U.S. DEPARTMENT OF
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Office of
ENERGY EFFICIENCY & RENEWABLE ENERGY

Electric-Drive Vehicles

Electric-drive vehicles use electricity as their primary fuel or to improve the efficiency of conventional vehicle designs. These vehicles can be divided into three categories:

- Hybrid electric vehicles (HEVs)
- Plug-in hybrid electric vehicles (PHEVs)
- All-electric vehicles (EVs)

Together, PHEVs and EVs can also be referred to as plug-in electric vehicles (PEVs).

Hybrid Electric Vehicles

HEVs are powered by an internal combustion engine (ICE) and by an electric motor that uses energy stored in a battery. The extra power provided by the electric motor allows for a smaller engine without sacrificing performance; the battery may also power auxiliary loads like audio systems and headlights and can reduce engine idling when the vehicle is stopped. Some HEVs can drive short distances at low speeds on electrical power alone. All these capabilities typically result in better fuel economy and lower emissions than comparable conventional vehicles. HEVs cannot be plugged in to charge the battery. Instead, the battery is charged through regenerative braking and by the ICE.

Regenerative Braking

Regenerative braking allows HEVs, PHEVs, and EVs to capture energy normally lost during braking by using the electric motor as a generator and storing that captured energy in the battery.

All-electric and plug-in hybrid electric vehicles are charged by plugging the vehicle in to an electric power source. *Photo by Dennis Schroeder, NREL 35158*

Plug-In Hybrid Electric Vehicles

PHEVs use batteries to power an electric motor and use another fuel, such as gasoline, to power an ICE. PHEVs can be plugged in to an electric power source to charge their batteries; their batteries can also be charged by the ICE and through regenerative braking.

PHEVs have larger battery packs than HEVs, providing an all-electric driving range of about 20 to 50-plus miles in today's light-duty models. As long as the battery is charged, a PHEV can draw most of its power from electricity stored in the battery during typical urban

Electric-Drive Vehicles at a Glance

HEVs are powered by a traditional gasoline or diesel ICE and by one or more electric motors that use energy stored in a battery. The battery is charged by the ICE and through regenerative braking. The vehicle cannot be plugged in to charge.

PHEVs are similar to HEVs but have a larger battery that allows them to travel on electricity alone. The battery can be charged by plugging in to an electric power source, through regenerative braking, and by the ICE.

Unlike EVs, PHEVs don't have to be plugged in before driving. They can be fueled solely with gasoline, like an HEV. However, they will not achieve maximum fuel economy or take full advantage of their all-electric capabilities without plugging in.

EVs run on electricity alone. They are powered by one or more electric motors that use the energy stored in a battery (larger than the batteries in an HEV or PHEV). EV batteries are charged by plugging the vehicle in to an electric power source and through regenerative braking.

driving. The ICE may power the vehicle when the battery is mostly depleted, during rapid acceleration, at high speeds, or when intensive heating or air conditioning is required.

When running on battery power alone, PHEVs produce no tailpipe emissions. Even when the ICE is operating, PHEVs consume less gasoline and typically produce lower emissions than similar conventional vehicles, performing similarly to HEVs. A PHEV's gasoline consumption depends on the distance traveled between charges. If the vehicle is never plugged in, its gasoline-only fuel economy will be about the same as that of a similarly sized HEV. If the vehicle is plugged in to charge and driven distances within its all-electric range, it may be possible to use only electric power.

All-Electric Vehicles

EVs (also called battery-electric vehicles, or BEVs) do not have ICEs but are driven solely by one or more electric motors powered by energy stored in batteries. The batteries are charged by plugging the vehicle in to an electric power source and EVs can also be charged through regenerative braking. EVs produce no tailpipe emissions, although there are "life cycle" emissions associated with the majority of electricity production in the United States.

Today's EVs typically have shorter driving ranges per charge than conventional vehicles have per tank of gasoline. Most new EVs have ranges of about 100 miles on a fully charged battery, although an increasing number of models have ranges exceeding 200 miles. According to the U.S. Department of Transportation, 90% of all household vehicle trips in the United States cover less than 100 miles.[1] An EV's range varies according to driving conditions and driving habits. Extreme ambient temperatures tend to reduce range because energy from the battery must power climate control systems in addition to powering the motor. Speeding, aggressive driving, and heavy loads can also reduce range.

Drivers of EVs and PHEVs have access to thousands of charging stations across the country. *Photo by Dennis Schroeder, NREL 22658*

What electric-drive vehicles are available?

In 2017, there were about 87 light-duty HEV, PHEV, and EV models available from major auto manufacturers, according to FuelEconomy.gov. Medium- and heavy-duty options are also available. For up-to-date information on today's models, use the Alternative Fuels Data Center's (AFDC) Vehicle Search tool (*afdc.energy.gov/tools*) and the Find a Car tool on FuelEconomy.gov (*fueleconomy.gov/feg/findacar.shtml*).

How much do they cost?

Electric-drive vehicles are generally more expensive than their conventional counterparts. However, lower fueling and maintenance costs can make them a competitive option. As battery technology improves, the cost of electric-drive vehicles is expected to continue dropping. Federal and state tax credits and rebates are also available to help offset the cost of these vehicles. For information on available vehicle incentives, see the AFDC Laws and Incentives page (*afdc.energy.gov/laws*).

How do these vehicles "fuel up"?

Charging stations provide electricity to charge the batteries of PEVs. The charging unit communicates with the vehicle to ensure that it supplies an appropriate and safe flow of electricity.

Charging equipment for PEVs is classified according to the rate at which the batteries are charged. Two types—AC Level 1 and AC Level 2—provide alternating current (AC) to the vehicle, with the vehicle's onboard equipment converting AC to the direct current (DC) needed to charge the batteries. The other type—DC fast charging— provides DC electricity directly to the vehicle.

Inductive charging equipment uses an electromagnetic field to transfer electricity to a PEV without a cord. This technology has been developed and introduced commercially. Currently available wireless charging stations operate at power levels comparable to AC Level 2, though this technology has been used internationally at higher power levels in mass transit applications.

Charging times range from less than 20 minutes to 20 hours or more, based on the type or level of charging; the type of battery, its capacity, and how depleted it is; and the size of the vehicle's internal charger. EVs generally have more battery capacity than PHEVs, so charging a fully depleted EV takes longer than charging a fully depleted PHEV.

The cost of charging stations also varies with the level of charging (see Charging Options table). Level 1 charging can be as simple as plugging in to a standard 110-volt outlet, whereas DC fast charging units can cost over $40,000. Some states and utilities offer financial incentives for charging stations; see the AFDC Laws and Incentives page for more information (*afdc.energy.gov/laws*).

Charging units can be installed in residential, fleet, workplace, and public settings. As of July 2017, there were

1 National Highway Travel Survey, U.S. Department of Transportation, Federal Highway Administration, 2008, *https://www.fhwa.dot.gov/policyinformation/pubs/pl08021/fig4_5.cfm*.

more than 42,000 public and private charging outlets across the country. To locate public stations, use the Alternative Fueling Station Locator (*afdc.energy.gov/stations*), which is also available as an iPhone app and Android app.

How much does it cost to fuel these vehicles?

Fuel costs for HEVs, PHEVs, and EVs are lower than those for similar conventional vehicles. Electric drivetrains are mechanically more efficient than internal combustion engines; EVs convert about 59%–62% of the electric energy from the grid to power at the wheels, while conventional gasoline vehicles only convert about 17%–21% of the energy stored in gasoline to power at the wheels. HEVs and PHEVs use significantly less gasoline or diesel fuel than their conventional counterparts, and the more electricity a PHEV uses, the lower its fuel costs. Additionally, electricity prices are less volatile than gasoline and diesel fuel prices, so drivers can reasonably forecast their fueling expenses over longer periods of time. Over the life of the vehicle, electric-drive vehicle owners can expect to save thousands of dollars in fuel costs, relative to the average new vehicle.

To find fuel economy ratings and fuel cost comparisons among currently available vehicle models, visit *FuelEconomy.gov*.

How do their emissions compare with those of conventional vehicles?

HEVs, PHEVs, and EVs typically produce lower levels of emissions than conventional vehicles. HEV emissions benefits vary by vehicle model and type of hybrid power system. EVs produce zero tailpipe emissions, and PHEVs produce no tailpipe emissions when in electric-only mode.

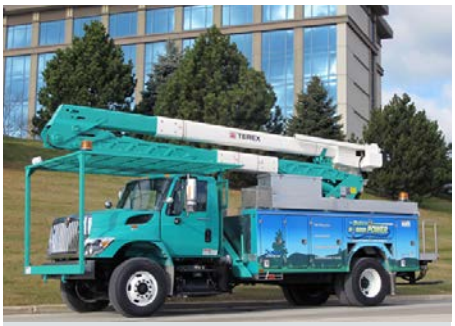
Life cycle emissions are generated when fuel or electricity are produced, as well as during the manufacturing of the vehicle itself. The life cycle emissions of a PEV largely depend on how the electricity powering the vehicle is generated, and this varies by region. In geographic areas that use relatively low-polluting energy sources for electricity generation, PEVs have substantial life cycle emissions advantages over similar vehicles running on gasoline or diesel. In regions that depend heavily on conventional fossil fuels for electricity generation, PEVs may not demonstrate as strong a life cycle benefit. In all cases, consumers may have the option of purchasing or installing renewable energy generation to further reduce emissions.

Charging Options

	Amperage	Voltage	Power Output	Typical Charging Time	Primary Use	Unit Cost Range*
AC Level 1	12 to 16 amps	120 V	1.3 to 1.9 kW	2 to 5 miles of range per hour of charging	Residential and workplace charging	$300 to $1,800
AC Level 2	Up to 80 amps	208 V or 240 V	Up to 19.2 kW, typically 7.2 kW for residential applications	10 to 20 miles of range per hour of charging	Residential, workplace, and public charging	$400 to $6,500
DC Fast Charging	Up to 200 amps	208 to 600 V, typically 208 V or 480 V	24 to 150 kW	50 to 70 miles of range in less than 20 minutes	Public charging	$10,000 to over $40,000

** 2015 costs for single port, excluding installation.*

Sources: "Costs Associated With Non-Residential Electric Vehicle Supply Equipment," U.S. Department of Energy, afdc.energy.gov/uploads/publication/evse_cost_report_2015.pdf.



HEVs work well for both light-duty and heavy-duty applications, particularly those that require frequent stops and starts. *Photo from Odyne Hybrid Systems, NREL 34045*

What about safety and maintenance?

HEVs, PHEVs, and EVs undergo the same rigorous safety testing as conventional vehicles sold in the United States and must meet Federal Motor Vehicle Safety Standards. Battery packs meet rigorous testing standards, and vehicles are designed with insulated high-voltage lines and safety features that deactivate electric systems when they detect a collision or short circuit. For additional safety information, refer to the AFDC's Maintenance and Safety of Hybrid and Plug-In Electric Vehicles page (*afdc.energy.gov/vehicles/electric_maintenance.html*).

What are the Benefits of Electric-Drive Vehicles?

Benefits	Hybrid Electric Vehicles	Plug-In Hybrid Electric Vehicles	All-Electric Vehicles
Fuel Economy	*Better than similar conventional vehicles* Most mid-size HEVs achieve combined fuel economy ratings higher than 40 mpg.	*Better than similar HEVs and conventional vehicles* Most PHEVs achieve combined fuel economy ratings higher than 90 mpge.*	*Better than similar HEVs, PHEVS, and conventional vehicles* Most EVs achieve fuel economy ratings higher than 100 mpge.*
Emissions Reductions	*Lower emissions than similar conventional vehicles* HEV emissions vary by vehicle and type of hybrid power system. HEVs are often used to offset fleet emissions to meet local air quality improvement strategies and federal requirements.	*Lower emissions than HEVs and similar conventional vehicles* PHEVs produce no tailpipe emissions when in electric-only mode. Life cycle emissions depend on the sources of electricity, which vary from region to region.	*Zero tailpipe emissions* EVs produce no tailpipe emissions. Life cycle emissions depend on the sources of electricity, which vary from region to region. Emissions reductions are substantial in most regions of the United States.
Fuel Cost Savings	*Less expensive to run than a conventional vehicle* HEV fuel cost savings vary by vehicle model and type of hybrid power system. For many HEV models, fuel costs are approximately 8¢ per mile.**	*Less expensive to run than an HEV or conventional vehicle* In electric-only mode, PHEV electricity costs range about 2¢–4¢ per mile. On gasoline only, fuel costs range about 5¢–10¢ per mile.**	*Less expensive to run than an HEV or conventional vehicle* EVs run on electricity only. Electricity costs for a typical EV range 2¢–4¢ per mile.**
Fueling Flexibility	*Can fuel at gas stations*	*Can fuel at gas stations; can charge at home, public charging stations, and some workplaces*	*Can charge at home, public charging stations, and some workplaces*

Sources: AFDC (afdc.energy.gov), FuelEconomy.gov

** PEVs are rated not in miles per gallon (mpg) but miles per gallon of gasoline equivalent (mpge). Similar to mpg, mpge represents the number of miles the vehicle can travel using a quantity of fuel (or, alternatively, electricity) with the same energy content as a gallon of gasoline.*

***For conventional sedans, costs range about 10¢–15¢ per mile.*

Because HEVs and PHEVs have ICEs, their maintenance requirements are similar to those of conventional vehicles. The electrical system (battery, motor, and associated electronics) requires minimal scheduled maintenance. A manufacturer's warranty of a battery typically covers 8 years or 100,000 miles, and the expected battery lifetime is 10 to 12 years under normal operating conditions. Brake systems on these vehicles typically last longer than those on conventional vehicles because regenerative braking reduces wear.

EVs typically require less maintenance than conventional vehicles or even HEVs or PHEVs. Like their hybrid counterparts, EV electrical systems require little to no regular maintenance, and their brake systems benefit from regenerative braking. In addition, EVs have far fewer moving parts and fewer fluids to change.

Find additional information on HEVs, PHEVs, and EVs on the AFDC at *afdc.energy.gov/vehicles/electric.html*. ■

Scan this code to learn more about electric-drive vehicles.

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