Hybrid and Plug-In Electric Vehicles

Hybrid and plug-in electric vehicles use electricity as their primary fuel or to improve the efficiency of conventional vehicle designs. This new generation of vehicles, often called electric drive vehicles, can be divided into three categories: hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and all-electric vehicles (EVs). Together, they have great potential to reduce U.S. petroleum use.

All-electric and plug-in hybrid electric vehicles are charged by plugging the vehicle into an electric power source. *Photo by Andrew Hudgins, NREL/PIX 17634*

Hybrid Electric Vehicles

HEVs are powered by an internal combustion engine or other propulsion source that runs on conventional or alternative fuel and an electric motor that uses energy stored in a battery. The extra power provided by the electric motor allows for a smaller engine, resulting in better fuel economy without sacrificing performance. HEVs combine the benefits of high fuel economy and low emissions with the power and range of conventional vehicles.

HEVs do not require a plug to charge the battery; instead, they charge using regenerative braking and the internal combustion engine. They capture energy normally lost during braking by using the electric motor as a generator, storing the captured energy in the battery. The energy from the battery provides extra power during acceleration and auxiliary power when idling.

Plug-In Hybrid Electric Vehicles

PHEVs are powered by conventional fuels and by electrical energy stored in a battery. Using electricity from the grid to charge the battery some of the time costs less and reduces petroleum consumption compared with conventional vehicles. PHEVs can also reduce emissions, depending on the electricity source.

PHEVs have an internal combustion engine or other propulsion source and an electric motor, which uses energy stored in a battery. PHEVs have larger battery packs than HEVs, making it possible to drive using only electric power (about 10 to 40 miles in current models). This is commonly referred to as the all-electric range of the vehicle.

PHEV batteries can be charged several ways: by an outside electric power source, by the internal combustion engine, or through regenerative braking. If a PHEV is never plugged in to charge, its fuel economy will be about the same as that of a similarly sized HEV. If the vehicle is fully charged and then driven a shorter distance than its all-electric range, it is possible to use electric power only.

Electric Drive Vehicles at a Glance

HEVs: HEVs are powered by conventional or alternative fuels as well as electrical energy stored in a battery. The battery is charged through regenerative braking and the internal combustion engine or other propulsion source and is not plugged in to charge.

PHEVs: PHEVs are powered by conventional or alternative fuels and electrical energy stored in a battery. The vehicle can be plugged into an electric power source to charge the battery in addition to using regenerative braking and the internal combustion engine or other propulsion source.

EVs: A battery stores the electrical energy that powers the motor. EV batteries are charged by plugging the vehicle into an electric power source.

All-Electric Vehicles

EVs use a battery to store the electrical energy that powers the motor. EV batteries are charged by plugging the vehicle into an electric power source. Although electricity production may contribute to air pollution, the U.S. Environmental Protection Agency (EPA) considers EVs

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to be zero-emission vehicles because their motors produce no exhaust or emissions. Since EVs use no other fuel, they help reduce petroleum consumption.

Currently available EVs have a shorter range per charge than most conventional vehicles have per tank of gas. EV manufacturers typically target a minimum range of 100 miles. According to the U.S. Department of Transportation's Federal Highway Administration, 100 miles is sufficient for more than 90% of all household vehicle trips in the United States.

Light-duty HEV, PHEV, and EV models are currently available from a number of auto manufacturers, with additional models expected to be released in coming years. There are also a variety of

HEVs work well for both light-duty and heavy-duty applications. This hybrid electric transit bus carries passengers along the 16th Street Mall in Denver.
Photo by Pat Corkery, NREL/PIX 17975

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** The fuel savings of driving a Honda Civic Hybrid versus a conventional Civic is about 38% in the city and 20% on the highway.	**Better than similar HEVs and conventional vehicles** PHEVs use 40% to 60% less fuel than conventional vehicles and permit driving at slow and high speeds using only electricity.	**No liquid fuels** Fuel economy of EVs is usually expressed as cost per mile, which is discussed below.
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** PHEV emissions are projected to be lower than HEV emissions, because PHEVs are driven on electricity some of the time. Most categories of emissions are lower for electricity generated from power plants than from vehicles running on gasoline or diesel.	**Zero emissions** EV emissions do not come from the tailpipe, so EVs are considered zero-emission vehicles. However, emissions are produced from the electric power plant. Most categories of emissions are lower for electricity generated from power plants than from vehicles running on gasoline or diesel.
Fuel Cost Savings	**Less expensive to run than a conventional vehicle** Because of their improved fuel economy, HEVs usually cost \$0.05 to \$0.07 per mile in fuel, compared to conventional vehicles, which cost \$0.10 to \$0.15 per mile in fuel.	**Less expensive to run than an HEV or conventional vehicle** When running on electricity, a PHEV can cost \$0.02 to \$0.04 per mile in fuel (based on average U.S. electricity price). When running on gasoline, the same vehicle can cost \$0.05 to \$0.07 per mile in fuel, compared to conventional vehicles, which cost \$0.10 to \$0.15 per mile in fuel.	**Less expensive to run than conventional vehicles** EVs only run on electricity. A typical electric vehicle costs \$0.02 to \$0.04 per mile for fuel (based on average U.S. electricity price).
Fueling Flexibility	**Can fuel at gas stations or public alternative fueling sites**	**Can fuel at gas stations or charge at home or public charging stations**	**Can charge at home or public charging stations**

Source: Alternative Fuels and Advanced Vehicles Data Center, www.afdc.energy.gov/afdc/vehicles/electric_benefits.html

EVSE Options

	Current Type	Amperage (amps)	Voltage (V)	Kilowatts (kW)	Charging Time	Primary Use
Level 1	Alternating current (AC)	12-16 amps	120V	1.3 to 1.9 kW	2-5 miles of range per hour of charging	Residential charging
Level 2	AC	Up to 80 amps	240V	Up to 19.2 kW	10-20 miles of range per hour of charging	Residential and public charging
Level 3 *(in development)*	AC	To be determined	To be determined	To be determined	60-80 miles of range in less than 30 minutes	Public charging
DC Fast Charging	Direct current (DC)	Up to 200 amps	208-600V	50 to 150 kW	60-80 miles of range in less than 30 minutes	Public charging

medium- and heavy-duty options available. For up-to-date information on available vehicle models, refer to the Alternative Fuels and Advanced Vehicles Data Center's (AFDC) Electric Vehicle Availability page (*www.afdc.energy.gov/afdc/vehicles/electric_availability.html*) and FuelEconomy.gov.

How are EV and PHEV batteries charged?

Charging EVs and PHEVs requires plugging the vehicle into charging equipment, also called electric vehicle supply equipment (EVSE). Charging times vary based on how depleted the battery is, how much energy it holds, and the type of battery and EVSE. The charging time for a fully depleted battery can range from 30 minutes to more than 20 hours, depending on the vehicle and the type of charging equipment used. Because charging an EV or PHEV takes significantly longer than fueling a conventional vehicle at a gas station, most EVSE will be available in locations where vehicles park for extended periods, including residences, workplaces, and parking garages. The table above presents several EVSE options.

Modern charging equipment and vehicles are designed with standard connectors and plug receptacles, so drivers do not need to worry about whether their vehicles are compatible with charging equipment. Utilities are also working to upgrade local distribution infrastructure in neighborhoods with higher EV and PHEV concentrations to handle increased electricity demand and ensure uninterrupted service.

Drivers of EVs and PHEVs will soon have access to thousands of charging stations across the country. *Photo by Andrew Hudgins, NREL/PIX 17834*

To locate EVSE in your area, see the Alternative Fueling Station Locator (*www.afdc.energy.gov/afdc/locator/stations*).

Are electric drive vehicles safe?

HEVs, PHEVs, and EVs undergo the same rigorous safety testing as conventional vehicles sold in the United States and must meet the Federal Motor Vehicle Safety Standards. In addition, their battery packs are encased in sealed shells and meet testing standards that subject batteries to conditions such as overcharge, vibration, extreme temperatures, short circuit, humidity, fire, collision, and water immersion. Manufacturers also design vehicles with insulated high-voltage lines and safety features that deactivate electric systems when they detect a collision or short circuit. For additional electric drive vehicle safety information, refer to the AFDC's Maintenance and Safety of Hybrid, Plug-In Hybrid, and All-Electric Vehicles page (*www.afdc.energy.gov/afdc/vehicles/electric_maintenance.html*).

How do maintenance requirements compare to those of conventional vehicles?

Because HEVs and PHEVs have internal combustion engines, their maintenance requirements are comparable to conventional vehicles. The electrical system (battery, motor, and associated electronics) doesn't require the same scheduled maintenance. Due to the use of regenerative braking, brake systems on these vehicles typically last longer than those on conventional vehicles.

EVs typically require less maintenance than conventional vehicles because:

- They have fewer moving parts
- Regenerative braking reduces brake wear
- Their electrical systems don't require frequent maintenance.

Well-to-wheels emissions of PHEVs and EVs depend on the source of electrical power used for charging. If electricity is generated from nonpolluting, renewable sources, these vehicles have the potential to produce zero emissions. *Left photo from iStock/6381513; right photo by Mike Linenberger, NREL/PIX 15152*

How do fuel costs compare to those of conventional vehicles?

When discussing electric drive vehicles, "fuel" includes the gasoline, diesel, or alternative fuel used in the internal combustion engine or other propulsion source, as well as the electricity used to charge the EV or PHEV battery. Taking both fuel types into account, fuel costs for electric drive vehicles are generally less than conventional vehicles due to the higher efficiency of electric motors. Electricity prices also tend to be more stable than conventional fuel prices, allowing greater certainty when budgeting for fuel costs.

Where can I learn more about electric drive vehicles?

For additional information, refer to the AFDC's Hybrid & Plug-In Electric Vehicles section, created by the National Renewable Energy Laboratory (*www.afdc.energy.gov/afdc/vehicles/electric.html*).

For EPA fuel economy ratings and fuel cost comparisons between different vehicle models currently available in the United States, refer to the FuelEconomy.gov website.

What are the emissions benefits of electric drive vehicles?

In general, HEVs, PHEVs, and EVs produce lower emissions than conventional vehicles. Vehicle emissions can be considered in terms of tailpipe emissions or well-to-wheel emissions. Tailpipe emissions refer to emissions produced through fuel combustion during a vehicle's operation. Well-to-wheel emissions take into consideration the production and distribution of the fuel as well as the actual operation of the vehicle.

HEV tailpipe emissions vary by vehicle, fuel, and type of hybrid power system. Because HEVs generally achieve better fuel economy than comparable conventional vehicles, they produce lower emissions.

Because PHEVs can operate either in all-electric mode or with the help of the internal combustion engine, emissions vary based on the vehicle's operating mode. When the vehicle is charged by an electrical power source, emissions calculations must take electricity production into account. On average, most categories of emissions are lower for electricity generated from power plants than from engines running on gasoline or diesel. However, emissions from electricity production depend on the efficiency of the power plant and the mix of fuel sources used. To determine your region's specific fuel mix, as well as the emissions rates of electricity in your zip code, see EPA's Power Profiler (*www.epa.gov/cleanenergy/energy-and-you/how-clean.html*).

All-electric vehicles do not produce tailpipe emissions, so EVs are considered zero-emission vehicles by EPA. However, as with PHEVs, there are emissions associated with most U.S. electricity production. If electricity is generated from nonpolluting, renewable sources, EVs have the potential to produce zero well-to-wheel emissions.

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