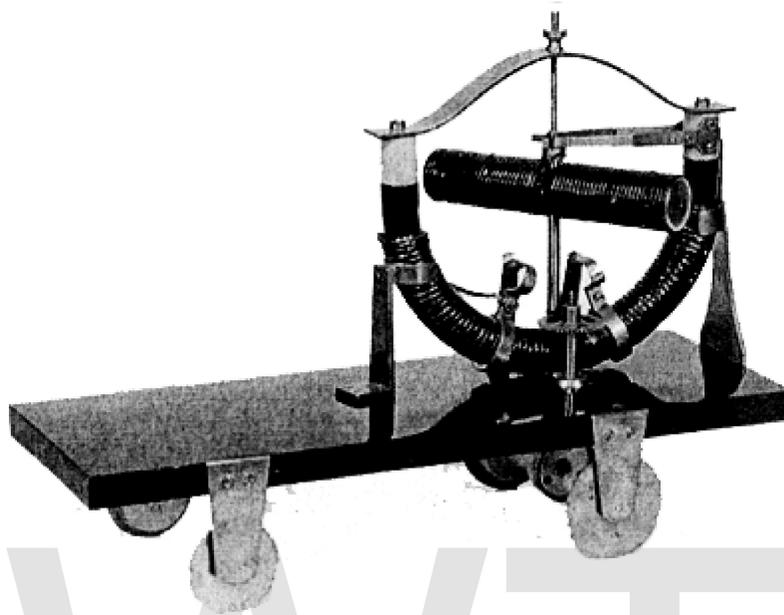
An **electric vehicle (EV)**, also referred to as an **electric drive vehicle**, uses one or more electric motors for propulsion. Electric vehicles include electric cars, electric trains, electric lorries, electric aeroplanes, electric boats, electric motorcycles and scooters and electric spacecraft.

Electric vehicles 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) is the dominant propulsion method for motor vehicles but electric power has remained commonplace in other vehicle types, such as trains and smaller vehicles of all types.

During the last few decades, increased concern over the environmental impact of the petroleum-based transportation infrastructure, along with the peak oil, has led to renewed interest in an electric transportation infrastructure. Electric vehicles 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. However it is generated, this energy is then transmitted to the vehicle through use of overhead lines, wireless energy transfer such as inductive charging, or a direct connection through an electrical cable. The electricity may then be stored onboard 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 electric or hybrid electric vehicles is regenerative braking and suspension; their ability to recover energy normally lost during braking as electricity to be restored to the on-board battery.

In 2003, the first mass-produced hybrid gasoline-electric car, the Toyota Prius, was introduced worldwide, in the same year GoinGreen in London launched the G-Wiz electric car, a quadricycle that became the world's best selling EV, and the first battery electric car produced by a major auto company, the Nissan Leaf will debut in December 2010. Other major auto companies have electric cars in development, and the USA and other nations are building pilot networks of charging stations to recharge them.

## History



Electric vehicle model by Ányos Jedlik, an early electric motor experimenter ( 1828, Hungary) .



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



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

Electric motive power started with a small drifter operated by a miniature electric motor, built by Thomas Davenport 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.

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.

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, 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.

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.

Electric vehicles 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 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 conspiracy, but were acquitted of conspiring to monopolize the provision of transportation services. Electric tram line technologies could be used to recharge BEVs and PHEVs on the highway while the user drives, providing virtually unrestricted driving range. The technology is old and well established. The infrastructure has not been built.

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 1) the auto industry's successful federal court challenge to California's zero-emissions vehicle mandate, 2) a federal regulation requiring GM to produce and maintain spare parts for the few thousands EV1s and 3) the success of the oil and auto industries' media campaign to reduce public acceptance of electric vehicles.



EV1

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.

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 now sell, five years later, at over their original forty-thousand-dollar price.

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

With increasing prices of gasoline, electric vehicles are hitting the mainstream.

Major car makers, such as Daimler AG, Toyota Motor Corp., General Motors Corp., Renault SA, Peugeot-Citroen, VW, Nissan and Mitsubishi Corp., are developing new-generation electric vehicles.

## Electricity sources



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



An electric Locomotive at Brig

There are many ways to generate electricity, some of them more ecological than others:

- 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)
  - static energy stored on the vehicle in on-board electric double-layer capacitors
  - kinetic energy storage: flywheels
- direct connection to generation plants as is common among electric trains, trolley buses, and trolley trucks
- renewable sources such as solar power: solar vehicle
- 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

It is also possible to have hybrid electric vehicles 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

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.

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

For especially large electric vehicles, 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.

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

## **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 most electric motors deliver 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.

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, DC motors are often used.

## **Vehicle types**

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

### **Hybrid electric vehicle**

A hybrid electric vehicle combines a conventional (usually fossil fuel-powered) powertrain with some form of electric propulsion. Common examples include hybrid electric cars such as the Toyota Prius.

## On- and off-road electric vehicles

Electric vehicles are on the road in many functions, including electric cars, electric trolleybuses, 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.

## Railborne electric vehicles



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

The fixed nature of a rail line makes it relatively easy to power electric vehicles 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 braking can put braking power back into the electrical grid rather than wasting it.

Maglev trains are also nearly always electric vehicles.

### **Airborne electric vehicles**

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 electric vehicles**

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. Submarines use batteries (charged by diesel or gasoline engines at the surface), nuclear power, or fuel cells to run electric motor driven propellers.

### **Spaceborne electric vehicles**

Electric power has a long history of use in spacecraft. 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



An electric bus at Lucerne

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.

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.

# Issues regarding electric vehicles

## Energy sources

Although electric vehicles 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 electric vehicles use whatever electricity is delivered by their electrical utility/grid operator, electric vehicles 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.

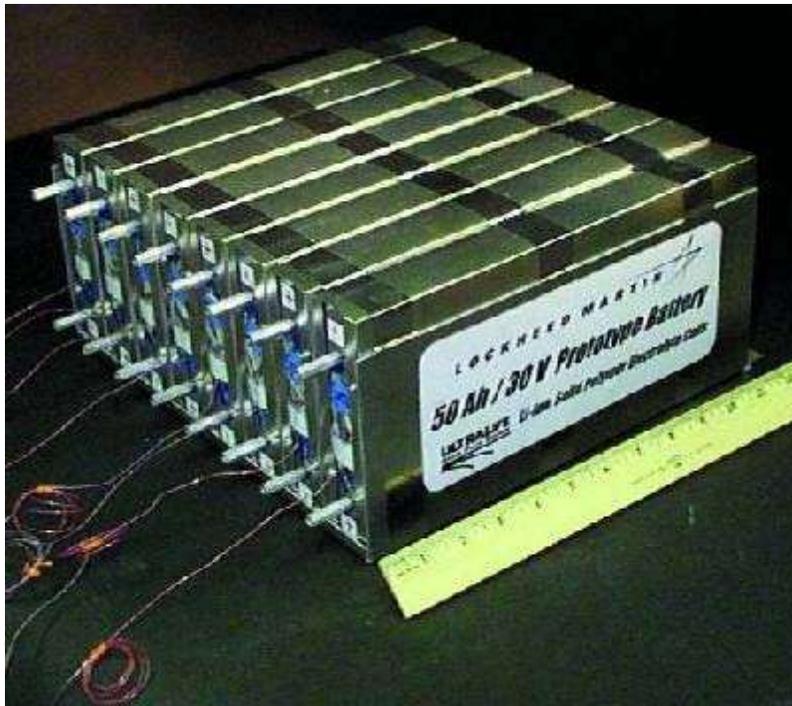
Fossil fuel vehicle efficiency and pollution standards take years to filter through a nation's fleet of vehicles. New efficiency and pollution standards rely on the purchase of new vehicles, often as the current vehicles already on the road reach their end-of-life. Only a few nations set a retirement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

Electric vehicles 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



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



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.

### **Efficiency**

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

### **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. 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 electric vehicles 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.

### **Charging stations**

Electric vehicles 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 in the UK and Europe, electric vehicle 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.

One proposed solution for daily recharging is a standardized inductive charging system such as Evatran's Plugless Power. Benefits are the convenience of with parking over the charge station and minimized cabling and connection infrastructure.

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 OEM's 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 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.

According to Department of Energy research conducted at Pacific National Laboratory, 84% of existing vehicles could be switched over to plug-in hybrids without requiring any new grid infrastructure. 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).

The emissions would be displaced away from street level, where they have "high human-health implications."

### **Battery swapping**

There is another way to "refuel" electric vehicles. Instead of recharging them from electric socket, batteries could be mechanically replaced on special stations just 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. 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.

### **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 EESstor's EESU, could improve lithium ion energy density several times over if they can be produced. Lithium-sulphur batteries offer 250Wh/kg. Sodium-ion batteries promise 400Wh/kg with only minimal expansion/contraction during charge/discharge and a very high surface area. Researchers from one of the Ukrainian state universities claim that they have manufactured samples of supercapacitor based on intercalation process with 318 W-h/kg specific energy, which seem to be at least two times improvement in comparison to typical Li-ion batteries.

### **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 to ensure that cars with a high voltage electric power train, such as hybrid and fully electric vehicles, are as safe as combustion 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

# Advantages of electric vehicles

## Environmental

Due to efficiency of electric engines as compared to combustion engines, even when the electricity used to charge electric vehicles comes from a CO<sub>2</sub> emitting source, such as a coal or gas fired powered plant, the net CO<sub>2</sub> production from an electric car is typically one half to one third of that from a comparable combustion vehicle.

Electric vehicles release almost no air pollutants at the place where they are operated. In addition, it is generally easier to build pollution control systems into centralised power stations than retrofit enormous numbers of cars.

Electric vehicles typically have less noise pollution than an internal combustion engine vehicle, whether it is at rest or in motion. Electric vehicles emit no tailpipe CO<sub>2</sub> or pollutants such as NO<sub>x</sub>, NMHC, CO and PM at the point of use.

Electric motors don't require oxygen, unlike internal combustion engines; this is useful for submarines.

## Mechanical



An Alkè electric city van.

Electric motors are mechanically very simple.

Electric motors often achieve 90% energy conversion efficiency 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.

Electric vehicles provide quiet and smooth operation and consequently have less noise and vibration than internal combustion engines. 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 electric vehicles are moving slowly, up to a speed when normal motion and rotation (road, suspension, electric motor, etc.) noises become audible.

### **Energy resilience**

Electricity is a form of energy that remains within the country or region where it was produced and can be multi-sourced. As a result it gives the greatest degree of energy resilience.

### **Energy efficiency**

Electric vehicle 'tank-to-wheels' efficiency is about a factor of 3 higher than internal combustion engine vehicles. It does not consume energy when it is not moving, unlike internal combustion engines where they continue running even during idling. However, looking at the well-to-wheel efficiency of electric vehicles, their emissions are comparable to an efficient gasoline or diesel in most countries because electricity generation relies on fossil fuels.

### **Cost of recharge**

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.

### **Stabilization of the grid**

Since electric vehicles can be plugged into the electric grid when not in use, there is a potential for battery powered vehicles to even out 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. This Vehicle to Grid (V2G) connection has the potential to reduce the need for new power plants.

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.

## **Disadvantages of electric vehicles**

### **Environmental impact**

While electric and hybrid cars have reduced tailpipe carbon emissions, the energy they consume is produced by means that have environmental impacts. A majority of the electricity produced in the United States comes from fossil fuels (coal and natural gas). Electric and hybrid cars can help decrease energy use and pollution and may someday use only renewable resources, but the choice that would have nearly zero environmental impact today would be a lifestyle change in favor of walking, biking, use of public transit or telecommuting. Governments may invest in research and development of electric cars with the intention of reducing the impact on the environment where they could instead develop pedestrian-friendly communities or electric mass transit.

### **Range**

Many electric designs have limited range, due to the low energy density of batteries compared to the fuel of internal combustion engines. Electric vehicles 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 electric vehicles**

In cold climates considerable energy is needed to heat the interior of the vehicle and to defrost the windows. With internal combustion engines, this heat already exists due to the combustion process (offsetting the greenhouse gases' external costs) from the waste heat from the engine cooling circuit. If this is done with battery electric cars, this will require extra energy from the battery or an additional battery and circuit for accessories. Although some heat could be harvested from the motor(s) and battery, due to their greater efficiency there is not as much waste heat available as from a combustion engine.

However, when plugged into the grid electric vehicles can be preheated, or cooled, and need little or no energy from the battery, especially for short trips.

Newer designs are focused on using super-insulated cabins which can heat the car 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 reversible AC-system, 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 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 reversible AC-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.

## **Electric public transit efficiency**

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

Research shows people do prefer trams, because they are quieter and more comfortable and perceived as having higher status.

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**

### **United States**

In 2003 the Energy Information Administration (EIA) estimated there would be 55,852 Full-electric vehicles (FEV) in 2004, with an annual growth rate of 39.1 % (excluding in this estimation electric hybrids).

The EIA's 2007 Annual Energy Review (AER) estimates the actual number of FEV's on the road in 2004 as 49,536 and a preliminary estimated 2006 number of 53,526.

President Barack Obama has announced \$2.4 billion for electric vehicles. \$1.5 billion in grants to U.S. based manufacturers to produce highly efficient batteries and their components; up to \$500 million in grants to U.S. based manufacturers to produce other components needed for electric vehicles, such as electric motors and other components; and up to \$400 million to demonstrate and evaluate Plug-In Hybrids and other electric infrastructure concepts—like truck stop charging station, electric rail, and training for technicians to build and repair electric vehicles (greencollar jobs).

Qualifying electric vehicles purchased new are eligible for a one-time federal tax credit that equals 10% of the cost of the vehicle up to \$4,000, provided under Section 179A of the Energy Policy Act of 1992; it was extended through 2007 by the Working Families Tax Relief Act of 2004. A tax deduction of up to \$100,000 per location is available for qualified electric vehicle recharging property used in a trade or business.

In 2008, San Francisco Mayor Gavin Newsom, San Jose Mayor Chuck Reed and Oakland Mayor Ron Dellums announced a nine-step policy plan for transforming the Bay Area into the "Electric Vehicle (EV) Capital of the U.S." Other local and state governments have also expressed interest in electric cars.

In March 2009, as part of the American Recovery and Reinvestment Act, the U.S. Department of Energy announced the release of two competitive solicitations for up to \$2 billion in federal funding for competitively awarded cost-shared agreements for manufacturing of advanced batteries and related drive components as well as up to \$400 million for transportation electrification demonstration and deployment projects. This announcement will also help meet President Barack Obama's goal of putting one million plug-in hybrid vehicles on the road by 2015.

The American Clean Energy and Security Act (ACES), which passed the Energy and Commerce Committee on May 21, 2009, has extensive provisions for electric cars. The bill calls for all electric utilities to, "develop a plan to support the use of plug-in electric drive vehicles, including heavy-duty hybrid electric vehicles". The bill also provides for "smart grid integration," allowing for more efficient, effective delivery of electricity to accommodate the additional demands of plug-in electric vehicles. Finally, the bill allows for the Department of Energy to fund projects that support the development of electric vehicle and smart grid technology and infrastructure.

The House of Representatives passed legislation in late 2008, enumerating tax credits ranging from \$2500 to \$7500 for electric vehicle buyers. The actual credit varies depending on the specified vehicle's battery capacity. The Chevrolet Volt and the Tesla vehicles are eligible for the full \$7500 credit. The bill called for the credit to be applicable for the first 250,000 vehicles sold per manufacturer. The credits were passed in 2008 but went into effect on January 1, 2009, and can be currently used on the Tesla all-electric models. The Volt, plug-in Prius, and other PHEV's and BEV's will also be eligible for the credit when they are released in the coming years. The new credits update incentives introduced in 2006, that offered credits for gas-electric hybrids, "Based on a formula determined by vehicle weight, technology, and fuel economy compared to base

year models", which expired after 60,000 units per manufacturer. The new credits will only apply to plug-in EVs and all-electric vehicles.

## **European Union**

Electrification of transport (electromobility) figures prominently in the Green Car Initiative (GCI), included in the European Economic Recovery Plan. DG TREN is supporting a large European "electromobility" project on electric vehicles and related infrastructure with a total budget of around €50-million as part of the Green Car Initiative.

There are measures to promote efficient vehicles in the Directive 2009/33/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of clean and energy-efficient road transport vehicles and in the Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services.

AVERE has a table summarizing the taxation and incentives for these vehicles in the different European countries, related to state subsidies, reduction of VAT and other taxes, insurance facilities, parking and charging facilities (including free recharging on street or in the parking areas), EVs imposed by law and banned circulation for petroleum cars, permission to use bus lanes, free road tax, toll free travel on highways, exemption from congestion charging, free or reduced parking rates, and free charging at charge points, amongst other initiatives. In Denmark, petrol cars are taxed at 180% + 25%, however, EV cars (max. 2000 kg total weight) are only taxed at 25%. Free parking is also offered to EVs in Copenhagen and other cities, and there is free recharging at some parking spaces.

## **EU member states**

### **Republic of Ireland**

In the Republic of Ireland, Green Party minister for Energy, Eamon Ryan announced a scheme to deploy 1,500 electrical recharging stations for use with EVs. In addition, 30 high voltage fast charging units will be deployed, providing a high speed recharge facility every 60 km on interurban routes. Electricity supplied from these recharging points will be free initially. Additional incentives towards the purchase of EVs were announced, including a €5,000 capital grant. Series production electric vehicles have been exempted from VRT. Annual motor tax for electric vehicles is €104. The Government has set a target of 10% for all vehicles on Irish roads to be electric by 2020.

### **Finland**

In Finland the prime minister of Finland Mr. Matti Vanhanen has mentioned that he wants to see more electric cars on Finnish roads as soon as possible and with any cost to the governmental car related tax incomes. Charging at home from motor and cabin heating outlets (common in all Nordic countries) has been determined to be a possible

load on the grid. If all cars in Finland run totally on electricity, it will add 7-9 TWh annually to the load, which corresponds to 10 % of Finland's annual consumption.

#### **Denmark**

Denmark was planning to introduce a greater number of battery driven electric cars on the streets — charged on renewable energy from the country's many windmills — ahead of the UN Climate Summit that descended on Copenhagen in December 2009. A great deal of the electricity is generated by windmills.

#### **Germany**

"National Electric Mobility Platform" (NEMP) is a German government initiative to develop Germany into a leading market for electric mobility, with about 1 million electric vehicles on its streets by 2020.

As the latest development (October 2010) DBM Energy's electric Audi A2 completes record setting 372 mile drive on a single charge.

#### **Portugal**

The Portuguese Government launched in early 2008 a national Programme for Electric Mobility called Mobi.E.

MOBI.E is based on an innovative approach to electric mobility. It has an open-access and market-oriented philosophy and, as a result, it proposes a fully integrated and totally interoperable system, multi-retailer and multi-operator model. Rather than a local experience, Mobi.E is deploying a national electric mobility system. However, the system was designed to be scalable and used in multiple geographies, overcoming the current situation of lack of communication among the different electric mobility experiences that are being deployed in Europe.

Mobi.E allows any individual the access to any provider of electricity in any charging point explored by any service operator. This ensures transparency, low entry barriers and competition along the value chain, with the goal of attracting private investors and benefiting the users, contributing to a faster expansion of the system.

Therefore, Portugal is one of the first countries in the world to have an integrated policy for electric mobility and a national charging network for Electric Vehicles. By the first semester of 2011, a wide public network of 1 300 normal and 50 fast charging points will be fully implemented in the main 25 cities of the country, thus allowing electric vehicle users the ability to travel throughout the country in all comfort and safety.

In the top of the system there is a “Managing Authority” which acts as a Clearing House and intermediates the financial, information and energy flows among users, electricity sellers, operators of charging points, and the providers of any other associated service.

Additionally, several measures were taken to increase the demand for EVs in Portugal: (1) EVs are fully exempt from both the Vehicle Tax due upon purchase (Imposto Sobre Veículos) and the annual Circulation Tax (Imposto Único de Circulação); (2) Personal Income Tax provides an allowance of EUR 803 upon the purchase of EVs; (3) EVs are fully exempt from the 5%-10% company car tax rates which are part of the Corporation Income Tax; (4) The Budget Law provides for an increase of the depreciation costs related to the purchase of EVs for the purpose of Corporation Income Tax; (5) the first 5,000 EVs to be sold in Portugal will receive a 5,000€ incentive fund, and the Cash-for-Clunkers program grants an additional 1,500€ fund if a internal combustion engine vehicle built before 2000 is delivered when acquiring the new EV; (6) The Portuguese State did also commit to play a pedagogic role and defined that EVs will have a 20% share of the annual renewal of public car fleet, starting in 2011.

## **Spain**

“ Electric vehicles are the future and the driver of the industrial revolution ”

—Miguel Sebastián, Spanish Industry Minister

Spain's government aims to have 1 million electric cars on the roads by 2014 as part of a plan to cut energy consumption and dependence on expensive imports, Industry Minister Miguel Sebastián said.

## **United Kingdom**

In October 2008 the then UK Prime Minister Gordon Brown pledged £100 million in government money to support electric, hybrid and other more environmentally friendly car projects over a five-year period to help make Britain "the European capital for electric cars".

One of these projects was the Plugged-in-Places initiative which was a UK government incentive to encourage the take up of electric vehicles. London, Milton Keynes and the North East were selected as part of phase 1 of the project and are set to receive £30 million funding from the Office of Low Emission Vehicles (OLEV) to install 11,000 recharging points and help shape the future of the UKs electric vehicle infrastructure

In July 2010, the UK also announced it would honour a grant starting in January 2011 to give EV buyers a discount of 25%, of up to £5000 when buying an electric vehicle, provided the vehicle is one of a pre-approved selection of electric vehicles.

In December 2010 it was announced that Midlands, Greater Manchester, East of England, Scotland and Northern Ireland will make up the areas included as part of phase 2 of the "Plugged-in places" program and will share £20 Million of government funding, supplied by the Office of Low Emission Vehicles (OLEV).

## **China**

Many electric vehicle companies are looking to China as the leader of future electric car implementation around the world. In April 2009, Chinese officials announced their plan to make China the world's largest producer of electric cars. The Renault-Nissan Alliance will work with China's Ministry of Industry and Information Technology (MITI) to help set up battery recharging networks throughout the city of Wuhan, the pilot city in the country's electrical vehicle pilot program. The corporation plans to have electric vehicles on the market by 2011. According to an April 10, 2009 *New York Times* article entitled "China Outlines Plans for Making Electric Cars" auto manufacturers will possess the opportunity to successfully market their cars to Chinese consumers due to the short and slow commutes that characterize Chinese transportation, and many first time car-buyers are less accustomed to the power of gasoline-powered cars, subsequently diminishing the hindering nature of lower powered electric vehicles. It reports that China would like to assist the industry with automotive innovation by launching a program that worths as much as 10 billion yuan (\$1.46 billion). In the same article, it also reports that the U.S. government is providing \$25 billion to help cover domestic automobile makers' research costs.

In 2010, it is reported that China, aiming to improve air quality and reduce reliance on fossil fuels, is going to commence a two-year pilot program of subsidizing buyers of alternative- energy cars in the five cities: Shanghai, Changchun, Shenzhen, Hangzhou and Hefei. The subsidy will be as much as 60,000 yuan for battery electric cars and 50,000 yuan (\$7,320) for plug-in hybrids. In 2009, BYD delivered 48 F3DM plug-in hybrids in the country. China also plans to expand a project of encouraging the use of energy-efficient and alternative-energy vehicles in public transport to 20 cities from 13. The chief executive of Nissan Carlos Ghosn said earlier that the auto maker would likely produce the Leaf, a battery electric vehicle, in China if there are "substantial" purchase incentives offered to buyers.

## **Japan**

In June 2009, it is reported that consumers in Japan who purchase an electric vehicle like i-MiEV from Mitsubishi can receive subsidies that reduce cost of the vehicle to 3.209 million yen(about \$33,000), down 30% from the original price of 4.59 million yen (\$47,560). At that time, it is reported the program runs from April 2009 to March 2010. Electric cars, as well as hybrids, are also exempt from taxes for three years in Japan.

## **Production**

Electric vehicles are hitting the mainstream. Automakers has showcased at the 2009 Washington Auto Show and subsequents their commitment to quickly bringing electric hybrid and all-electric vehicles to market as early as 2010.

## **World production race**

All major carmakers, such as Ford Motor Co., Daimler AG, Toyota Motor Corp., General Motors Corp., Renault SA, Peugeot-Citroen, VW and Mitsubishi Corp., are developing new-generation electric vehicles. Automakers are in a new race to be the first to market an all-electric car to claim the mantle as the world's greenest automaker.

## **South Africa**

- Joule, designed by Cape Town-based Optimal Energy, made its debut at the 2008 Paris Motor Show, has a maximum driving range of 300 km. It accommodates two large-cell lithium ion battery packs.
- GridCars, Is a Pretoria based company promoting Commuter Cars, their launch vehicle is based on the TREV from Australia. The idea is to build ultra-light electric vehicles, placing less demand on battery requirements, and making the vehicle more affordable.

## **China**

- Shenzhen GreenWheel Electric Vehicle
- Zotye International
- EPower Cars
- Guangzhou Langqing Electric Car Co., Ltd.
- BYD F6DM (2008)
- Nanjing Dongyu Electric Motorcycle&Electric Bicycle
- Tradwin Hongkong International(Distributor)

## **European Union**

### **Cars**

- Malone TAZR (2010) Small private company producing lithium battery powered three wheeled electric sports car.
- Morgan LifeCar (2009+)
- Lightning GT (2009+)
- Imperia GP (2010), from 70,248€ Excl. VAT, preorders in 2009
- eRUF

## Commercial



An Aixam electric van.

- Smith Electric Vehicles Edison Van
- Modec Van
- Aixam *Mega* mini van

Portugal and Spain want to create the first green car in Iberia, hoping to generate 150 million euros worth of investment and 800 new jobs in the region's struggling motor industry. The green car, which could be powered by electricity. The Mobi-green car, as the vehicle is named, is being developed by two automotive research centres in Portugal and Spain using funds from both the public and private sectors.

London, England is at the forefront and a London-based entrepreneur has just unveiled a three-wheeled zero-emission electric vehicle aimed at delivery fleets. The A-Kar is powered by lithium-ion battery cells and takes five hours for a full charge, giving a range of 70 miles and a top speed of 35 mph.

## **India**

Practically the only EV to have been manufactured for several years is the Indian REVA. It is produced by REVA Electric Car Company Private Ltd. (RECC) in Bangalore, India, a company established in 1994 as a joint venture between the Maini Group India and AEV LLC, California USA. After seven years of R&D, they commercialized the first REVA car in June 2001.

The current version of the REVA is the REVAi. It was first reserved for the Indian market, but it is now distributed in several European countries: UK (by GoinGreen under the name G-Wiz), Cyprus and Greece (by REVA Phaedra Electricity Mobility Ltd., Belgium (by Green Mobil), Norway (by Ole Chr. Bye AS), Iceland (by Perlukafarinn ehf), Spain (by Emovement) and Germany (by Elektro PKW, the REVA is also available in the Republic of Ireland GreenAer. It may be exported to the USA with a speed limiter for use as a Neighborhood Electric Vehicle (NEV).

In July 2010, the government of Tamil Nadu allocated land in Ranipet to Bavina Cars India for production of electric cars. The plant is set to be operational by 2011.

In addition to Bangalore-based Reva, which currently is the only company actually selling EVs today, electric cars made in India includes:

- Mahindra & Mahindra: Four-seat model by 2010.
- Tata: 2008-2009 (also possibly an air car).
- Ajanta Group: clockmaker with plans for low-cost electric vehicle.
- Tara: Low-cost EV less than a Tata Nano.
- Hero Electric: 2013 Electric car.

With Tata, Ajanta and Tara talking about 'low-cost' cars and "less than a Tata Nano".

## **United States**

Startups are taking the lead in electric vehicles in North America

- Myers Motors, a small private compan

## **Buying and leasing**

### **U.S. Army**

The U.S. Army has announced that it will lease 4,000 Neighborhood Electric Vehicles (NEVs) within three years. The Army plans to use NEVs at its bases for transporting people around the base, as well as for security patrols and maintenance and delivery services. The Army accepted its first six NEVs at Virginia's Fort Myer in March 2009 and will lease a total of 600 NEVs through the rest of the year, followed by the leasing of 1,600 NEVs for each of the following two years. With a full eight-hour recharge, the NEVs can travel 30 miles (48 km) at a top speed of 25 mph (40 km/h).

### **General Electric**

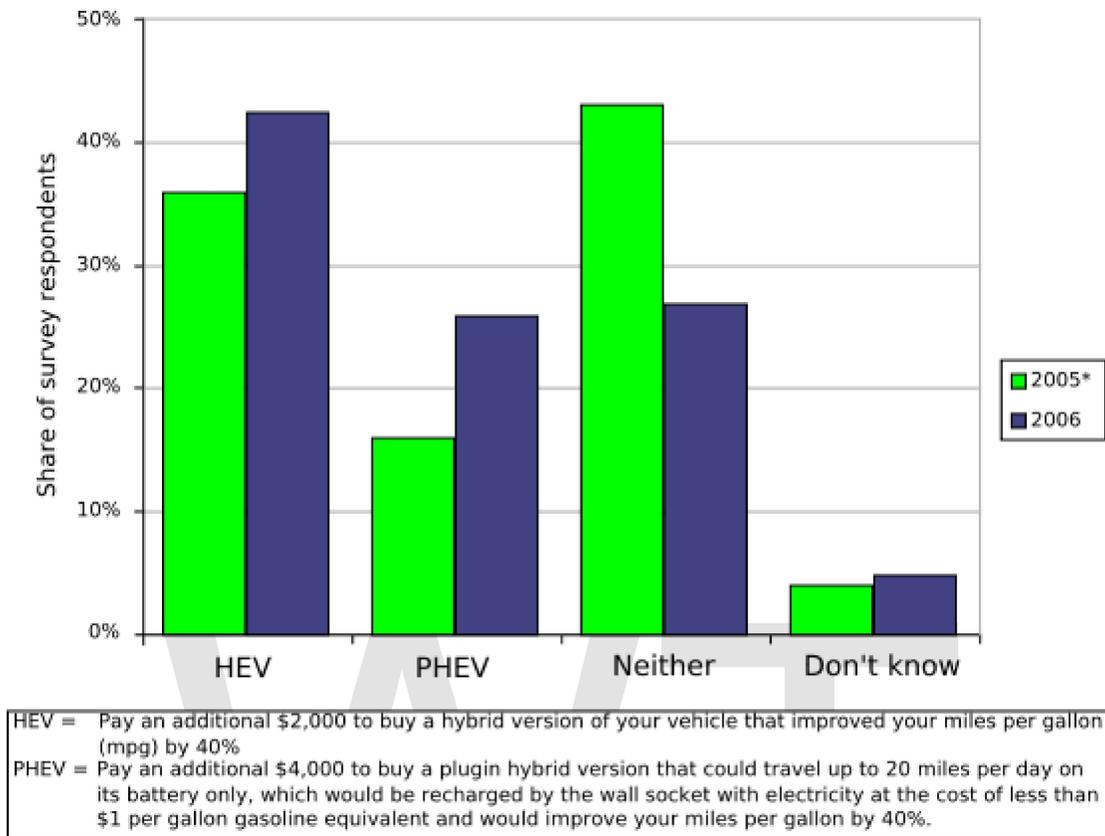
On November 11, 2010, General Electric (GE) announced its plans to buy 25,000 electric vehicles by the year 2015. GE's chief executive, Jeffrey Immelt, said that specifically, the company would convert half of its corporate fleet vehicles to electric vehicles by the year 2015 in an effort to give the new technology a jump start along with helping to develop a potentially big new consumer market for the vehicles. GE told the media that by electrifying its own fleet, the company will accelerate the adoption curve, drive scale, and move of electric vehicles from anticipation to action. The company had originally hinted at this plan in late September.

The details of the announcement were that GE said it will buy 12,000 GM vehicles starting next year, beginning with the Chevy Volt. GE also plans to add other different types of electric vehicles as a variety of automakers expand their electric car offerings and more cars come to the market. Every major automaker has plans to introduce cars that can be powered by electricity over the next two years. In addition, GE is hoping that its planned purchase will help drive down costs by increasing production volumes and assuring automakers that they will have at least one big buyer in the near future.

# Future



Eliica Battery Electric Car with 370 km/h top speed and 200 km range



The number of US survey respondents willing to pay \$4,000 more for a plug-in hybrid car increased from 17% in 2005 to 26% in 2006.

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.

Several startup companies like Tesla Motors, Ronaele Incorporated, Commuter Cars, Phoenix Motorcars, Miles Electric Vehicles, and Aptera Motors will have powerful battery-electric vehicles available to the public in 2008. Battery and energy storage technology is advancing rapidly. The average distance driven by 80% of citizens per day in a car in the US is about 50 miles (US dept of transport, 1991), which fits easily within the current range of the electric car. This range can be improved by technologies such as Plug-in hybrid electric vehicles which are capable of using traditional fuels for unlimited range, rapid charging stations for BEVs, improved energy density batteries, flow batteries, or battery swapping.

In 2006 GM began the development of a plug-in hybrid that will use a lithium-ion battery. The vehicle, initially known as the iCar, is now called the Chevrolet Volt. The basic design was first exhibited January 2007 at the North American International Auto Show. GM is planning to have this EV ready for sale to the public in the latter half of 2010. The car is to have a 40-mile (64 km) range. If the battery capacity falls below 30

percent a small internal combustion engine will kick in to charge the battery on the go. This in effect increases the range of the vehicle, allowing it to be driven until it can be fully charged by plugging it into a standard household AC electrical source.

On October 29, 2007, Shai Agassi launched Project Better Place, a company focused on building massive scale Electric Recharge Grids as infrastructure supporting the deployment of electric vehicles (including plug-in hybrids) in countries around the world. On January 21, PBP and the Nissan–Renault group signed a MOU - PBP will provide the battery recharging and swapping infrastructure and Renault-Nissan will mass-produce the vehicles.

### **Improved long term energy storage and nano batteries**

There have been several developments which could bring electric vehicles outside their current fields of application, as scooters, golf cars, neighborhood vehicles, in industrial operational yards and indoor operation. First, advances in lithium-based battery technology, in large part driven by the consumer electronics industry, allow full-sized, highway-capable electric vehicles 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, and now last longer than the typical vehicle. The production cost of these lighter, higher-capacity lithium batteries is gradually decreasing as the technology matures and production volumes increase.

Rechargeable Lithium-air batteries potentially offer increased range over other types and are a current topic of research.

### **Introduction of battery management and intermediate storage**

Another improvement is to decouple the electric motor from the battery through electronic control, employing ultra-capacitors 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.

### **Faster battery recharging**

By soaking the matter found in conventional lithium ion batteries in a special solution, lithium ion batteries were supposedly said to be recharged 100x faster. This test was however done with a specially-designed battery with little capacity. Batteries with higher capacity can be recharged 40x faster. The research was conducted by Byoungwoo Kang and Gerbrand Ceder of MIT. The researchers believe the solution may appear on the market in 2011. Another method to speed up battery charging is by adding an additional oscillating electric field. This method was proposed by Ibrahim Abou Hamad from

Mississippi State University. The company Epyon specializes in faster charging of electric vehicles.

WWT

## Chapter- 2

# Electric Car



The REVAi/G-Wiz i electric car charging from an on-street station in London

An **electric car** is a plug-in battery powered automobile which is propelled by electric motor(s). Electric cars have the potential of significantly reducing city pollution by having zero tail pipe emissions. Vehicle greenhouse gas savings depend on how the electricity is generated. With the current U.S. energy mix, using an electric car would result in a 30% reduction in carbon dioxide emissions. Given the current energy mixes in other countries, it has been predicted that such emissions would decrease by 40% in the UK, 19% in China, and as little as 1% in Germany.

Electric cars are expected to have a major impact in the auto industry given advantages in city pollution, less dependence on oil, and expected rise in gasoline prices. World governments are pledging billions to fund development of electric vehicles and their components. The U.S. has pledged US\$2.4 billion in federal grants for electric cars and batteries. China has announced it will provide US\$15 billion to initiate an electric car industry. Nissan CEO Carlos Ghosn has predicted that one in 10 cars globally will run on battery power alone by 2020. Additionally a recent report claims that by 2020 electric cars and other green cars will take a third of the total of global car sales.

## Etymology

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 road-going automobiles powered by electricity. 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 powered by sunlight 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 pure battery electric vehicles.

## History



Bundesarchiv, Bild 183-1990-1126-500  
Foto: o. Ang. | 1904

German electric car, 1904, with the chauffeur on top

Electric cars enjoyed popularity between the mid-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. Advances in internal combustion technology soon rendered this advantage moot; the greater range of gasoline cars, quicker refueling times, and growing petroleum infrastructure, along with the mass production of gasoline vehicles by companies such as the Ford Motor Company, which reduced prices of gasoline cars to less than half that of equivalent electric cars, led to a decline in the use of electric propulsion, effectively removing it from important markets such as the United States by the 1930s. However, in recent years, increased concerns over the environmental impact of gasoline cars, along with reduced consumer ability to pay for fuel for gasoline cars, and the prospect of peak oil, has brought about renewed interest in electric cars, which are perceived to be more environmentally friendly and cheaper to maintain and run, despite high initial costs. Electric cars currently enjoy relative popularity in countries around the world, though they are notably absent from the roads of the United States, where electric cars briefly reappeared in the late 90s as a response to changing government regulations.



1912 Detroit Electric advertisement

### **1890s to 1900s: Early history**

Before the pre-eminence of internal combustion engines, electric automobiles held many speed and distance records. Among the most notable of these records was the breaking of

the 100 km/h (62 mph) speed barrier, by Camille Jenatton on April 29, 1899 in his 'rocket-shaped' vehicle *Jamais Contente*, which reached a top speed of 105.88 km/h (65.79 mph). Before the 1920s, electric automobiles were competing with petroleum-fueled cars for urban use of a quality service car.



Thomas Edison and an electric car in 1913 (courtesy of the National Museum of American History)

Proposed as early as 1896 in order to overcome the lack of recharging infrastructure, an exchangeable battery service was first put into practice by Hartford Electric Light Company for electric trucks. The vehicle owner purchased the vehicle from General Electric Company (GEC) without a battery and the electricity was purchased from Hartford Electric through an exchangeable battery. The owner paid a variable per-mile charge and a monthly service fee to cover maintenance and storage of the truck. The service was provided between 1910 to 1924 and during that period covered more than 6 million miles. Beginning in 1917 a similar service was operated in Chicago for owners of Milburn Light Electric cars who also could buy the vehicle without the batteries.

In 1897, electric vehicles found their first commercial application in the U.S. as a fleet of electrical New York City taxis, built by the Electric Carriage and Wagon Company of Philadelphia. Electric cars were produced in the US by Anthony Electric, Baker, Columbia, Anderson, Edison, Fritchle, Studebaker, Riker, Milburn, and others during the early 20th century.



The low range of electric cars meant they could not make use of the new highways to travel between cities

Despite their relatively slow speed, electric vehicles had a number of advantages over their early-1900s competitors. They did not have the vibration, smell, and noise associated with gasoline cars. They did not require gear changes, which for gasoline cars was the most difficult part of driving. Electric cars found popularity among well-heeled customers who used them as city cars, where their limited range proved to be even less of a disadvantage. The cars were also preferred because they did not require a manual effort to start, as did gasoline cars which featured a hand crank to start the engine. Electric cars were often marketed as suitable vehicles for women drivers due to this ease of operation.



The Henney Kilowatt, a 1961 production electric car based on the Renault Dauphine

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. Reporting this in 2010, the *Washington Post* commented that "the same unreliability of electric car batteries that flummoxed Thomas Edison persists today."

### **1990s to present: Revival of mass interest**

The energy crises of the 1970s and 80s brought about renewed interest in the perceived independence electric cars had from the fluctuations of the hydrocarbon energy market. In the early 1990s, the California Air Resources Board (CARB), the government of California's 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. 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 lithium-battery Altra EV minivan and Toyota RAV4 EV.



First Nissan Leaf delivered in the U.S. on the road south of San Francisco

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 car maker Tesla Motors began development in 2004 on the Tesla Roadster, which was first delivered to customers in 2008. As of January 2011 Tesla had produced more than 1,500 Roadsters sold in at least 31 countries. The Mitsubishi i MiEV was launched for fleet customers in Japan in July 2009, and for individual customers in April 2010, followed by sales to the public in Hong Kong in May 2010, and Australia in July 2010 via leasing. As of November 2010 Mitsubishi reported 5,000 units produced.

Retail customer deliveries of the Nissan Leaf in Japan and the United States began in December 2010, allowing the Leaf to become the first modern all electric car to be produced for the mass market from a major manufacturer, though initial availability is restricted to a few launch markets and in limited quantities. As of January 2011 other electric automobiles and city cars available in some markets included the Th!nk City, REVAi, Buddy, Citroën C1 ev'ie, and several neighborhood electric vehicles.

## **Comparison with internal combustion engine vehicles**

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).

## Price



Sales of the Mitsubishi i MiEV to the public began in Japan in April 2010, in Hong Kong in May 2010 and in Australia in July 2010.

Electric cars are generally more expensive than gasoline cars. The primary reason is the high cost of car batteries. US and British car buyers seem to be unwilling to pay more for an electric car. This prohibits the mass transition from gasoline cars to electric cars. A survey taken by Nielsen for the Financial Times has shown that 65 percent of Americans and 76 percent of Britons are not willing to pay more for an electric car above the price of a gasoline car. also a report by J.D. Power and Associates claims that about 50 percent of U.S. car buyers are not even willing to spent more than US\$5,000 on a green vehicle above the price of a petrol car despite their concern about the environment.

The Nissan LEAF is the most affordable five door family electric car in the U.S. at a price of US\$32,780 going down to US\$25,280 after federal tax rebate of US\$7,500, going further down to US\$20,280 after the US\$5,000 tax rebate in California and similar incentives in other states.

The Renault Fluence Z.E. five door family saloon electric car will be priced at less than US\$20,000 before any U.S. federal and state tax rebates are applied. It will be sold

without the battery thus the significant price difference. The customer will buy the Renault Fluence Z.E. with a contract to lease the battery from the company Better Place.

The electric car company Tesla Motors is using laptop battery technology for the battery packs of their electric cars that are 3 to 4 times cheaper than dedicated electric car battery packs that other auto makers are using. While dedicated battery packs cost \$700–\$800 per kilowatt hour, battery packs using small laptop cells cost about \$200. That could potentially drive down the cost of electric cars that are using Tesla's battery technology such as the Toyota RAV4 EV and the Smart ED as well as their own upcoming 2014 models such as the Model X.

### **Running costs and Maintenance**



The Tesla Roadster is sold in the US and Europe and has a range of 245 miles per charge

Most of the running cost of an electric vehicle can be attributed to the maintenance and replacement of the battery pack because an electric vehicle has only around 5 moving parts in its engine, compared to a gasoline car that has hundreds of parts in its internal combustion engine. Electric cars have expensive batteries that must be replaced but otherwise incur very low maintenance costs, particularly in the case of current Lithium based designs.

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. This can be difficult due to the fact that it will have a slightly lower capacity each time it is charged and is only considered to

be at the end of its life when the owner decides its performance is no longer acceptable. Even then an 'end of life' battery is not completely worthless as it can be re-purposed, recycled or used as a spare.

Since a battery is made of many individual cells that do not necessarily wear evenly periodically replacing the worst of these can retain the vehicle's range.

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. 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 company Better Place provides another cost comparison as they anticipate 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. 40 miles (64 km) of driving would initially cost US\$3.20 and fall over time to US\$0.80.

In 2010 the U.S. government estimated that a battery with a 100 miles (160 km) range would cost about US\$33,000. Concerns remain about durability and longevity of the battery.

Nissan estimates that the Leaf's 5 year operating cost will be US\$1,800 versus US\$6,000 for a gasoline car. The documentary film *Who Killed the Electric Car?* shows a comparison between the parts that require replacement in a gasoline powered cars and EVs, 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.

### **Electricity vs. Fuel**

"Fuel" cost comparison: the Tesla Roadster sport car's plug-to-wheel energy use is 280 W·h/mi. In Northern California, the local electric utility company PG&E says that "The E-9 rate is mandatory for those customers that are currently on a residential electric rate and who plan on refueling an EV on their premises." Combining these two facts implies that driving a Tesla Roadster 40 miles (64 km) a day would use 11.2 kW·h of electricity costing between US\$0.56 and US\$3.18 depending on the time of day chosen for recharging. For comparison, driving an internal combustion engine-powered car the same 40 miles (64 km), at a mileage of 25 miles per US gallon (9.4 L/100 km; 30 mpg<sub>imp</sub>), would use 1.6 US gallons (6.1 l; 1.3 imp gal) of fuel and, at a cost of US\$3 per 1 US gallon (3.8 l; 0.83 imp gal), would cost US\$4.80.

The Tesla Roadster uses about 17.4 kW·h/100 km (0.63 MJ/km; 0.280 kW·h/mi), the EV1 used about 11 kW·h/100 km (0.40 MJ/km; 0.18 kW·h/mi).

## Range

"Range anxiety" is a reason that many automakers marketed EVs as "daily drivers" suitable for city trips and other short hauls. The average American drives less than 40 miles (64 km) per day; so the GM EV1 would have been adequate for the daily driving needs of about 90% of U.S. consumers.

The Tesla Roadster gets 245 miles (394 km) per charge; more than double that of prototypes and evaluation fleet cars currently on the roads. The Roadster can be fully recharged in about 3.5 hours from a 220-volt, 70-amp home outlet.

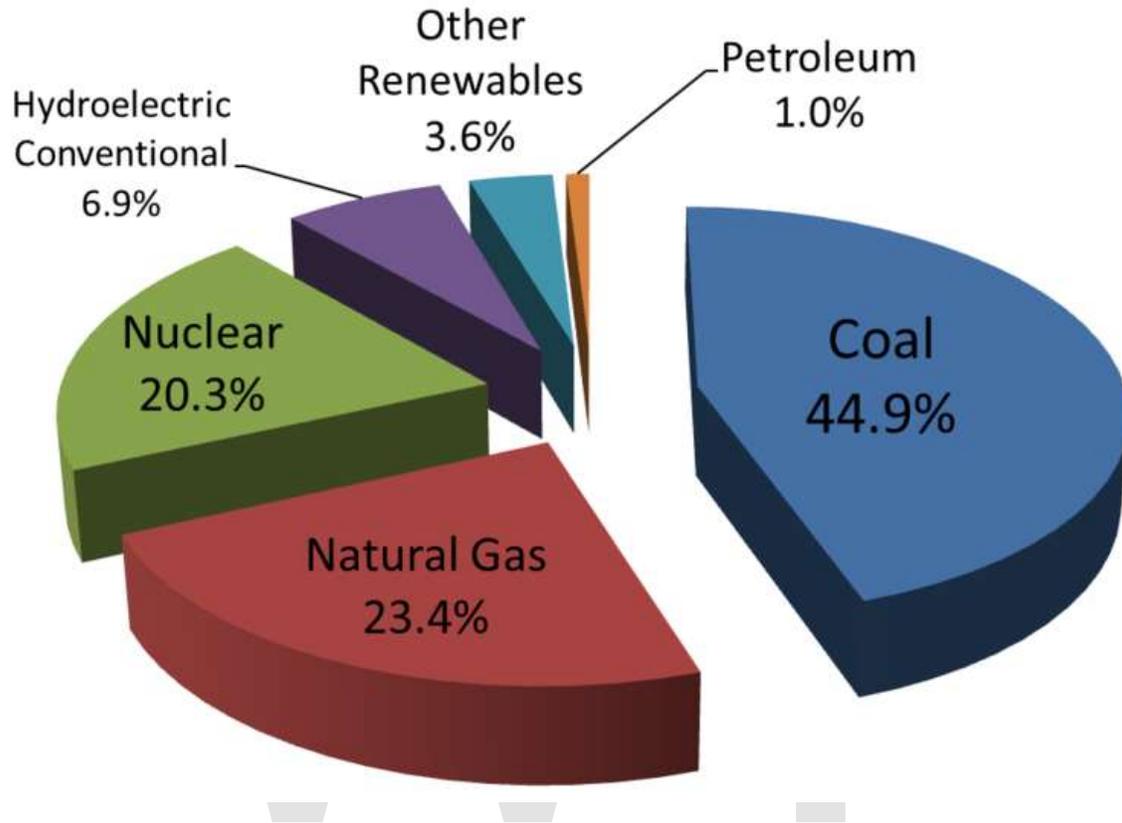
One way automakers can extend the short range of electric vehicles is by building them with battery switch technology. An EV with battery switch technology and a 100 miles (160 km) driving range will be able to go to a battery switch station and switch a depleted battery with a fully charged one in 59.1 seconds giving the EV an additional 100 miles (160 km) driving range. The process is cleaner and faster than filling a tank with gasoline and the driver remains in the car the entire time. As of late 2010 there are only 2 companies with plans to integrate battery switching technology to their electric vehicles. The company Better Place is already operating a battery switch station in Japan up to the end of 2010 and announced a commitment to open four battery switch stations in the US from San Francisco to San Jose in California.

Another way is the installation of DC Fast Charging stations with high-speed charging capability from three-phase industrial outlets so that consumers could recharge the 100 mile battery of their electric vehicle to 80 percent in about 30 minutes. A nationwide fast charging infrastructure is currently being deployed in the US that by 2013 will cover the entire nation. 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. The EV Project will deploy charge infrastructure in 16 cities and major metropolitan areas in six states. 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.

## Pollution

---

### 2009 U.S. Electricity Generation by Source



Sources of electricity in the U.S. in 2009

Electric cars produce no pollution at the tailpipe which will contribute to cleaner air in cities, but their use increases demand for electricity generation. 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, the availability of renewable sources and the efficiency of the fossil fuel-based generation used at a given time. Charging a vehicle using off-grid renewable energy yields very low carbon intensity (only that to produce and install the off-grid generation system e.g. domestic wind turbine).

An EV recharged from the existing US grid electricity emits about 115 grams of CO<sub>2</sub> per kilometer driven (6.5 oz(CO<sub>2</sub>)/mi), whereas a conventional US-market gasoline powered car emits 250 g(CO<sub>2</sub>)/km (14 oz(CO<sub>2</sub>)/mi) (most from its tailpipe, some from the production and distribution of gasoline). 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<sub>2</sub> per kilometer driven, although a study in Scotland gave 149.5gCO<sub>2</sub>/km as the average for new cars in the UK), but would be more significant in countries with cleaner electric infrastructure. 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<sub>2</sub>)/km (11 oz(CO<sub>2</sub>)/mi), compared with an average of 170 g(CO<sub>2</sub>)/km (9.7 oz(CO<sub>2</sub>)/mi) for a gasoline powered compact car. This study concluded that introducing 1 million EV cars to Germany would, in the best case scenario, only reduce CO<sub>2</sub> emissions by 0.1%, if nothing is done to upgrade the electricity infrastructure or manage demand.

In France, which has a clean energy grid, CO<sub>2</sub> emissions from electric car use would be about 12g per kilometer.

A study done in the UK in 2008 has concluded that electric vehicles have the potential to cut down carbon dioxide and greenhouse gas emissions by at least 40% even when taking into account the emissions of current electricity generation in the UK and emissions relating to the production and disposal of electric vehicles.

### **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.

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. Another early solution was American Motors' experimental Amitron piggyback system of batteries with one type designed for sustained speeds while a different set boosted acceleration when needed.

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. In some cases, the motor can be housed directly in the wheel, such as in the Whispering Wheel design, which lowers the vehicle's center of gravity and reduces the number of moving parts. When not fitted with an axle, differential, or transmission, electric vehicles have less drivetrain rotational inertia.

### **Transmission**

A gearless or single gear design in some EVs eliminates the need for gear shifting, giving such vehicles both smoother acceleration and smoother braking. Because the torque of an

electric motor is a function of current, not rotational speed, electric vehicles have a high torque over a larger range of speeds during acceleration, as compared to an internal combustion engine. As there is no delay in developing torque in an EV, EV drivers report generally high satisfaction with acceleration.

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. The Tesla Roadster 2.5 Sport can accelerate from 0 to 60 mph (97 km/h) in 3.7 seconds with a motor rated at 215 kW (288 hp).

Also the Wrightspeed X1 prototype created by Wrightspeed Inc is the worlds fastest street legal electric car. With an acceleration of 0-60 mph in 2.9 seconds the X1 has bested some of the worlds fastest sports cars.

## **Energy 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. 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%.

Production and conversion electric cars typically use 10 to 23 kW·h/100 km (0.17 to 0.37 kW·h/mi). 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).

## **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.

Firefighters and rescue personnel receive special training to deal with the higher voltages and chemicals encountered in electric and hybrid electric vehicle accidents. While BEV accidents may present unusual problems, such as fires and fumes resulting from rapid

battery discharge, there is apparently no available information regarding whether they are inherently more or less dangerous than gasoline or diesel internal combustion vehicles which carry flammable fuels.

### **Vehicle safety**

Great effort is taken to keep the mass of an electric vehicle as low as possible, in order to improve the EV's range and endurance. Despite these efforts, the high density and weight of the electric batteries usually results in an EV being heavier than a similar equivalent gasoline vehicle leading to less interior space, and 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 despite having a negative effect on the car's performance. 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. 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. Many electric cars have a small, light and fragile body, though, and therefore offer inadequate safety protection. Because of this, the Insurance Institute for Highway Safety in America had condemned the use of such vehicles.

### **Hazard to pedestrians**

At low speeds, electric cars produced less roadway noise as compared to vehicles propelled by a internal combustion engine. 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. 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.

The US Congress, the European Commission and the Government of Japan are exploring legislation to establish a 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. The Nissan Leaf is the first electric car to include Nissan's Vehicle Sound for Pedestrians system, which will include one sound for forward motion and another for reverse.

### **Differences in controls**

Presently most EV manufacturers do their best to emulate the driving experience as closely as possible to that of a car with automatic transmission that American motorists are most familiar with. Most models have the PRNDL gate or PRND push-buttons 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 handbrake 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.

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, and applying mild regenerative braking instead provides a more familiar response. Selecting the "B" (Brake) mode will increase this effect for sustained downhill driving.

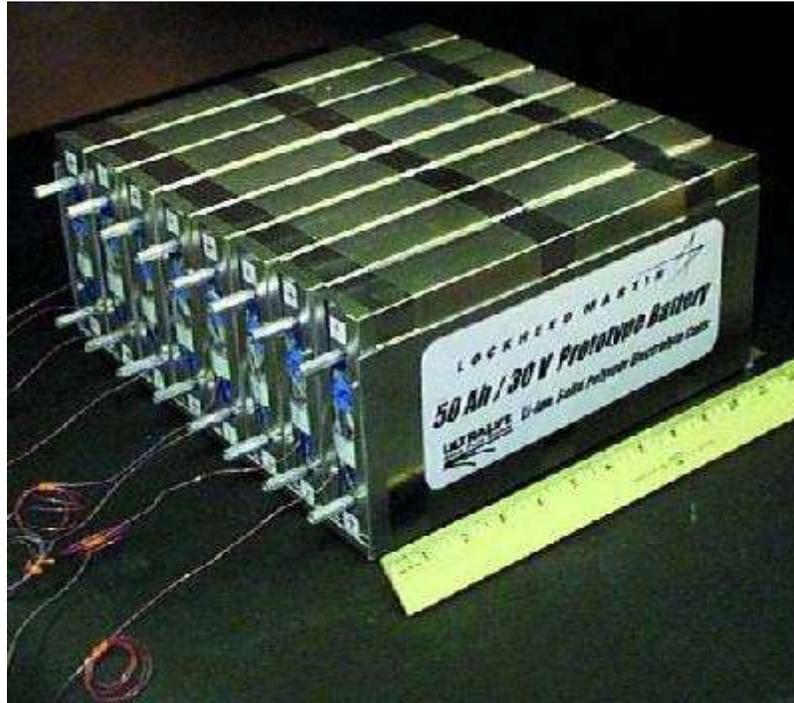
## **Cabin heating and cooling**

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 can not 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 is also attractive for its simplicity - this kind of system is used for example in the Tesla Roadster.

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 as aftermarket kits for conventional vehicles). Two models of the 2010 Toyota Prius include this feature as an option.

# 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.

Finding the economic balance of range against performance, energy density, and accumulator type versus cost challenges every EV manufacturer.

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 technologies include:

- Lead acid batteries 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, and while power output to weight is poorer than other designs, range and power can be easily added by increasing the number of batteries.
- NiCd - Largely superseded by NiMH
- Nickel metal hydride (NiMH)
- Nickel iron battery - Known for its comparatively long lifetime and low power density

Several battery technologies are also in development such as:

- Zinc-air battery
- Molten salt battery
- Zinc-bromine flow batteries or Vanadium redox batteries can be refilled, instead of recharged, saving time. The depleted electrolyte can be recharged at the point of exchange, or taken away to a remote station.

### **Travel range before recharging**

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. The range of an electric vehicle conversion depends on the battery type:

### **Replacing**



The Renault Fluence Z.E. plans to have easily replaceable batteries. Available in 2011 in Europe.

An alternative to quick recharging is to exchange the drained or nearly drained batteries (or battery range extender modules) with fully charged batteries, rather as stagecoach

horses were changed at coaching inns. Batteries could be leased or rented instead of bought, and then maintenance deferred to the leasing or rental company, and ensures availability.

Renault announced at the 2009 Frankfurt Motor Show that they have sponsored a network of charging stations and plug-in plug-out battery swap stations. Other vehicle manufacturers and companies are also investigating the possibility.

Replaceable batteries were used in the electric buses at the 2008 Summer Olympics.

### **Vehicle-to-grid: uploading and grid buffering**

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.

Such a system will not be widely feasible until the cycle durability of battery packs is significantly increased.

### **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 technology 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.

### **Future**

The future of battery electric vehicles depends primarily upon the cost and availability of batteries with high specific energy, power density, and long life, as all other aspects such as motors, motor controllers, and chargers are fairly mature and cost-competitive with internal combustion engine components. Diarmuid O'Connell, VP of Business Development at Tesla Motors, estimates that by the year 2020 30% of the cars driving on the road will be battery, electric or plug-in hybrid.

It is estimated that there are sufficient lithium reserves to power 4 billion electric cars.

### **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. 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**

Solar cars are electric cars that derive most or all of their electricity from built in solar panels. After the 2005 World Solar Challenge established that solar race cars could exceed highway speeds, the specifications were changed to provide for vehicles that with little modification could be used for transportation.

## **Charging**



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

Batteries in BEVs must be periodically recharged. BEVs most commonly charge from the power grid (at home or using a street or shop charging station), which is in turn generated from a variety of domestic resources; such as coal, hydroelectricity, nuclear and others. Home power 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.

## Level 1, 2, and 3 charging

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.

Level	Original definition	Coulomb Technologies' definition	Connectors
Level 1	AC energy to the vehicle's on-board charger; from the most common U.S. grounded household receptacle, commonly referred to as a 120 volt outlet.	120 V AC; 16 A (= 1.92 kW)	SAE J1772 (16.8 kW), ordinary household 120 volt outlet
Level 2	AC energy to the vehicle's on-board charger; 208-240 volt, single phase. The maximum current specified is 32 amps (continuous) with a branch circuit breaker rated at 40 amps. Maximum continuous input power is specified as 7.68 kW (= 240V x 32A*).	208-240 V AC; 12 A to 80 A (= 2.5 to 19.2 kW)	SAE J1772 (16.8 kW), IEC 62196 (44 kW), Magne Charge, Avcon, IEC 60309 16 A (3.8 kW)
Level 3	DC energy from an off-board charger; there is no minimum energy requirement but the maximum current specified is 400 amps and 240 kW continuous power supplied.	very high voltages (300-600 V DC); very high currents (100s of Amperes)	CHAdeMO (62.5 kW)

\*. or potentially 208V x 37A, 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 32A.

The term "Level 3" has also been used by the SAE J1772 Connector Standard Committee for a possible future higher-power AC fast charging connector. SAE has not approved standards for either higher-power connector.

## **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 as the charging interface for electric vehicles in California in June 2001.

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.

## **Regenerative braking**

Using regenerative braking, a feature which is present on many hybrid electric vehicles, approximately 20% of the energy usually lost in the brakes is recovered to recharge the batteries.

## **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 230V supply). The main connection to a house may sustain 10, 15 or even 20 kW in addition to "normal" domestic loads - though 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 and the Tesla Roadster appears to accept 16.8 kW (240V at 70A) from the Tesla Home Connector. These power numbers are small compared to the effective power delivery rate of an average petrol pump, about 5,000 kW. Even if the electrical supply power can be increased, most batteries do not accept charge at greater than their charge rate("1C"), because high charge rates have an adverse effect on the discharge capacities of batteries. Despite these power limitations, plugging in to even the least-powerful conventional home outlet provides more than 15 kilowatt-hours of energy overnight, sufficient to propel most electric cars more than 70 kilometres (43 mi).

## **Faster charging**

Some types of batteries such as Lithium-titanate, LiFePO<sub>4</sub> and even certain NiMH variants can be charged almost to their full capacity in 10–20 minutes. Fast charging requires very high currents often derived from a three-phase power supply. Careful charge management is required to prevent damage to the batteries through overcharging.

Most people do not usually require fast recharging because they have enough time, six to eight hours (depending on discharge level) during the work day or overnight at home to

recharge. BEV drivers frequently prefer recharging at home, avoiding the inconvenience of visiting a public charging station.

## Hobbyists, conversions, and racing



Eliica prototype



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

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. 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 thoroughways (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).

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. 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 ( $\text{LiFePO}_4$ ) 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  $\text{LiFePO}_4$  cells feature life ratings of 3,000 cycles, compared to typical lead acid battery ratings of 300 cycles, the life expectancy of  $\text{LiFePO}_4$  cells is around 10 years. This has led to a resurgence in the number of vehicles converted by individuals.  $\text{LiFePO}_4$  cells do require more expensive battery management and charging systems than lead acid batteries.

Electric drag racing is a sport where electric vehicles start from standstill and attempt the highest possible speed over a short given distance. Organizations such as NEDRA keep track of records world wide using certified equipment.

## Currently available electric cars



The Th!nk City is sold in several European countries and production began in the U.S. in late 2010

### Highway capable

As of early 2011 there are only a few mass production highway-capable models currently on the market including the Tesla Roadster, Mitsubishi i MiEV, Th!nk City, and Nissan Leaf. The remainder of currently available electric cars are mostly low-speed, low-range neighborhood electric vehicles, electric city cars as well as some small-scale commercial conversion of internal-combustion based vehicles.

The following electric cars are currently in an advanced stage of development.

**Selected list of future electric cars capable of at least 100 km/h (62 mph)**

Model	Top speed	Acceleration	Capacity Adults+kids	Charging time	Nominal range	Market release date
Wheego Whip LiFe	105 km/h (65 mph)		2		161 km (100 mi)	Dec 2010
CODA Sedan	129 km/h (80 mph)	0–60 mi/h in 11 seconds	4	full charge in approx. 6 hours	193 km (120 mi)	Q3 2011
REVA NXR	104 km/h (65 mph)		4		160 km (99 mi)	2011
Renault Fluence Z.E.	135 km/h (84 mph)	0-62 mph: 9.0 seconds (est)	5	6–8 hours with standard AC power; 30 minute rapid charge to 80%	161 km (100 mi)	Early 2011
Tata Indica Vista EV	105 km/h (65 mph)	0-62 mph: 10.0 seconds (est)	4		241 km (150 mi)	Q1 2011
Ford Focus BEV	137 km/h (85 mph)		5	approx 6 to 8 hours, 230 V/16A	160 km (99 mi)	Late 2011
Hyundai BlueOn	130 km/h (81 mph)	0–100 km/h in 13.1	4	6 hours with 220 V power; 25 minute rapid charge to 80%	140 km (87 mi)	Late 2012
Tesla Model S	193 km/h (120 mph)	0 to 97 km/h (0 to 60 mph) in 5.6 s	5+2	Full charge 3.5 hours using the High Power Connector or 45 minute QuickCharge	483 km (300 mi)	2012

The following pre-production models and plug-in conversions of existing models are currently undergoing field trials or are part of demonstration programs: Mini E, Smart ED, BYD e6, Audi A1 e-tron, Ford Focus BEV, and Volvo C30 DRIVe Electric.

**Government subsidy**

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, and several states have additional incentives. The U.K. offers a Plug-in Car

Grant up to a maximum of GB£5,000 (US\$7,600) beginning in January 2011. As of April 2010, 15 European Union member states provide tax incentives for electrically chargeable vehicles, which consist of tax reductions and exemptions, as well as of bonus payments for buyers of plug-ins and hybrid vehicles.

WWT

## Chapter- 3

# Electric Locomotive



British Rail Class 90 90021 in First ScotRail livery at Edinburgh Waverley



Deutsche Bahn DBAG Class 152 pulling a freight train



New Jersey Transit ALP-46 AC locomotive based on the DBAG Class 101

An **electric locomotive** is a locomotive powered by electricity from overhead lines, a third rail or an on-board energy storage device (such as a chemical battery or fuel cell). Electrically propelled locomotives with on-board fuelled prime movers, such as diesel engines or gas turbines, are classed as diesel-electric or gas turbine electric locomotives because the electric generator/motor combination only serves as a power transmission system. Electricity is used to eliminate smoke and take advantage of the high efficiency of electric motors; however, the cost of railway electrification means that usually only heavily-used lines can be electrified.

## Characteristics

One advantage of electrification is the lack of pollution from the locomotives themselves. Electrification also results in higher performance, lower maintenance costs and lower energy costs for electric locomotives.

Power plants, even if they burn fossil fuels, are far cleaner than mobile sources such as locomotive engines. Also the power for electric locomotives can come from clean and/or renewable sources, including geothermal power, hydroelectric power, nuclear power, solar power and wind turbines. Electric locomotives are also quiet compared to diesel

locomotives since there is no engine and exhaust noise and less mechanical noise. The lack of reciprocating parts means that electric locomotives are easier on the track, reducing track maintenance.

Power plant capacity is far greater than what any individual locomotive uses, so electric locomotives can have a higher power output than diesel locomotives and they can produce even higher short-term surge power for fast acceleration. Electric locomotives are ideal for commuter rail service with frequent stops. They are used on high-speed lines, such as ICE in Germany, Acela in the US, Shinkansen in Japan, China Railway High-speed in China and TGV in France. Electric locomotives are also used on freight routes that have a consistently high traffic volume, or in areas with advanced rail networks.

Electric locomotives benefit from the high efficiency of electric motors, often above 90%. Additional efficiency can be gained from regenerative braking, which allows kinetic energy to be recovered during braking to put some power back on the line. Newer electric locomotives use AC motor-inverter drive systems that provide for regenerative braking.

The chief disadvantage of electrification is the cost for infrastructure (overhead power lines or electrified third rail, substations, control systems). Public policy in the US currently interferes with electrification—higher property taxes are imposed on privately owned rail facilities if they have electrification facilities. Also, US regulations on diesel locomotives are very weak compared to regulations on automobile emissions or power plant emissions.

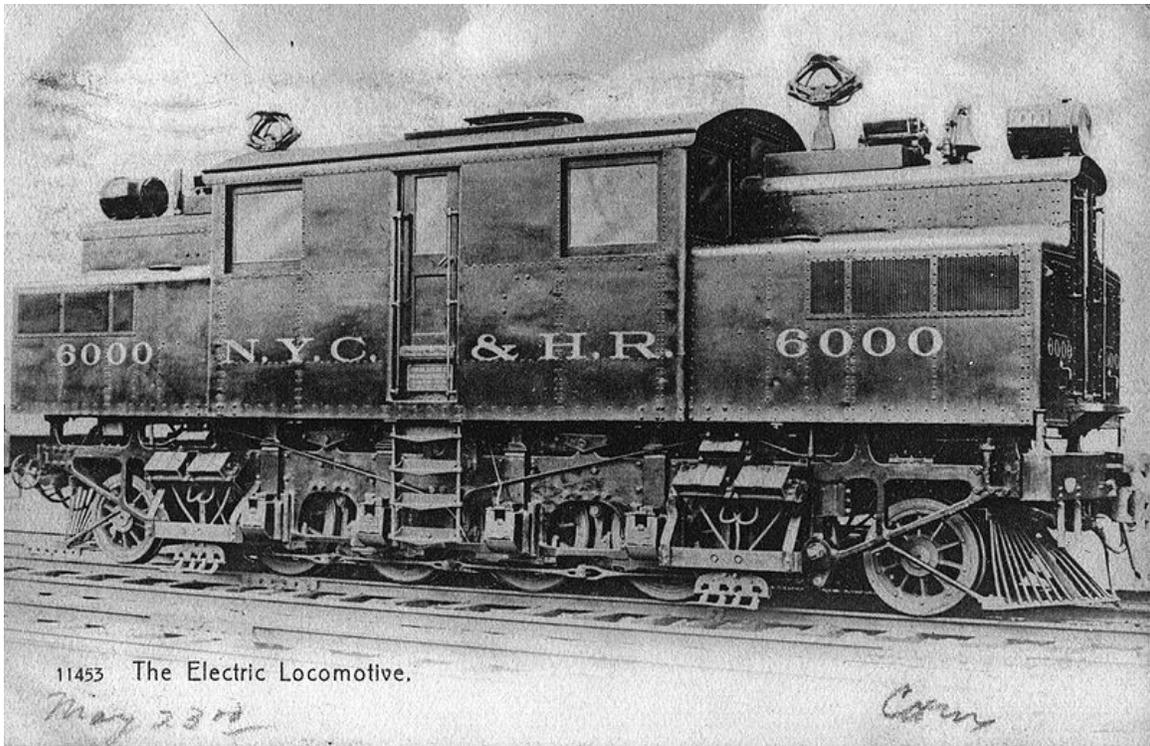
In Europe and elsewhere, railway networks are considered part of the national transport infrastructure, just like roads, highways and waterways, and therefore are often financed by the state. Operators of the rolling stock pay fees according to rail use. This makes possible the large investments required for the technically and in the long-term also, economically advantageous electrification. Because railroad infrastructure is privately owned in the US, railroads are unwilling to make the necessary investments for electrification.

## History

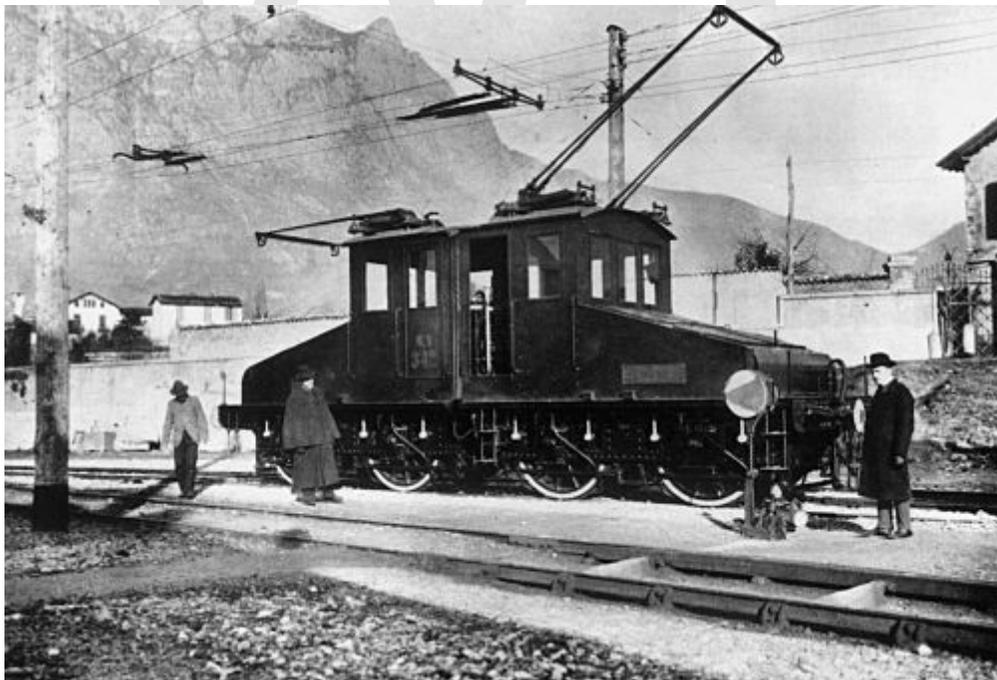


THE NEW ELECTRIC LOCOMOTIVE OF THE BALTIMORE AND OHIO RAILROAD COMPANY

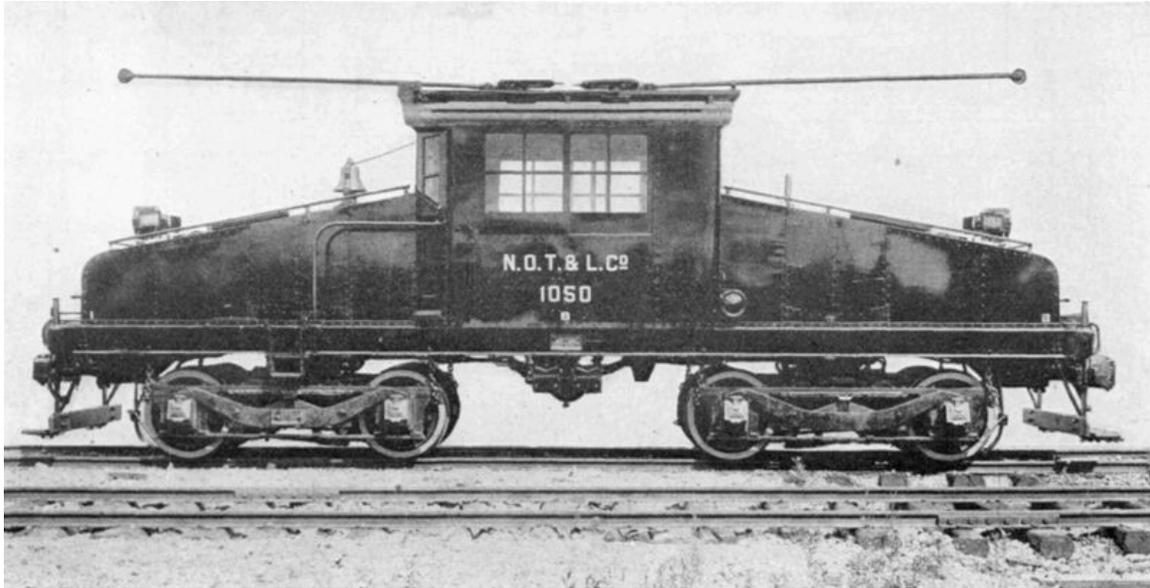
Electric locomotive of the Baltimore Belt Line, 1895. The steam locomotive was not detached for passage through the tunnel. The overhead conductor was a  $\cap$  section bar at the highest point in the roof, so a flexible, flat pantograph was used



Alco-GE Prototype Class S-1, NYC & HR no. 6000 (DC)



AC locomotive in Valtellina (1898-1902). Power supply: 3-phase 15 Hz AC, 3000 V.  
Designed by Kálmán Kandó in Ganz Company, Hungary and supplied by Westinghouse.



A GE steeplecab electric locomotive. This example is fitted with trolley poles for service on an interurban railroad.



A Milwaukee Road class ES-2, an example of a larger steeplecab switcher for service on an electrified heavy-duty railroad

The first known electric locomotive was built by a Scotsman, Robert Davidson of Aberdeen in 1837 and was powered by galvanic cells ('batteries'). Davidson later built a larger locomotive named *Galvani* which was exhibited at the Royal Scottish Society of Arts Exhibition in 1841. It was tested on the Edinburgh and Glasgow Railway in September of the following year but the limited electric power available from batteries prevented its general use. The first electric passenger train was presented by Werner von Siemens at Berlin in 1879. The locomotive was driven by a 2.2 kW motor and the train, consisting of the locomotive and three cars, reached a maximum speed of 13 km/h. During four months, the train carried 90,000 passengers on a 300 metre long circular track. The electricity was supplied through a third, insulated rail situated between the

tracks. A stationary dynamo nearby provided the electricity. The world's first electric tram line opened in Lichterfelde near Berlin, Germany, in 1881. It was built by Werner von Siemens. In Britain, Volk's electric railway was opened in 1883 in Brighton. In the US, electric trolleys were pioneered in 1888 on the Richmond Union Passenger Railway, using equipment designed by Frank J. Sprague.

Much of the early development of electric locomotion was driven by the increasing use of tunnels, particularly in urban areas. Smoke from steam locomotives was noxious and municipalities were increasingly inclined to prohibit their use within their limits. Thus the first successful working, the City and South London Railway underground line in the UK, was prompted by a clause in its enabling act prohibiting use of steam power. This line opened in 1890, using electric locomotives built by Mather and Platt. Electricity quickly became the power supply of choice for subways, abetted by the Sprague's invention of multiple-unit train control in 1897. Surface and elevated rapid transit systems generally used steam until forced to convert by ordinance.

The first use of electrification on a mainline was on a four-mile stretch of the Baltimore Belt Line of the Baltimore and Ohio Railroad (B&O) in 1895. This track connected the main portion of the B&O to the newly built line to New York and it required a series of tunnels around the edges of Baltimore's downtown. Parallel tracks on the Pennsylvania Railroad had shown that coal smoke from steam locomotives would be a major operating issue, as well as a public nuisance. Three Bo+Bo units were initially used, at the south end of the electrified section; they coupled onto the entire train, locomotive and all and pulled it through the tunnels. Railroad entrances to New York City required similar tunnels and the smoke problems were more acute there. A collision in the Park Avenue tunnel in 1902 led the New York State legislature to outlaw the use of smoke-generating locomotives south of the Harlem River after 1 July 1908. In response, electric locomotives began operation in 1904 on the New York Central Railroad. In the 1930s, the Pennsylvania Railroad, which also had introduced electric locomotives because of the NYC regulation, electrified its entire territory east of Harrisburg, Pennsylvania.

## **Introduction of alternating current**

The first practical AC electric locomotive was designed by Charles Brown, then working for Oerlikon, Zürich. In 1891, Brown had demonstrated long-distance power transmission, using three-phase AC, between a hydro-electric plant at Lauffen am Neckar and Frankfurt am Main West railway station, a distance of 280 km. Brown, using the experience he had gained while working for Jean Heilmann on steam-electric locomotive designs, had observed that three-phase motors had a higher power-to-weight ratio than DC motors and, because of the absence of a commutator, were simpler to manufacture and maintain. However, they were much larger than the DC motors of the time and could not be mounted in underfloor bogies: they could only be carried within locomotive bodies. In 1896, Oerlikon installed the first commercial example of the system on the Lugano Tramway. Three-phase motors, which run at constant speed and provide regenerative braking, are well suited to steeply graded routes and the first mainline three-phase locomotives were installed by Brown (by then in partnership with Walter Boveri)

in 1899 on the Burgdorf—Thun line, Switzerland. Each thirty-tonne locomotive had two 150 h.p. motors. A development by Kálmán Kandó of the Ganz works, Budapest, working with Westinghouse of Italy, introduced an electro-mechanical converter, allowing the use of three-phase motors powered from single-phase alternating current, thus eliminating the need for two overhead conductor wires. The first implementation of industrial frequency single-phase AC supply for locomotives came from Oerlikon in 1901, using the designs of Hans Behn-Eschenburg and Emil Huber-Stockar; installation on the Seebach-Wettingen line of the Swiss Federal Railways was completed in 1904. The 15 kV, 50 Hz 345 kilowatts (460 hp), 48 tonne locomotives used transformers and rotary converters to power DC traction motors.

Italian railways were the first in the world to introduce electric traction for the entire length of a mainline rather than just a short stretch, using a system from Westinghouse, designed by Kálmán Kandó and a team from the Ganz works. The 106 km Valtellina line was opened on 4 September 1902. The electrical system was three-phase at 3 kV 15 Hz. The converter transformed single-phase current into three-phase alternating current within the locomotive. The voltage was significantly higher than used earlier and it required new designs for electric motors and switching devices. During the period of electrification of the Italian railways, some tests were made as to which type of power supply to use: in some sections there was a 3,600 V  $16\frac{2}{3}$  Hz three-phase power supply, in others there was 1,500 V DC, 3 kV DC and 10 kV AC 50Hz supply. During the 1930s, 3kV DC power was chosen for the entire Italian railway system. (Nowadays, 1,500 V DC is still used on some lines near France and 25kV 50Hz is used on high speed trains) Kandó designed a three phase AC traction in Evian Les Bains (Switzerland) in 1898.

In the United States, the Chicago, Milwaukee, St. Paul and Pacific Railroad (the Milwaukee Road), the last transcontinental line to be built, electrified its lines across the Rocky Mountains and to the Pacific Ocean starting in 1915. A few East Coast lines, notably the Virginian Railway and the Norfolk and Western Railway, found it expedient to electrify short sections of their mountain crossings. However, by this point, electrification in the United States was more associated with dense urban traffic and the centre of development shifted to Europe, where electrification was widespread.



A Swiss Re 420 leads a freight train down the South side of the Gotthard line, which was electrified in 1922. The masts and lines of the catenary can be seen.

In 1923, the first phase-converter locomotive in Hungary was constructed on the basis of Kandó's designs and serial production began soon after. The first installation, at 50 Hz, 16 kV, was in 1932 on the 56 km section of the Hungarian State Railways between Budapest and Komárom. This proved successful and the electrification was extended to Hegyeshalom in 1934.

In Europe, electrification projects initially focused on mountainous regions for several reasons: coal supplies were difficult, hydroelectric power was readily available, and electric locomotives gave more traction on steeper lines. This was particularly applicable in Switzerland, where today close to 100% of lines are electrified. An important contribution to the wider adoption of AC traction came from SNCF of France after World War 2. The company had assessed the industrial-frequency AC line routed through the steep Höllental Valley, Germany, which was under French administration following the war. After trials, the company decided that the performance of AC locomotives was sufficiently developed to allow all its future installations, regardless of terrain, to be of this standard, with its associated cheaper and more efficient infrastructure. The SNCF decision, ignoring as it did the 2,000 miles (3,200 km) of high-voltage DC already

installed on French routes, was influential in the standard selected for other countries in Europe.

The 1960s saw the electrification of many European main lines (Eastern Europe included). European electric locomotive's technology had improved steadily from the 1920s onwards. By comparison, the Milwaukee Road class EP-2 (1918) weighed 240 t, with a power of 3,330 kW and a maximum speed of 112 km/h; in 1935, German E 18 had a power of 2,800 kW, but weighed only 108 tons and had a maximum speed of 150 km/h. On 29 March 1955, French locomotive CC 7107 reached a speed of 331 km/h. In 1960 the SJ Class Dm 3 locomotives introduced on the Swedish Railways produced a record 7,200 kW. Locomotives capable of commercial passenger service at 200 km/h appeared in Germany and France in the same period. Further improvements resulted from the introduction of electronic control systems, which permitted the use of increasingly lighter and more powerful motors that could be fitted entirely inside the bogies (standardising from the 1990s onwards on asynchronous three-phase motors, fed through GTO-inverters).

In the United States, the use of electric locomotives declined in the face of dieselization. Diesels shared some of the electric locomotive's advantages of over steam and the cost of building and maintaining the power supply infrastructure, which had always worked to discourage new installations, brought on the elimination of most mainline electrification outside the Northeast. Except for a few captive systems (e.g. the Black Mesa and Lake Powell), by 2000, electrification was confined to the Northeast Corridor and some commuter service; even there, freight service was handled by diesels.

In the 1980s, development of very high-speed service brought a revival of electrification. The Japanese Shinkansen and the French TGV were the first systems for which devoted high-speed lines were built from scratch. Similar programs were undertaken in Italy, Germany and Spain; in the United States the only new mainline service was an extension of electrification over the Northeast Corridor from New Haven, Connecticut to Boston, Massachusetts, though new light rail systems, using electrically powered cars, continued to be built.

On 2 September 2006, a standard production Siemens Electric locomotive of the Europrinter type ES64-U4 (ÖBB Class 1216) achieved a speed of 357 km/h, the record for a locomotive-hauled train, on the new line between Ingolstadt and Nuremberg.

## Electric locomotive types



The operating controls of the 1,000 mm (3 ft 3 <sup>3</sup>/<sub>8</sub> in) gauge cogwheel electric locomotive BDeh 4/4 view, operating in line Luzern-Engelberg. The wheel controls motor power, not driving direction.



Electric locomotive used in mining operations in Flin Flon, Manitoba. This locomotive is on display and not currently in service.

An electric locomotive can be supplied with power from

- Rechargeable energy storage systems, as battery or ultracapacitor-powered mining locomotives.
- A stationary source, such as a third rail or overhead wire.

This is in marked contrast to a diesel-electric locomotive, which combines an onboard diesel engine with an electrical power transmission or store (battery, ultracapacitor) system.

The distinguishing design features of electric locomotives are:

- The type of electrical power used, either alternating current or direct current.
- The method for store (batteries, ultracapacitors) or collecting (transmission) electrical power.
- The means used to mechanically couple the traction motors to the driving wheels (drivers).

## Direct and alternating current

The most fundamental difference lies in the choice of direct (DC) or alternating current (AC). The earliest systems used direct current as, initially, alternating current was not well understood and insulation material for high voltage lines was not available. Direct current locomotives typically run at relatively low voltage (600 to 3,000 volts); the equipment is therefore relatively massive because the currents involved are large in order to transmit sufficient power. Power must be supplied at frequent intervals as the high currents result in large transmission system losses.

As alternating current motors were developed, they became the predominant type, particularly on longer routes. High voltages (tens of thousands of volts) are used because this allows the use of low currents; transmission losses are proportional to the square of the current (e.g. twice the current means four times the loss). Thus, high power can be conducted over long distances on lighter and cheaper wires. Transformers in the locomotives transform this power to a low voltage and high current for the motors. A similar high voltage, low current system could not be employed with direct current locomotives because there is no easy way to do the voltage/current transformation for DC so efficiently as achieved by AC transformers.



Italian freight locomotive E554 working with three-phase current. Note the two current collectors with separate heads for each phase.

AC traction seldom uses two-phase lines in place of single phase lines. The transmitted three-phase current drives induction motors, which do not have sensitive commutators and permit easy realisation of a regenerative brake. Speed is controlled by changing the number of pole pairs in the stator circuit and by switching additional resistors in the rotor circuit. The two-phase lines are heavy and complicated near switches, where the phases have to cross each other. The system was widely used in the northern part of Italy until 1976 and is still in use on some Swiss rack railways. The simple feasibility of a fail safe electric brake is an advantage of the system, while the speed control and the two-phase lines are problematic.



The Swedish Rc locomotive was the first series locomotive that used thyristors with DC engines.

Rectifier locomotives, which used AC power transmission and DC motors, were common, though DC commutators had problems both in starting and at low velocities. Today's advanced electric locomotives use brushless three-phase AC induction motors. These polyphase machines are powered from GTO-, IGCT- or IGBT-based inverters. The cost of electronic devices in a modern locomotive can be up to 50% of the total cost of the vehicle.

Electric traction allows the use of regenerative braking, in which the motors are used as brakes and become generators that transform the motion of the train into electrical power that is then fed back into the lines. This system is particularly advantageous in mountainous operations, as descending locomotives can produce a large portion of the power required for ascending trains.

Most systems have a characteristic voltage and, in the case of AC power, a system frequency. Many locomotives over the years were equipped to handle multiple voltages and frequencies as systems came to overlap or were upgraded. American FL9 locomotives were equipped to handle power from two different electrical systems and could also operate as conventional diesel-electrics.

While recently designed systems invariably operate on alternating current, many existing direct current systems are still in use – e.g. in South Africa and the United Kingdom (750 V and 1,500 V); Netherlands, Japan, Mumbai, Ireland (1,500 V); Slovenia, Belgium, Italy, Poland, Russia, Spain (3,000 V) and the cities of Washington DC (750 V).

### **Power transmission**



A modern pantograph. The device shown is technically a half-pantograph.

Electrical circuits require two connections (or for three phase AC, three connections). From the very beginning, the trackwork itself was used for one side of the circuit. Unlike model railroads, however, the trackwork normally supplies only one side, the other side(s) of the circuit being provided separately.

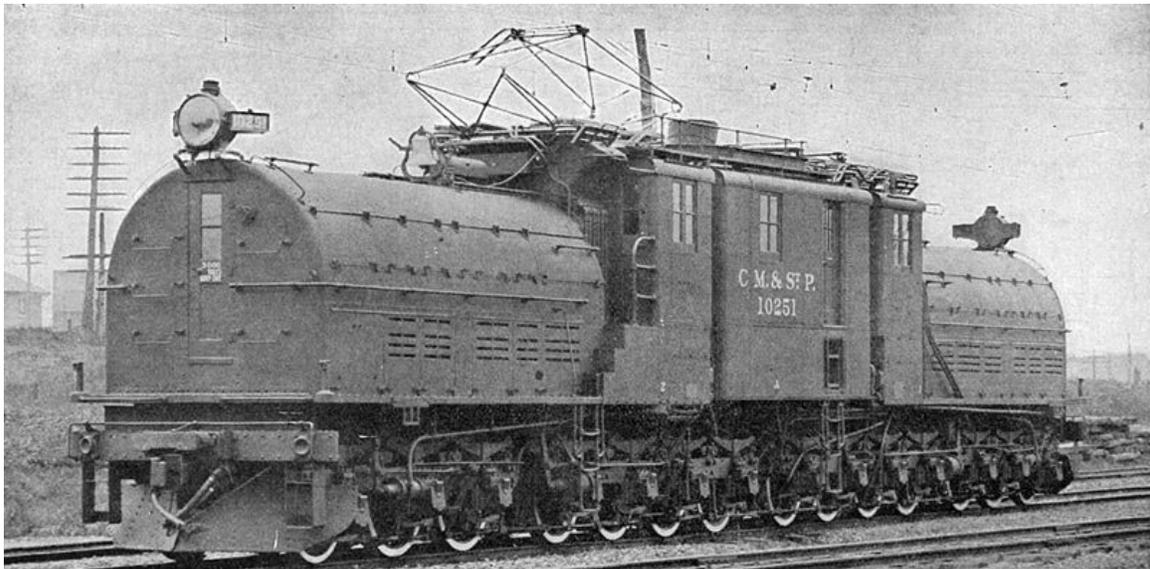
The original Baltimore and Ohio Railroad electrification used a sliding shoe in an overhead channel, a system quickly found to be unsatisfactory. It was replaced with a third rail system, in which a pickup (the "shoe") rode underneath or on top of a smaller rail parallel to the main track, somewhat above ground level. There were multiple pickups on both sides of the locomotive in order to accommodate the breaks in the third rail required by trackwork. This system is preferred in subways because of the close clearances it affords.

However, railways generally tend to prefer overhead lines, often called "catenaries" after the support system used to hold the wire parallel to the ground. Three collection methods are possible:

- Trolley pole: a long flexible pole, which engages the line with a wheel or shoe.
- Bow collector: a frame that holds a long collecting rod against the wire.
- Pantograph: a hinged frame that holds the collecting shoes against the wire in a fixed geometry.

Of the three, the pantograph method is best suited for high-speed operation. Some locomotives are equipped to use both overhead and third rail collection (e.g. British Rail Class 92).

### Driving the wheels



One of the Milwaukee Road EP-2 "Bi-polar" electrics

During the initial development of railroad electrical propulsion, a number of drive systems were devised to couple the output of the traction motors to the wheels. Early locomotives used often jackshaft drives. In this arrangement, the traction motor is mounted within the body of the locomotive and drives the jackshaft through a set of gears. This system was employed because the first traction motors were too large and heavy to mount directly on the axles. Due to the number of mechanical parts involved, frequent maintenance was necessary. The jackshaft drive was abandoned for all but the smallest units when smaller and lighter motors were developed,

Several other systems were devised as the electric locomotive matured. The Buchli drive was a fully-sprung loaded system, in which the weight of the driving motors was completely disconnected from the driving wheels. First used in electric locomotives from the 1920s, the Buchli drive was mainly used by the French SNCF and Swiss Federal

Railways. The quill drive was also developed about this time and mounted the traction motor above or to the side of the axle and coupled to the axle through a reduction gear and a semi-flexible hollow shaft - the quill. The Pennsylvania Railroad GG1 locomotive used a quill drive. Again, as traction motors continued to shrink in size and weight, quill drives gradually fell out of favour.

Another drive example was the "bi-polar" system, in which the motor armature was the axle itself, the frame and field assembly of the motor being attached to the truck (bogie) in a fixed position. The motor had two field poles, which allowed a limited amount of vertical movement of the armature. This system was of limited value since the power output of each motor was limited. The EP-2 bi-polar electrics used by the Milwaukee Road compensated for this problem by using a large number of powered axles.

Modern electric locomotives, like their Diesel-electric counterparts, almost universally use axle-hung traction motors, with one motor for each powered axle. In this arrangement, one side of the motor housing is supported by plain bearings riding on a ground and polished journal that is integral to the axle. The other side of the housing has a tongue-shaped protuberance that engages a matching slot in the truck (bogie) bolster, its purpose being to act as a torque reaction device, as well as a support. Power transfer from motor to axle is effected by spur gearing, in which a pinion on the motor shaft engages a bull gear on the axle. Both gears are enclosed in a liquid-tight housing containing lubricating oil. The type of service in which the locomotive is used dictates the gear ratio employed. Numerically high ratios are commonly found on freight units, whereas numerically low ratios are typical of passenger engines.

## Wheel arrangements



A GG1 electric locomotive

The Whyte notation system for classifying steam locomotives is not adequate for describing the varieties of electric locomotive arrangements, though the Pennsylvania Railroad applied classes to its electric locomotives as if they were steam or concatenations of such. For example, the PRR GG1 class indicates that it is arranged like two 4-6-0 class G locomotives that are coupled back-to-back.

In any case, the UIC classification system was typically used for electric locomotives, as it could handle the complex arrangements of powered and unpowered axles and could distinguish between coupled and uncoupled drive systems.

# Electric traction around the world

## Asia

### Japan

The rail system of Japan consists of the following (as of 2005):

- 20,264 km (12,591 mi) of 1,067 mm (42.0 in) Cape gauge, of which 13,280 kilometres (8,250 mi) is electrified;
- 3,204 km (1,991 mi) of 1,435 mm (56.5 in) standard gauge, all electrified;
- 117 km (73 mi) of 1,372 mm (54.0 in) Scotch gauge, all electrified;
- 11 km (6.8 mi) of 762 mm (30.0 in) narrow gauge, all electrified.

Electrification systems used by the JR group, Japan's formerly state owned operators, are 1,500V DC and 20kV AC for conventional lines and 25kV AC for Shinkansen. Electrification with 600V DC and 750V DC are also seen in private lines. The frequency of the AC power supply is 50 Hz in Eastern Japan and 60 Hz in Western Japan.

Japan has come close to complete electrification largely due to the relatively short line distances and mountainous terrain which make electrical service a particularly economical investment. Additionally, the mix of freight to passenger service is weighted much more toward passenger service (even in rural areas) than in many other countries, and this has helped drive government investment into electrification of many remote lines.

Electrification began in earnest for local railways in the 1920s and main lines electrification began following World War II using a universal 1,500V DC standard and eventually, a 20kV standard for rapid intercity main lines (this is often overlaying 1,500V DC lines) and a 25kV AC standard for high-speed Shinkansen lines). Because most of the electrification infrastructure was destroyed in the war, the only variances to this standard with significant traffic are a few of the older subway lines in Tokyo and Osaka. The Tōkaidō Main Line, Japan's busiest line, completed electrification in 1956 and Tōkaidō Shinkansen was complete in 1964. By the mid 1970s, most main lines had been converted. During the 1970s and into the 1980s, when a fast growing Japanese economy encouraged massive infrastructure spending, almost every line with any significant traffic was electrified. Though the massive debts incurred for these upgrades (along with the more publicised expense of Shinkansen expansions) led to the privatization and break-up of the national rail company. By the time of the break up in 1987, electric service had penetrated to every line with significant traffic. In the 1990s, and 2000s, rural infrastructure was the focus of a lot of government stimulus funding and this included some rail electrification on infrequently used lines, as well as quite a lot of funding for further expanding the Shinken network (which, as with all high speed trains, is electric). The latter was mostly in the form of loans rather than direct investment as in the former.

## **Malaysia**

Keretapi Tanah Melayu of Malaysia operated 25 kV AC electric multiple unit services, starting from their KTM Komuter in 1995. In December 2009, a fleet of new ETS are arrived.

## **Australia**

Both Victorian Railways and New South Wales Government Railways, which pioneered electric traction in Australia in the early 20th century and continue to operate 1,500 V DC Electric Multiple Unit services, have withdrawn their fleets of main line electric locomotives.

In both states, the use of electric locomotives on principal interurban routes proved to be a qualified success. In Victoria, because only one major line (the Gippsland line) had been electrified, the economic advantages of electric traction were not fully realised due to the need to change locomotives for trains that extended beyond the range of the electrified network. VR's entire electric locomotive fleet was withdrawn from service by 1987 and the Gippsland line electrification was dismantled by 2004. Similarly, the new fleet of 86 class locomotives introduced to NSW in 1983 had a relatively short life as the costs of changing locomotives at the extremities of the electrified network, together with the higher charges levied for electricity use, saw diesel-electric locomotives make inroads into the electrified network and the electric locomotive fleet was progressively withdrawn. Electric power car trains are still used for urban passenger services.

Queensland Rail, conversely, implemented electrification relatively recently and utilises the more recent 25 kV AC technology with around 1,000 km of the QR narrow gauge network now electrified. It operates a fleet of electric locomotives to transport coal for export, the most recent of which are those of the 3,000 kW (4,020 HP) 3300/3400 Class. Queensland Rail is currently rebuilding its 3100 and 3200 class locos into the 3700 class, which use AC traction and only need three locomotives on a coal train rather than five. Queensland Rail is getting thirty 3800 class locomotives from Siemens in Munich, Germany, which will arrive during late 2008 to 2009. QRNational (Queensland Rail's Coal and Freight after separation) has increased the order of 3800 class locomotives from Germany. They continue to arrive late into 2010.

## Europe



NER No.1, Locomotion museum, Shildon

Electrification is widespread in Europe. Due to higher density schedules, the operating costs of the locomotives are more dominant with respect to the infrastructure costs than in the US and electric locomotives have much lower operating costs than diesels. In addition, governments were motivated to electrify their railway networks due to coal shortages experienced during the First and Second World Wars.

It should also be noted that diesel locomotives have little power compared to electric locomotives, given the same weight and dimensions. For instance, the 2,200 kW of a modern British Rail Class 66 were already met in 1927 by the electric SBB-CFF-FFS Ae 4/7 (2,300 kW), which is even a bit lighter. However, for low speeds, tractive effort is more important than power. This is why diesel engines are competitive for slow freight traffic (as it is common in the US) but not for passenger or mixed passenger/freight traffic like on many European railway lines, especially where heavy freight trains must be run at comparatively high speeds (80 km/h or more).

These factors led to high degrees of electrification in most European countries. In some countries like Switzerland, even electric shunters are common and many private sidings

can be served by electric locomotives. During World War 2, when materials to build new electric locomotives were not available, the Swiss Federal Railways installed electric heating elements, fed from the overhead supply, in the boilers of some steam shunters to deal with the shortage of imported coal.

The recent political developments in many European countries to enhance public transit have led to another boost for electric traction. High-speed trains like the TGV, ICE, AVE and Pendolino can only be run economically using electric traction and the operation of branch lines is usually less in deficit when using electric traction, due to cheaper and faster rolling stock and more passengers due to more frequent service and more comfort. In addition, gaps of un-electrified track are closed to avoid replacing electric locomotives by diesels for these sections. The necessary modernisation and electrification of these lines is possible due to financing of the railway infrastructure by the state.

## India

In India, both AC and DC type of electrified train systems operate today. A 1,500 V DC-based train system is only operating in the Mumbai area. It is being converted to the 25 kV AC system. The rest of the India, where routes are electrified fully, operate under the 25 kV AC overhead wire. As of 2006, Indian railways haul 80% of freight and 85% of passenger traffic with electric locomotives.

## Russia and former USSR



Soviet electric locomotive VL60<sup>P</sup><sub>k</sub> (BJI60<sup>II</sup><sub>k</sub>), c. 1960

Russia and other countries of the former USSR have a mix of 3,300 V DC and 25 kV AC electric railroads due to historical reasons.

The special "junction stations" (around 15 over the whole former USSR - Vladimir, Mariinsk near Krasnoyarsk etc.) were equipped with contact wiring switchable from DC to AC. Locomotive replacement is essential at these stations and is performed together with the contact wiring switching.

Most Soviet, Czech (USSR ordered the passenger electric locomotives to Czech Skoda factory), Russian and Ukrainian locomotives can only operate as DC or as AC. For instance, VL80 is an AC machine, with VL10 being something like a DC version of VL80. There were some half-experimental small-series like VL82, which could switch from AC to DC and were used in small amounts around the city of Kharkov in Ukraine. Also, the latest Russian passenger locomotive EP10 (experimental only?) is dual-system.

Historically, first the 3,300 V DC wiring was used due to vehicle simplicity. The first experimental track was in Georgian mountains, then the suburban zones of the largest cities were electrified for motor-car locomotive-less trains to be used - very advantageous due to much better dynamic of such a train compared to the steam one, which is important for the suburban service with frequent stops. Then the large mountain line between Ufa and Chelyabinsk was electrified.

For some time, electric railways were only considered to be suitable for suburban or mountain lines. In around 1950, a decision was made (according to the legend - by Joseph Stalin) to electrify the highly-loaded plain prairie line of Omsk-Novosibirsk. After this, electrifying the major railroads with 3,000 V DC became a mainstream.

25 kV AC contact wiring started in the USSR in around 1960, when the industry managed to build the rectifier-based AC-wire DC-motor locomotive (all Soviet and Czech AC locomotives were such; only the post-Soviet ones switched to electronically controlled induction motors). The first major line with AC power was Mariinsk-Krasnoyarsk-Tayshet-Zima; the lines in European Russia like Moscow-Rostov-on-Don followed.

In 1990s, some DC lines were rebuilt as AC ones to allow the usage of the huge 10 MWt AC locomotive of VL85. The line around Irkutsk is one of them. The DC locomotives freed by this rebuild were transferred to St. Petersburg region.

The Trans-Siberian Railway has been partly electrified since 1929 and entirely electric hauled since 2002. The system is 25 kV AC 50 Hz after the junction station of Mariinsk near Krasnoyarsk, 3,000 V DC before it and train weights are up to 6,000 tonnes.

## **United States**

For most large systems, the cost of electrifying the whole system is impractical and generally only some divisions are electrified. In the United States, only certain dense

urban areas and some mountainous areas were electrified and the latter have all been discontinued. The junction between electrified and non-electrified territory is the locale of engine changes; for example, Amtrak trains had extended stops in New Haven, Connecticut as diesel and electric locomotives were swapped, a delay which contributed to the electrification of the remaining segment of the Northeast Corridor in 2000.

In North America, the flexibility of diesel locomotives and the relative low cost of their infrastructure has led them to prevail except where legal or other operational constraints dictate the use of electricity. An example of the latter is the use of electric locomotives by Amtrak and commuter railroads in The Northeast (e.g. New Jersey Transit New York corridor uses ALP-46 electric locomotives).

## **Canada**

No railways in Canada use electric locomotives on their lines as of January 2011.

Agence métropolitaine de transport (AMT) has ordered the ALP-45DP dual mode electro-diesel locomotives for use on the Repentigny-Mascouche Line (AMT). The locomotives will run as electric while in the Mount Royal Tunnel only and as diesel elsewhere.

GO Transit has completed a study on electrifying some or all of their commuter rail lines, but so far no target date or purchases have been initiated.

## Battery locomotive



A London Underground battery-electric locomotive at West Ham station

A battery locomotive (or battery-electric locomotive) is a type of electric locomotive powered by on-board batteries; a kind of battery electric vehicle. Such locomotives are used where a conventional diesel or electric locomotive would be unsuitable. An example of use is the hauling of maintenance trains on electrified lines when the electricity supply is turned off, such as by the London Underground battery-electric locomotives.

Another use for battery locomotives is in industrial facilities – as an alternative to the fireless locomotive – where a combustion-powered locomotive (i.e., steam- or diesel-powered) could cause a safety issue, due to the risks of fire, explosion or fumes in a confined space.

### **Kennecott Copper**

In 1928, Kennecott Copper ordered four 700-series electric locomotives with on-board batteries. These locomotives weighed 85 tons and operated on 750-volt overhead trolley wire with considerable further range whilst running on batteries. The locomotives

provided several decades of service using Nickel-iron battery (Edison) technology. The batteries were replaced with lead-acid batteries, and the locomotives were retired shortly afterward. All four locomotives were donated to museums, but one was scrapped. The others can be seen at the Boone and Scenic Valley Railroad, Iowa, and at the Western Railway Museum in Rio Vista, California.

WWT

## Chapter- 4

# Electric Aircraft



Helios electric-powered UAV

An **electric aircraft** is an aircraft that runs on electric motors rather than internal combustion engines, with electricity coming from fuel cells, solar cells, ultracapacitors, power beaming, and/or batteries.

Currently flying electric aircraft are mostly experimental demonstrators, including manned and unmanned aerial vehicles. Electrically powered model aircraft have been flown since the 1970s, with one report in 1957.

## History

In 1883 Gaston Tissandier was the first to use electric motors in airship propulsion. The following year, Charles Renard and Arthur Krebs flew La France with a more powerful motor.

Electric motors have been used for model fixed-wing aircraft since from at least 1957, with a challenged claim from 1909.

## Experimental projects

### 1970s and 1980s

#### Sunrise

The 27 lb (12 kg) unmanned AstroFlight Sunrise, the result of an ARPA contract, made the world's first solar-powered flight from Bicycle Lake, a dry lakebed on the Fort Irwin Military Reservation, on 4 November 1974. The improved Sunrise II flew on 27 September 1975 at Nellis AFB.

#### Solar Riser

The world's first official flight in a solar powered, man carrying aircraft took place on April 29, 1979. The Solar Riser was built by Larry Mauro and was based on the Easy Riser biplane hang glider. The aircraft used photovoltaic cells that produced 350 watts at 30 volts, which charged a Hughes 500 helicopter battery, which in turn powered the electric motor. The aircraft was capable of powering the motor for 3 to 5 minutes, following a 1.5 hour charge, enabling it to reach a gliding altitude.

#### Gossamer Penguin and Solar Challenger

The Gossamer Penguin, a smaller version of the human powered Gossamer Albatross was completely solar powered. A second prototype, the Solar Challenger, flew 262 km (163 mi) from Paris to England. On 7 July 1981, the aircraft, under solar-power, flew 163 miles from Cormeilles-en-Vexin Airport near Paris across the English Channel to RAF Manston near London, flying for 5:23. Designed by Dr. Paul MacCready the Solar Challenger set an altitude record of 14,300 feet.

#### Solair 1

The human piloted Solair 1 was developed by Günther Rochelt and based on a Farner canard design. It employed 2499 wing-mounted solar cells giving an output of between 1.8 kW (2 hp) and 2.2 kW (3 hp). The aircraft first flew at Unterwössen, Germany on 21 August 1983. It flew for 5 hours and 41 minutes, "mostly on solar energy and also thermals". The aircraft is now displayed at the German Museum in Munich. The newly

developed piloted Solair II made its first flight in May 1998 and further test flights that summer but the propulsion system overheated too fast. Development stopped when Günther Rochelt suddenly died in September 1998.

### **NASA Pathfinder and Helios**

NASA's Pathfinder and Helios were a series of solar and fuel cell system-powered unmanned aircraft. AeroVironment, Inc. developed the vehicle under NASA's Environmental Research Aircraft and Sensor Technology program.

### **1990s**



Solar Flight's Sunseeker flying over Southern California's high desert

### **Sunseeker**

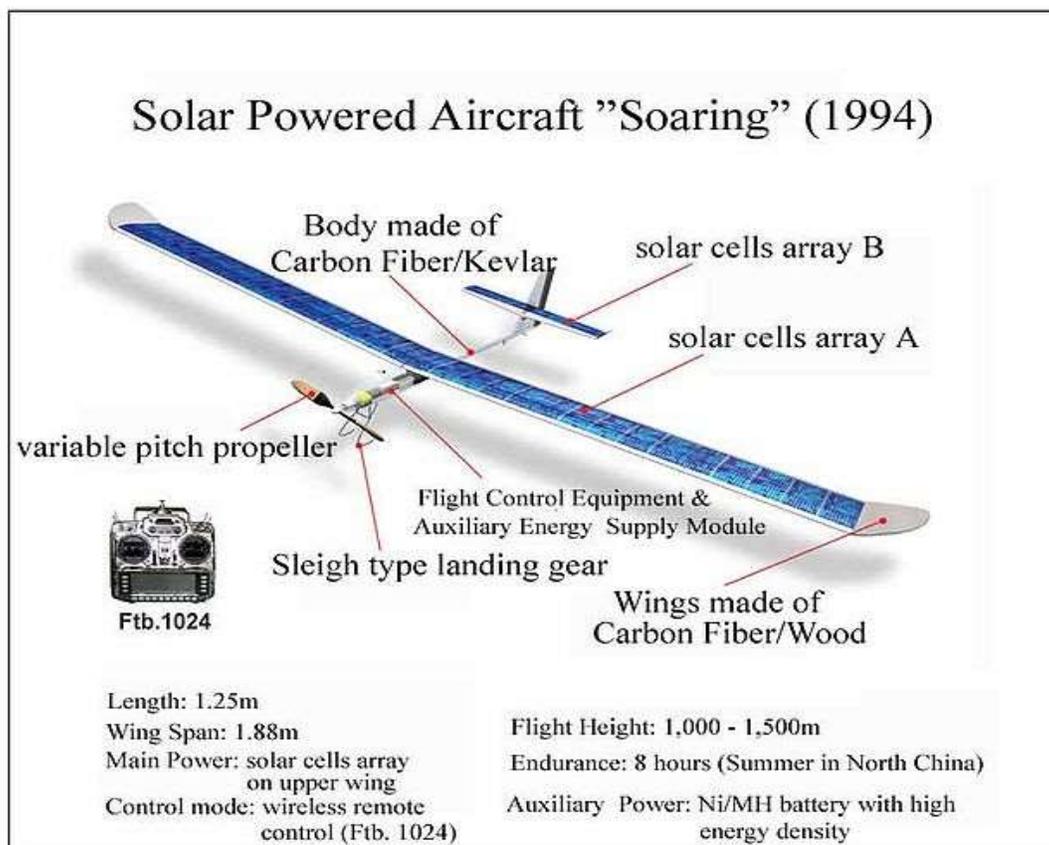
In 1990 the solar powered airplane *Sunseeker* successfully flew across the USA, piloted by Eric Raymond. It used a small battery charged by solar cells on the wing to drive a propeller for takeoff, and then flew on direct solar power and took advantage of soaring conditions when possible.

The *Sunseeker II*, built in 2002, was updated in 2005-2006 with a more powerful motor, larger wing, lithium battery packs and updated control electronics. As of Dec, 2008 it was the only manned solar powered airplane in flying condition and is operated regularly by Solar Flight. In 2009 it became the first solar-powered aircraft to cross the Alps, 99 years after the first crossing of the Alps by an aircraft.

## Soaring



Test Flight of *Soaring* in 1994



Summary of Configuration and Performance Parameter of "Soaring"

China's first solar powered aircraft "Soaring" was designed and built by Danny H. Y. Li and Zhao Yong in 1992. The body and wings are hand-built predominantly of carbon fiber, Kevlar and wood. The design uses winglets to increase the effective wing span and reduce induced drag.

## **2000s**

### **Antares 20E**

The Antares 20E is an electric, self-launching sailplane with a 42-kW DC/DC brushless motor (called EM42) and lithium-ion batteries. It can climb up to 3,000 meters with fully charged cells.

### **Solar Impulse**

The first short-hop (350m) test flight of the Solar Impulse prototype was made on 3 December 2009.

In its present configuration it has a wingspan of 210 ft (64 m), weighs 3,500 lb (1,588 kg) and is powered by four 10-horsepower (7 kW) electric motors. The aircraft has over 11,000 solar cells on its wings and horizontal stabilizer. Power from the solar cells is stored in lithium polymer batteries and used to drive 3.5-metre (11 ft) propellers turning at a speed of 200–400 rpm. Take-off speed is 19 knots (35 km/h) and cruising speed is 60 kn (111 km/h).

The aircraft had its first high flight on 7 April 2010, when it flew to an altitude of 1,200 meters (3,937 feet) in a 1.5 hour flight on battery power alone. The Solar Impulse team is planning to use the aircraft to circumnavigate the globe in 2012.

The aircraft first flew on purely solar power, charging its batteries in flight, on 28 May 2010

On 8 July 2010 it completed the first manned 24 hour flight completely powered by solar power.

### **APAME Electra**

The Association pour la Promotion des Aéronefs à Motorisation Électrique (APAME) (*English: Association for the Promotion of Electric Powered Aircraft*) first flew their Electra electric-powered open-cockpit airplane at 1150 hrs (local) on Sunday, 23 December 2007 at Aspres sur Buech airfield, Hautes Alpes, France. Test pilot Christian Vandamme flew the strut-equipped aircraft for 48 minutes, covering 50 km (31 miles). The Electra is powered by an 18-kW (24 hp) disk-brush electrical motor driven by a 47 kg (104 lb) lithium polymer battery power pack.

## **First manned AA battery powered aircraft**

Matsushita Electric Industrial Co. and undergraduates at the Tokyo Institute of Technology teamed up to build an aircraft powered by 160 AA battery cells and successfully flew it for a distance of 391 meters (1,283 ft) in July, 2006.

## **Boeing-FCD Project**



In 2008, The Boeing Fuel Cell Demonstrator achieved straight-level flight on a manned mission powered by a hydrogen fuel cell.

The FCD (Fuel Cell Demonstrator) is a project lead by Boeing that uses a Diamond Super Dimona HK-36 motor glider as a test bed for a fuel cell powered light airplane research project.

Successful test flights took place in February and March 2008.

Boeing's partners in the project are Intelligent Energy of Britain (fuel-cell); Diamond Aircraft of Austria (Airframe); Spanish Sener (control system); Spanish Aerlyper (integrate motor with airframe); Advanced Technology Products, a U.S. company (motor, batteries, flight testing).

## **QinetiQ Zephyr**

The QinetiQ Zephyr is a lightweight solar-powered unmanned aerial vehicle engineered by the United Kingdom defence firm, QinetiQ. As of 23 July 2010 it holds the endurance record for an unmanned aerial vehicle of over 2 weeks (336 hours).

It is of carbon fiber-reinforced polymer construction, the 2010 version weighing 50 kg (110 lb) (the 2008 version weighed 30 kg (66 lb)) with a span of 22.5 metres (the 2008 version had 18 metres (59 feet)). It uses sunlight to charge lithium-sulphur batteries during the day, which power the aircraft at night. The aircraft has been designed for use in observation and communications relay.

The 2008 Zephyr version flew for 82-hours, reaching 61,000 foot in altitude in July 2008, the then unofficial world record for the longest duration unmanned flight. In July 2010 the 2010 version of the Zephyr made a world record unmanned aerial vehicle endurance flight of 336 hours, 22 minutes and 8 seconds (more than two weeks) and also set an altitude record of 70,000 feet.

## **SkySpark**



Skyspark in flight 2009

The SkySpark is a joint project of engineering company DigiSky and Polytechnic University of Turin. The two-seat Pioneer Alpi 300 has a 75 kW (101 hp) brushless electric motor powered by lithium polymer batteries. The aircraft achieved a world record of 250 km/h (155 mph) for a human-carrying electric aircraft on 12 June 2009.

## **Green Pioneer I**



Test Flight of “Green Pioneer I” in 2004

The *Green Pioneer* solar powered aircraft research programme was announced at the 4th China International Aviation and Aerospace Exhibition in 2002. The experimental programme was intended to provide research data for future Chinese solar powered aircraft. The programme was run by New Concept Aircraft (Zhuhai), the China Aviation Industry Development Research Center, and China Academy of Space Technology. The project leader and chief designer was Danny H. Y. Li.

## **EADS Cri-Cri**

In June 2010 French aerospace company EADS unveiled an electric version of the 1970s vintage Colomban Cri-cri ultralight aircraft powered by four electric engines. The Cri-Cri will have lithium batteries and will be able to fly for 30 minutes at 60 kn (111 km/h) or 15 minutes of aerobatics at speeds up to 135 kn (250 km/h), with a climb rate of 1,000 feet per minute. The aircraft is a demonstrator for future technology, as Jean Botti, EADS's chief technical officer explained: "The Cri-Cri is a low-cost test bed for system integration of electrical technologies in support of projects like our hybrid propulsion concept for helicopters." The Cri-Cri first flew on 2 September 2010 at Le Bourget airport near Paris.

## **Design concepts**

### **Puffin**

The *Puffin* is a proposed hover-capable, electric-powered, low-noise, personal, vertical takeoff and landing (VTOL) technology-concept, proprotor aircraft. It would be capable of flying a single person at a speed of 150 miles per hour. Range is expected to be less than 50 miles with initial battery technology. The design has a 13.5 foot wingspan and stands 12 feet tall on the ground in its take-off or landing configuration.

As of January 2010, a one third-size, hover-capable Puffin demonstrator was planned for March 2010. Future designs might incorporate additional rotors to provide redundant systems.

As of August 2010, the one-third scale model of the Puffin was on display at the NASA Langley campus for filming for the Discovery network series "Dean of Invention." The Puffin simulator was also demonstrated. The Puffin will appear in the eighth and final episode of the show.

## **Production aircraft**

### **1990s**

#### **Alisport Silent Club**

The first commercially available production electric aircraft was the Alisport Silent Club self-launching sailplane, first tested in 1997. It is optionally driven by a 13 kW (17 hp) DC electric motor running on 40 kg (88 lb) of batteries that provide 1.4 kWh of power.

### **2000s**

#### **Electraflyer**

In April 2007 the Electric Aircraft Corporation began offering complete electric ultralights and engine kits under the ElectraFlyer brand name, to convert existing ultralight aircraft to electric power, in what is the first commercial offering of an electric aircraft.

The 18 hp (13 kW) engine package weighs 26 lbs and an efficiency of 90% is claimed by the company. The battery consists of two lithium-polymer battery packs which provides 1.5 hours of flying in the trike application.

In January 2008 the company introduced their new ElectraFlyer-C at the Sebring Light Sport Aircraft Show. This aircraft is a converted Monnett Moni motor glider equipped with an 18-hp electric motor, regenerative-braking-capable controller package and two lithium polymer battery packs. The engine weighs 29 lbs and the battery packs weigh 78 lbs total. The aircraft has a climb rate of 500 ft/min, cruise of 70 mph and an endurance of 90 minutes. It is capable of being recharged from a 110 volt source in six hours or from a 220 volt source in two hours. The aircraft began flying in May 2008 and was demonstrated before the crowds on August 2 at AirVenture 2008.

In April 2009 the ElectraFlyer-C prototype was offered for sale on eBay. The designer intends to use the funds from the sale, plus a Lindbergh Foundation grant of \$10,580 to complete two-place design that will eventually qualify for Light-sport aircraft status. The new design will incorporate composite construction, detachable wingtips to aid storage and will be powered by a 50 hp (37 kW) electric motor. Its design goals include a 28:1 glide ratio and a cruise speed of 80 mph (129 km/h) for two hours.

Electraflyer president Randall Fishman announced in April 2010 that the company's latest model, the Electraflyer-X, would fly in May or June 2010. The aircraft will be a two-

seater and will utilize a new 20 hp (15 kW) single rotor electric powerplant. Fishman is also developing 40 hp (30 kW) two-rotor and 60 hp (45 kW) three rotor engine designs.

### **Sonex Aircraft**

During AirVenture 2007 Sonex Aircraft announced that they are working on a series of alternate power initiatives, including an electric-powered aircraft. The electric powered Waix motor glider was first flown in December 2010 and is powered by a 54 kW (72 hp) brushless DC electric motor, managed by a newly-designed controller. Power is from a collection of 14.5kw-hour lithium polymer batteries, giving the aircraft an endurance of one hour at low-speed cruise or 15 minutes of aerobatics.

### **Yuneec International E430**

A new Chinese aircraft was announced in 2009. The Yuneec International E430 is a two seat, V tailed, composite aircraft with a high-aspect ratio wing. Take-off speed is 40 mph and top speed is 93 mph. The aircraft is being developed as a homebuilt aircraft for the US market.

The prototype E430 was displayed at EAA AirVenture Oshkosh in July 2009, by which time it had flown over 22 hours. The company claims that the battery packs have an expected lifespan of 1500 hours and cost US\$7000 each, with the aircraft carrying 3-5 battery packs, giving two to two and half hours endurance. The batteries can be recharged in 3 hours. The company projects that by the time the first customers require replacement battery packs that improved and less expensive ones will be available. Projected price for a commercially available light sport aircraft production version of the E430 is US\$89,000.

### **Flightstar e-Spyder**

The e-Spyder is an electric-powered version of the Flightstar Spyder ultralight, developed by Flightstar Sportplanes president Tom Peghiny of South Woodstock, Connecticut, USA in cooperation with electric engine manufacturer Yuneec. The aircraft replaces the Spyder's two-stroke engine with a Yuneec 20 kW (27 hp) electric motor and two 28 lb (13 kg) lithium-polymer battery packs which provide a 40 minute endurance. The aircraft was exhibited at EAA AirVenture Oshkosh in July 2009 and is intended as a commercially available kit plane, forecast to be available for under US\$25,000.

### **Lange Antares 20E**

The Lange Antares 20E is a self-launching motor glider with a 42-kW electric motor and SAFT VL 41M lithium-ion batteries. The motor actuates 2-blade fixed pitch propeller. It can climb up to 3,000 meters with fully charged cells. After launch it can function as a conventional, though heavy, glider. As of January 2010, over 50 had been built.

### **2010s**

## **Cessna 172**

In July 2010 Cessna announced it was developing an electrically-powered Cessna 172 as a proof-of-concept in partnership with Bye Energy. Cessna CEO Jack Pelton stated that the project reflects "encouraging news for the future of mainstream general aviation." Pelton pointed out "the electric power plant offers significant benefits, but there are significant challenges to get there."

## **PC-Aero Elektra One**

The Elektra One is a development of a commercial electric aircraft design by PC-Aero of Germany. The single seat composite aircraft is expected to have its first flight in early 2011. The Elektra One is powered by a 21 hp (16 kW) electric motor and is expected to have an endurance of three hours, with a 100 mph (161 km/h) top speed.

The company is planning a whole line of aircraft including a version of the Elektra One with longer wings and built-in solar panels and an aerobatic version with double Elektra One's power and airframe strength. The company is also planning two and four seat developments.

## **Design and operation of electric aircraft**

### **Regenerative flight**

A design concept has been put forward for soaring-type aircraft called regenerative soaring. In this approach, a propeller, using symmetrical blade sections, would be used as a turbine to recharge stored energy when the aircraft encounters an updraft. At high altitudes, the energy available from vertical atmospheric motion within a thermal can exceed available solar power by a factor of ten or more.

## Chapter- 5

# Electric Boat



Passenger solar boat Solifleur, Switzerland 1995

While most boats on the water today are powered by diesel engines, and sail power and gasoline engines are also popular, it is perfectly feasible to power boats by electricity too. **Electric boats** were very popular from the 1880s until the 1920s, when the internal combustion engine took dominance. Since the energy crises of the 1970s, interest in this quiet and potentially renewable marine energy source has been increasing steadily again, especially as solar cells became available, for the first time making possible motorboats with an infinite range like sailboats. The first practical **solar boat** was probably constructed in 1975 in England.

## History

Possibly the first electric boat was developed by Moritz von Jacobi in 1839 in St Petersburg, Russia - a 24-foot (7.3 m) boat which carried 14 passengers at 3 mph. But it took more than 30 years of battery and motor development before they began to be deployed in any numbers. In 1886 an electric boat crossed the English Channel both ways in 8 hours. By 1889 the first 6 electric charter boats were working on the Thames and in the 1893 Chicago World Fair 55 boats carried more than a million passengers.

Electric boats had an early period of popularity between around 1890 and 1910, before the emergence of the internal combustion engine drove them out. For example, an 1893 pleasure map of the Thames shows 8 "charging stations for electric launches" between Kew (Strand-on-the-Green) and Reading (Caversham). Most of these were small passenger boats on non-tidal waters at a time when the only power alternative was steam. One of the largest in Britain, and the only surviving example, is the *Mary Gordon* which was built on the Thames for Leeds City Council for use on the Roundhay Park Lake. It was 52 feet (16 m) long and could take 75 passengers, and is now being restored.

In the US, the Electric Boat Company was founded in 1899 and built the first submarine purchased by the U.S. Navy in 1900. Since then, electric power has been used almost exclusively for powering submarines underwater, although diesel was used for powering them on the surface until the development of diesel-electric transmission by the US Navy in 1928. The Electric Boat Company eventually became General Dynamics Corporation in 1952.

The use of combined fuel and electric propulsion has gradually been extended over the years to the extent that some modern liners such as the *Queen Mary 2* use only electric motors, powered by diesel and gas turbine engines. The advantages include being able to run the fuel engines at an optimal speed at all times and being able to mount the electric motor in a pod which may be rotated by 360° for increased manoeuvrability.

The use of electricity alone to power boats stagnated apart from their outboard use as trolling motors until the Californian firm of Duffy started producing small electric craft in 1968. It wasn't until the 1980s that the *Electric Boat Association* was formed and solar powered boats started to emerge.

## Components

The main components of the drive system of any electrically powered boat are similar in all cases, and similar to the options available for any electric vehicle.

### Charger

Electric energy has to be obtained for the battery bank from some source.



Solar panels deployed on a small yacht at sea

- **Mains charger** allows the boat to be charged from shore-side power when available. Shore-based power stations are subject to much stricter environmental controls than the average marine diesel or outboard motor. By purchasing green electricity it is possible to operate electric boats using sustainable or renewable energy.
- **Solar panels** can be built into the boat in reasonable areas in the deck, cabin roof or as awnings. Some solar panels, or photovoltaic arrays, can be flexible enough to fit to slightly curved surfaces and can be ordered in unusual shapes and sizes. Nonetheless, the heavier, rigid mono-crystalline types are more efficient in terms of energy output per square meter. The efficiency of solar panels rapidly decreases when they are not pointed directly at the sun, so some way of tilting the arrays while under way is very advantageous.
- **Towed generators** are common on long-distance cruising yachts and can generate a lot of power when travelling under sail. If an electric boat has sails as well, and will be used in deep water (deeper than about 15 m or 50 ft), then a towed generator can help build up battery charge while sailing (there is no point in trailing such a generator while under electric propulsion as the extra drag from the generator would waste more electricity than it generates). Some electric power systems use the free-wheeling drive propeller to generate charge through the drive motor when sailing, but this system, including the design of the propeller and any gearing, cannot be optimised for both functions. It may be better locked off or feathered while the towed generator's more efficient turbine gathers energy.
- **Wind turbines** are common on cruising yachts and can be very well suited to electric boats. There are safety considerations regarding the spinning blades,

especially in a strong wind. It is important that the boat is big enough that the turbine can be mounted out of the way of all passengers and crew under all circumstances, including when alongside and when coming alongside a dock, a bank or a pier. It is also important that the boat is big enough and stable enough that the *top hamper* created by the turbine on its pole or mast does not compromise its stability in a strong wind or gale. Large enough wind generators could produce a completely wind-powered electric boat. No such boats are yet known although a few *mechanical* wind turbine powered boats exist.

- If the boat has an **internal combustion engine** anyway, then its alternator will provide significant charge when it is running. Two schemes are in use: the combustion engine and the electric motor both coupled to the drive, or a separate generator with the combustion engine only charging the storage batteries.

In all cases, a **charge regulator** is needed. This ensures that the batteries are charged at the maximum rate that they safely can stand when the power is available. It also ensures that they are not overcharged when nearing full charge and not overheated when a large charge current becomes available.

### Battery bank

There have been significant technical advances in battery technology in recent years, and more are to be expected in the future.



Example of a modern production electric boat

- **Lead-acid batteries** may still be the most viable option at the moment (2008). Deep-cycle, 'traction' batteries are the obvious choice. They are heavy and bulky, but not much more so than the diesel engine, tanks and fittings that they may replace. They need to be securely mounted, low down and centrally situated in the boat. It is essential that they *cannot* move around under *any* circumstances. Care must be taken that there is no risk of spilled, strong acid in the event of a capsize as this could be very dangerous. Venting of explosive hydrogen and oxygen gases is also necessary. Typical lead-acid batteries must be kept topped-up with distilled water.
- **Valve-regulated lead-acid (VRLA) batteries**, usually known as sealed lead-acid, Gel, or AGM batteries, minimize the risk of spillage, and gases are only vented when the batteries are overcharged. These batteries require minimal maintenance, as they cannot and usually do not need to be refilled with water.
- **Nickel metal hydride, lithium-ion** and other solid-state batteries are becoming available, but are still expensive. These are the kind of batteries currently common in rechargeable hand tools like drills and screwdrivers, but they are relatively new to this environment. They require different charge controllers to those that suit lead-acid types.
- **Fuel cells** may provide significant advantages in years to come. Today (2010) however they are still expensive and require specialist equipment and knowledge.

The size of the battery bank determines the *range* of the boat under electric power alone. The speed that the boat is motored at also affects this - a lower speed can make a big difference to the energy required to move a hull. Other factors that affect range include sea-state, windage and any charge that can be reclaimed while under way, for example by solar panels in full sun. A wind turbine in a good following wind will help, and motor-sailing in any wind could do so even more.



SB Collinda, the first solar powered boat to cross the English Channel

## **Speed controller**

To make the boat usable and maneuverable, a simple-to-operate forward/stop/backwards speed controller is needed. This must be efficient—i.e. it must not get hot and waste energy at any speed—and it must be able to stand the full current that could conceivably flow under any full-load condition. One of the most common types of speed controllers uses Pulse-width modulation (PWM). PWM controllers send high frequency pulses of power to the motor(s). As more power is needed the pulses become longer in duration.

## **Electric motor**

A wide variety of electric motor technologies are in use. Traditional field-wound DC motors were and still are used. Today many boats use lightweight permanent magnet DC motors. The advantage of both types is that while the speed can be controlled electronically, this is not a requirement. Some boats use AC motors or permanent magnet brushless motors. The advantages of these are the lack of commutators which can wear out or fail and the often lower currents allowing thinner cables; the disadvantages are the total reliance on the required electronic controllers and the usually high voltages which require a high standard of insulation.

## Drive train

Traditional boats use an inboard motor powering a propeller through a propeller shaft complete with bearings and seals. Often a gear reduction is incorporated in order to be able to use a larger more efficient propeller. This can be a traditional gear box, coaxial planetary gears or a transmission with belts or chains. Because of the inevitable loss associated with gearing, many drives eliminate it by using slow high-torque motors. The electric motor can be encapsulated into a pod with the propeller and fixed outside the hull (saildrive) or on an outboard fixture (outboard motor).

## Types

There are as many types of electric boat as there are boats with any other method of propulsion, but some types are significant for various reasons.



RA66 Helio is a solar-powered 20m-catamaran cruising on the Untersee, a part of Lake Constance. It is based in Radolfzell, Germany.

- **Historical and restored** electric boats exist and are often important projects for those involved.
- **Canal, river and lake** boats. Electric boats, with their limited range and performance, have tended to be used mostly on inland waterways, where their

complete lack of local pollution is a significant advantage. Electric drives are also available as auxiliary propulsion for sailing yachts on inland waters.

- **Electric outboards** and trolling motors have been available for some years at prices from about \$100 (US) up to several thousand. These require external batteries in the bottom of the boat, but are otherwise practical one-piece items. Most available electric outboards are not as efficient as custom drives, but are optimised for their intended use, e.g. for inland waterway fishermen. They are quiet and they do not pollute the water or the air, so they do not scare away or harm fish, birds and other wildlife. Combined with modern waterproof battery packs, electric outboards are also ideal for yacht tenders and other inshore pleasure boats.
- **Cruising yachts** usually have an auxiliary engine, and there are two main uses for it: One is to power ahead or motor-sail at sea when the wind is light or from the wrong direction. The other is to provide the last 10 minutes or so of propulsion when the boat is in port and needs to be manoeuvred into a tight berth in a crowded and confined marina or harbour. Electric propulsion is not suitable for prolonged cruising at full power although the power required to motor slowly in light airs and calm seas is small. Regarding the second case, electric drives are ideally suited as they can be finely controlled and can provide substantial power for short periods of time. However, several cruising yachts have sailed across the Atlantic on solar power alone and one is in the process of crossing the Pacific Ocean on solar power alone.
- **Diesel-electric.** There is a third potential use for a diesel auxiliary and that is to charge the batteries, when they suddenly start to wane far from shore in the middle of the night, or at anchor after some days of living aboard. In this case, where this kind of use is to be expected, perhaps on a larger cruising yacht, then a combined diesel-electric solution may be designed from the start. The diesel engine is installed with the prime purpose of charging the battery banks, and the electric motor with that of propulsion. There is some reduction in efficiency if motoring for long distances as the diesel's power is converted first to electricity and then to motion, but there is a balancing saving every time the wind-, sail- and solar-charged batteries are used for manoeuvring and for short journeys without starting the diesel. There is the flexibility of being able to start the diesel as a pure generator whenever required. The main losses are in weight and installation cost, but on the bigger cruising boats that may sit at anchor running large diesels for hours every day, these are not too big an issue, compared to the savings that can be made at other times.
- **Solar powered.** A boat propelled by direct solar energy is a marine solar vehicle. The available sunlight is almost always converted to electricity by solar cells, temporarily stored in accumulator batteries, and used to drive a propeller through an electric motor. Power levels are usually on the order of a few hundred watts to a few kilowatts. Solar powered boats started to become known around 1985 and

in 1995 the first commercial solar passenger boats appeared. Solar powered boats have been used successfully at sea. The first crossing of the Atlantic Ocean was achieved in the winter of 2006/2007 by the solar catamaran Sun21.

## Pollution and embodied energy

All the component parts of any boat have to be manufactured and will eventually have to be disposed of. Some pollution and use of other energy sources are inevitable during these stages of the boat's life and electric boats are no exception. The benefits to the global environment that are achieved by the use of electric propulsion are manifested during the working life of the boat, which can be many years. These benefits are also most directly felt in the sensitive and very beautiful environments in which such a boat is used.

The May 2010 edition of *Classic Boat* magazine carried a pro and con article entitled *Electric debate*. Jamie Campbell argued against electric boating on four main counts, which were rebuffed by Kevin Desmond and Jamie Campbell, Vice Chairman, Electric Boat Association. He asserted that electric propulsion can no more be justified afloat than a *Seagull* outboard motor, proposing wooden sailing boats and rowing dinghies as "by far the most environmentally sensitive and renewable options for recreational boating".

### Electricity production

Campbell asserts that the lack of pollution from an electric boat "reeks of nimbyism" as "the discharge is all in someone else's back yard" and that the provision of re-charging points may involve digging up miles of habitat. Desmond responds that while there is no doubt that rechargeable batteries derive their energy from power stations (when not charged on board by solar and wind generation), noisier internal-combustion-engined boats obtain their fuel from even further away and that, once installed a power cable is less environmentally disruptive than a petrol station. Rutter notes that electric boats tend to recharge overnight, using 'base load'.

### Efficiency

While there are losses in the charge/discharge cycle and in the conversion of electricity to motive power, Rutter points out that most electric boats need only about 1.5 kW or 2 hp to cruise at 5 mph, a common maximum river speed and that a 30 hp petrol or diesel engine producing only 2 hp is considerably more inefficient. While Campbell refers to heavy batteries requiring a "load-bearing hull" and "cranky, even unseaworthy vessels", Desmond points out that electric boaters tend to prefer efficient, low-wash hull forms that are more friendly to river banks.

### Pollution

Campbell discusses the pollution that "traditional" batteries put into the water when a boat sinks, but Desmond says that electric boats are no more liable to sinking than other types and lists the leakage of fuel, engine oil and coolant additives as inevitable when an internal-combustion-engined boat sinks. Rutter

points to the "very nasty cocktail of pollutants" that come out of a diesel wet exhaust in normal use.

#### Battery manufacture

Campbell mentions "all manner of noxious chemicals ... involved in battery manufacture", but Rutter describes them as being "lead and sulphuric acid with a few extra trace metals in a modest plastic box" with a potential lifetime of 10–12 years. Desmond says that the US has a 98% recycling rate for lead acid batteries and that the battery and lead-smelting industries observe some of the tightest pollution control standards in the world.

The article mentions 25% and 30% discounts being offered to electric boaters by the UK Environment Agency and the Broads Authority and that battery powered vehicles have  $\frac{3}{5}$  the carbon footprint of their petrol equivalents. It is claimed that a typical recharge after a day's cruising costs £1.50, without the use of solar or wind power.

## Solar ships



Tûranor PlanetSolar, the world's largest solar-powered boat

Japan's biggest shipping line Nippon Yusen KK and Nippon Oil Corporation said solar panels capable of generating 40 kilowatts of electricity would be placed on top of a 60,000 tonne car carrier ship to be used by Toyota Motor Corporation.

In 2010, the Tûranor PlanetSolar, a 30 metre long, 15.2 metre wide catamaran yacht powered by 470 square metres of solar panels, was unveiled. It is set to circumnavigate the Earth and is so far the largest solar-powered boat ever built.

The Monaco yacht company Wally has announced a "gigayacht" designed for billionaires torn between buying a mansion and a superyacht. The *Why 58 x 38* is designed to have an autonomous cruising range of 12,000 miles at 12 knots by means of 900m<sup>2</sup> of solar panels which generate 150 kW to assist the diesel-electric motors and optional Skysails.

WWT

## Chapter- 6

# Electric Motorcycles and Scooters



Electric motorcycle of Zero Motorcycles



Brammo Enertia electric motorcycle



E-max electric scooter

**Electric motorcycles and scooters** are vehicles with two or three wheels that use electric motors to attain locomotion.

Increasingly accepted as capable, even appealing, forms of transportation, particularly in densely populated urban areas, electric two-wheel vehicles is a category that includes electric bicycles, electric kick scooters, electric motorcycles, and electric scooters. According to a recent report from Pike Research, worldwide sales of electric two-wheel vehicles (E2WVs) are expected to increase at a compound annual growth rate (CAGR) of 9.4% through 2016.

## History

- **Late 1860s:** Earliest references to electric motorcycles can be found in patents.
- **1911:** Electric motorcycle available according to early Popular Mechanics article.
- **2007:** Li-Ion cell-powered Killacycle makes new quarter mile (400-metre) record of 7.824 seconds and 168 mph (270 km/h) in Phoenix, AZ, US at AHDRA 2007.

## Power source



Yamaha FC Aqel

Generally, the source of power for the electric motor has been batteries, but development in fuel cell technology has created several prototypes. Some examples are: the ENV from Intelligent Energy, Honda's scooter using the Honda FC Stack, and the Yamaha FC-AQEL. Also, petroleum hybrid-electric motorcycles are available. Some examples are the Ecycle, and Yamaha's Gen-RYU.

## Advantages and disadvantages

Electric motorcycles and scooters are rising in popularity because of higher gasoline prices. Battery technology is gradually improving making this form of transportation more practical.



Stylish Eped City, Epeds Uk Ltd

Advantages of electric over gasoline power:

1. The fuel costs for electric power are approximately 25% the cost of gasoline power
2. Nearly silent
3. Better acceleration characteristics than the conventional motorcycles in the same speed category
4. Some motorcycles have a removable lithium ion batteries that can be charged using any 120/230V outlet outside of the motorcycle
5. Environmental friendly (no exhausted gases at point of use)
6. Carbon tax and vehicle registration tax exemption in some countries
7. No parking/congestion charges in some countries
8. No road tax in some countries

9. Using grid power to charge batteries causes less pollution than gasoline scooters; (MIT wheel to well analysis of EVs) the amount of emissions and residues caused depends on the sources of the electricity used
10. No trips needed to a gas station—can be recharged at home or in charging stations. But charging or battery swapping in service stations, when needed, are faster
11. It can be used in a V2G system
12. Lower maintenance costs and fewer maintenance activities
13. Can be ridden indoors
14. More affordable than electric cars
15. Many models dispense with a transmission or the need to shift gears, simplifying operation
16. Instant on / no warm-up time
17. Much lower amount of heat given off by motor than is typical for some internal combustion motorcycle engines



Electric scooters (and an electric bicycle) parked in Chengdu, China

Disadvantages:

1. Up front costs may be higher than for a comparable gasoline powered motorcycle or scooter depending of the battery type used.

2. Shorter range before recharging.
3. Longer "fill up" or recharge time.
4. Lower maximum speed at similar price points.
5. Electric power outlets are often not conveniently located near streets or driveways.
6. Battery capacity can be as low as 20% on a cold winter day with -20 °C. This disadvantage could be solved by using a lithium batteries which hold their capacity even in a cold weather.
7. As it is already difficult for motorcycles to be "noticed" by drivers of cars and trucks, the loss of characteristic engine noise might make riding these even more dangerous than their internal combustion engine powered counterparts.
8. The user have to take care of the batteries even when the motorcycle is not in use

## Types



50+ mph fun-ev electric scooter

A scooter is a type of motorcycle with a step-through frame and usually with smaller wheels designed for urban transportation.

## Various types of scooters

Scooters are divided into categories as per the particular niche that they are designed to operate in and speed requirements:

- Two-wheeled high speed seated scooters separated from motorcycles by swing through space in chassis 0-72 mph (0–116 km/h)
- Two-wheeled Stand-up scooters (like a kick scooter) 0-25 mph (0–40 km/h)
- Two-wheeled Seated scooters 0-25 mph (0–40 km/h)
- Two-wheeled, side-by-side stand-up scooters like manufactured by Segway PT 0-12 mph (0–20 km/h)
- Three-wheeled stand-up cambering scooter like Trikke Tribred (3CV 3-point carving vehicle) 18 mph (28 km/h) with dynamic suspension and front wheel drive
- Three-wheeled standup scooters 0-15 mph (0–25 km/h) (i.e. Easyglider X6)
- Three- and four-wheeled Mobility scooter (disability riders) 0-10 mph (0–15 km/h)
- Three- and four-wheeled Seated scooters/golf carts 0-25 mph (0–40 km/h)

## Electric motorcycle or electric bicycle



Electric motorcycle "Electrocat"

Two-wheeled motorcycles are generally differentiated from electric bicycles and mopeds (motorized pedal cycles) by speed, with motorcycles having greater speeds—usually

greater than 30 mph (about 50 km/h). This line for what constitutes a 2 wheeled motorcycle has blurred due to marketing, styling, and public opinion.

Certain models of electric bicycle take the form of scooters or small motorcycles, with the standard features of common e-bikes, but with plastic or metal cladding, lighting systems; such as indicators and brake lights, and speedometers. They are however, classed as electric bicycles in most areas.

### **3-wheeled motorcycles**

Due to vagueness in motor vehicle laws, any three-wheeled vehicle that can travel over 31 mph (50 km/h) may be classified as a motorcycle. This classification does not depend on whether the operator is fully enclosed by a "cage" or exposed to the elements. Several automotive startup companies made their initial designs three wheeled vehicles, because the motorcycle classification does not require the same costly battery of crash safety testing as a four wheeled vehicle. They may find a sales advantage because insurance and licensing requirements are simplified or non-existent if the local laws classify these types of vehicles as a bicycles.

For design purposes, three wheeled vehicles are divided into 2 categories:

- 1 wheel in front and 2 in back, known as a delta design or the traditional trike (tricycle) design
- 2 wheels in front and 1 in back, known as a tadpole design.

Some three wheeled motorcycles enclose the rider in a "cabin" or cockpit. These include the Twike, Myers Motors NmG.

Some three wheeled motorcycles have independent suspension allowing the vehicle to tilt or lean, such as the Carver one.

### **Self-balancing unicycle**

The Uno dicycle is another type of electric vehicle that is sometimes described as an electric motorcycle.