

Range Extender (Vehicle)

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A range extender vehicle is a battery electric vehicle that includes an auxiliary power unit (APU) known as a 'range extender'. The range extender drives an electric generator which charges a battery which supplies the vehicle's electric motor with electricity. This arrangement is known as a series hybrid drivetrain. The most commonly used range extenders are internal combustion engines, but fuel-cells or other engine types can be used. Range extender vehicles are also referred to as extended-range electric vehicles (EREV), range-extended electric vehicles (REEV), and range-extended battery-electric vehicle (BEVx) by the California Air Resources Board (CARB). The key function of the range extender is to increase the vehicle's range. Range autonomy is one of the main barriers for the commercial success of electric vehicles, and extending the vehicle's range when the battery is depleted helps alleviate range anxiety. A range extending vehicle design can also reduce the consumption of the range extending fuel (such as gasoline) by using the primary fuel (such as battery power), while still maintaining the driving range of a single fuel vehicle powered by a range extending fuel such as gasoline. The range extending fuel is generally considered to be less environmentally and economically friendly to use than the primary fuel source, so the vehicle control system gives preference to using the primary fuel if it's available. However, due to range limitations with the primary fuel source, the range extending fuel allows the vehicle to get many of the cost and environmental benefits of the primary fuel, while maintaining the full driving range of the range extending fuel source. For example, in the Chevy Volt, battery power from the electric grid can be cheaper and more environmentally sustainable than burning gasoline (depending on the electric generation source), but due to the trade offs between the range of a pure electric vehicle and its battery size, adding the range extending gasoline is considered by many to be good compromise to give the Chevy Volt a significantly greater driving range. How many benefits are derived from using the primary fuel however depend on how the vehicles are driven. For example, a first generation Chevy Volt will operate 100% on battery power from the electric grid for the first 60 km (37 miles), while the second generation Volt will operate on 100% battery power for the first 85 km (53 miles) when fully recharged between trips. However, if the same Chevy Volt is driven for hundreds of miles a day it will require significant gasoline as the battery will be quickly depleted. Using the gasoline engine to generate power for the motors, the economy ratings are 6.4 L/100 km (37 mpg-US) and 5.6 L/100 km (42 mpg-US) for the different generation models. Therefore, it is critical to understand the driving patterns of the average commuter to fully understand the impact these range extending vehicles will have in the real world. Many range extender vehicles, including the Chevrolet Volt and the BMW i3, are able to charge their batteries from the grid as well as from the range extender, and therefore are a type of plug-in hybrid electric vehicle (PHEV). When a range extender uses conventional fuels they can re-fuel at regular fuel stations, which provides them with a similar driving range to conventional automobiles. As an REEV is only propelled by the electric motor it can do away with the weight and cost associated with the gearbox transmission system typically used in internal combustion engine cars. Further, as the range extender does not need to increase or decrease output in line with the power needs of the vehicle (this task is handled by the electric motor) the range extender can be sized to satisfy the vehicle's average power requirement rather than its peak power requirement (such as when accelerating). The range extender can also operate much closer to its most efficient rotational speed. These design features allow an REEV to convert fossil fuel energy to electric power and vehicle motion very efficiently.

Keywords: fossil fuel energy ; battery electric vehicle ; pure electric vehicle

1. Generations

- The first generation range extenders are off the shelf internal combustion engines.
- The second generation consists of piston engines with new designs from scratch for fairly constant load in series hybrids. They include the wankel engines, rotary combustion engines and free piston engines.
- The third generation are micro turbines and fuel cells that work at constant load.^[1]

2. CARB Regulation

According to 2012 Amendments to the Zero Emission Vehicle Regulations adopted in March 2012 by the California Air Resources Board (CARB), a range-extended battery-electric vehicle, designated as BEVx, should comply, among others, with the following criteria:^[2]

- The vehicle must have a rated all-electric range of at least 120 km (75 miles). This is higher than the 80 km (50 miles) required of a zero-emission vehicle;
- The auxiliary power unit (APU) must provide range less than or equal to battery range;
- The APU must not be capable of switching on until the battery charge has been depleted;
- The vehicle must meet super ultra low emission vehicle (SULEV) requirements; and
- The APU and all associated fuel systems must comply with zero evaporative emissions requirements.

3. Applications

Range extenders are commonly used in marine (autonomous underwater vehicle), aircraft and Generator/Utility, automotive^[3] and hybrid electric vehicle applications.^[4]

3.1. Automotive

Chevrolet Volt



The Chevrolet Volt is a series plug-in hybrid referred by General Motors as "an electric car with extended range."

General Motors describes the Chevrolet Volt as an electric vehicle equipped with a 16 kWh battery plus a "range extending" gasoline powered internal combustion engine (ICE) as a genset and therefore dubbed the Volt an "Extended Range Electric Vehicle" or E-REV.^{[5][6][7]} In a January 2011 interview, the Chevy Volt's Global Chief Engineer, Pamela Fletcher, referred to the Volt as "an electric car with extended range."^[8] The Volt operates as a purely electric car for the first 40 to 80 km (25 to 50 miles) in charge-depleting mode. When the battery capacity drops below a pre-established threshold from full charge, the vehicle enters charge-sustaining mode, and the Volt's control system will select the most optimally efficient drive mode to improve performance and boost high-speed efficiency.^{[9][10]}

According to General Motors' real time tally of miles driven by Volt owners in North America, by mid June 2014 they had accumulated more than 800 million all-electric km (500 million miles). GM also reported that Volt owners driving is more than 63% in all-electric mode. Volt owners who charge regularly typically drive more than 1,560 km (970 miles) between fill-ups and visit the gasoline station less than once a month.^[11] A similar report, issued by GM in August 2016, reported that Volt owners have accumulated almost 2.4 billion km (1.5 billion miles) driven in EV mode, representing 60% of their total miles traveled.^[12]

BMW i3



An optional range-extender is available for the BMW i3, which allows the car to qualify as a range-extended battery-electric vehicle (BEVx) according to the California Air Resources Board regulations.

The BMW i3 all-electric car with at least 22 kWh battery capacity offers an optional gasoline-powered range extender APU.^[13] The range extender is the same 647 cc two-cylinder gasoline engine used in the BMW C650 GT scooter with a 9 L (2.0 imp gal; 2.4 US gal) fuel tank. The US model offers a smaller 7 L tank. The range extender engages when the battery level drops to 6%. It generates electricity to extend the range from 130–160 km (80–100 mi) to 240–300 km (150–190 mi)^{[14][15]} Performance in range-extending mode may be more limited than when it is running on battery power, as BMW designed the range extender as a backup to enable reaching a recharging location.^[16]

According to BMW, at the beginning of the i3 release, the use of range-extender was much more than the carmaker expected, more than 60%. Over time it has decreased significantly, with some people almost never using it, and by 2016 it is being regularly used in fewer than 5% of i3s.^[17]

The range-extender option costs an additional US\$3,850 in the United States,^[18] an additional €4,710 (~ US\$6,300) in France,^[19] and €4,490 (~ US\$6,000) in the Netherlands.^[20]

The range-extender option of the BMW i3 was designed to meet the CARB regulation for an auxiliary power unit (APU) called REx. According to rules CARB adopted in March 2012, the 2014 BMW i3 with a REx unit fitted will be the first car to qualify as a range-extended battery-electric vehicle or "BEVx." CARB describes this type of electric vehicle as "a relatively high-electric range battery-electric vehicle (BEV) to which an APU is added." The APU, which maintains battery charge at about 6% after the pack has been depleted in normal use, is strictly limited in the additional range it can provide.^{[21][22]}

Other examples



The discontinued Fisker Karma was an extended-range electric vehicle.

Other range-extended electric vehicles include the discontinued Cadillac ELR and the discontinued Fisker Karma.^{[22][23][24]} In June 2016, Nissan announced it will introduce a compact range extender car in Japan before March 2017. The series plug-in hybrid will use a new hybrid system, dubbed e-Power, which debuted with the Nissan Gripz concept crossover showcased at the 2015 Frankfurt Auto Show.^[25]

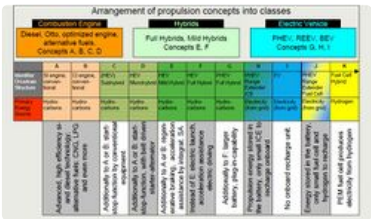
The LEVC TX London taxi was launched in 2017 and features a 33 kWh battery that is charged by a 1.5-litre petrol engine.^[26]

This approach has also been used for heavy vehicles, such as Wrightbus's Gemini 2^[27] and New Routemaster^[28] buses.

3.2. Unmanned Aerial Vehicles

The 2010 Wolverine 3 program included an ICE range extender for its unmanned aerial vehicle.^[29]

4. Powertrain



Schematic classification of alternative powertrains

A range-extended electric vehicle uses a series hybrid drivetrain.

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