Hybrid and Plug-In Electric 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, they have great potential to cut U.S. petroleum use and vehicle emissions.

All-electric and plug-in hybrid electric vehicles are charged by plugging the vehicle into an electric power source. *Photo by Andrew Hudgins, NREL 17416*

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

Plug-In Hybrid Electric Vehicles

PHEVs (sometimes called extended range electric vehicles, or EREVs) use batteries to power an electric motor and use another fuel, such as gasoline, to power an ICE. PHEVs can be plugged into the grid to charge their batteries; their batteries can also be charged by the ICE and through regenerative braking.

PHEVs have larger battery packs than HEVs do, providing an all-electric driving range of about 10 to 40-plus miles for today's light-duty models. So long as the battery is charged, a PHEV can draw most of its power from electricity stored in the battery during typical urban 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 do. 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 a shorter distance than its all-electric range, it may be possible to use only electric power.

Electric-Drive Vehicles at a Glance

HEVs: HEVs are powered by an ICE and by an electric motor that uses energy stored in a battery. The battery is charged through regenerative braking and by the ICE. The vehicle cannot be plugged in to charge.

PHEVs: PHEVs are powered by an ICE and by an electric motor that uses energy stored in a battery. The battery can be charged by plugging into an electric power source, through regenerative braking, and by the ICE.

EVs: EVs are powered by an electric motor that uses energy stored in a battery. EV batteries are charged by plugging the vehicle into an electric power source and through regenerative braking.

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EVs, which are now widely available, must plug in to charge. Increasing numbers of fleets and consumers are turning to EVs to cut petroleum use, fuel costs, and emissions. *Photo from City of Fort Collins, NREL 27238*

All-Electric Vehicles

EVs (also called battery-electric vehicles, or BEVs) use batteries to store the electrical energy that powers one or more motors. The batteries are charged by plugging the vehicle into the grid. EVs can also be charged in part through regenerative braking. EVs do not have ICEs and, therefore, do not produce tailpipe emissions. However, 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 EVs have ranges of about 70 to 90 miles on a fully charged battery, although a few models have longer ranges. 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.

Vehicle Availability

Dozens of light-duty HEV, PHEV, and EV models are available from major auto manufacturers. A variety of 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) Light-Duty and Heavy-Duty Vehicle Searches (*afdc.energy.gov/tools*) and the Find a Car tool on FuelEconomy.gov (*fueleconomy.gov/feg/findacar.shtml*).

Charging EV and PHEV Batteries

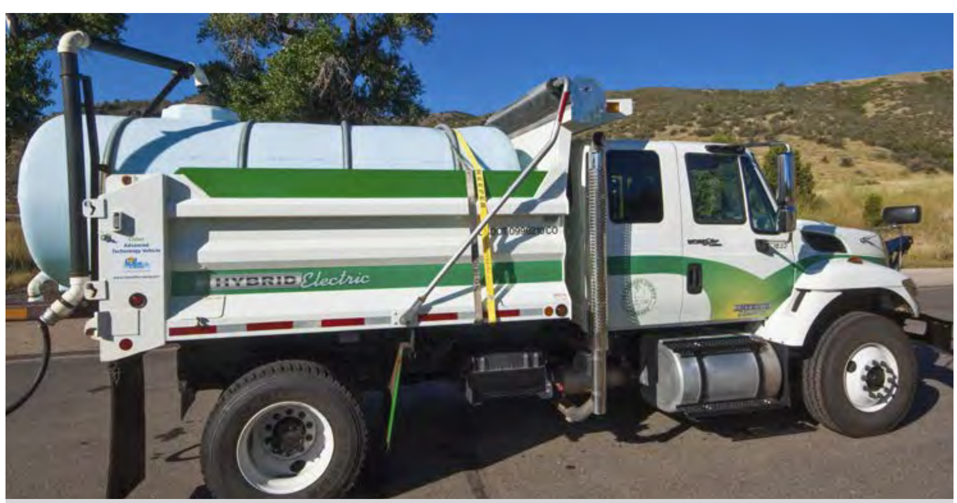
Charging stations, also known as electric vehicle supply equipment (EVSE), provide electricity to charge the batteries of EVs and PHEVs. The EVSE communicates with the vehicle to ensure that it supplies an appropriate and safe flow of electricity.

EVSE for plug-in vehicles 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 (charger) 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. DC fast charging is sometimes referred to as DC Level 2.

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

Hydrogen Fuel Cell Vehicles

A hydrogen fuel cell vehicle combines hydrogen gas with oxygen from the air to produce electricity, which drives an electric motor. Fuel cell vehicles produce no harmful tailpipe emissions. Limited numbers of fuel cell cars are currently leased to customers in select regions; some manufacturers are planning to introduce new models in the California market within the next two years.



HEVs work well for both light-duty and heavy-duty applications, particularly those that require frequent stops and starts. *Photo by Pat Corkery, NREL 18142*

EVSE Options					
	Amperage	**Voltage**	**Kilowatts**	**Charging Time**	**Primary Use**
AC Level 1	12 to 16 amps	120V	1.3 to 1.9 kW	2 to 5 miles of range per hour of charging	Residential and workplace charging
AC Level 2	Up to 80 amps	208V or 240V	Up to 19.2 kW	10 to 20 miles of range per hour of charging	Residential, workplace, and public charging
DC Fast Charging	Up to 200 amps	208 to 600V	50 to 150 kW	60 to 80 miles of range in less than 20 minutes	Public charging

Charging times range from less than 20 minutes to 20 hours or more, based on the type or level of EVSE; 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.

Charging units can be installed in residential, fleet, workplace, and public settings. As of January 2014, there were nearly 20,000 charging outlets across the country. To locate public charging stations, use the Alternative Fueling Station Locator (*afdc.energy.gov/stations*), also available as an iPhone app from the App Store (QR code on page 4).

Emissions Benefits

HEVs, PHEVs, and EVs typically produce lower levels of emissions than conventional vehicles do. 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.

The life cycle emissions of an EV or PHEV depend on how that electricity is generated, and this varies by region. In geographic areas that use relatively low-polluting energy sources for electricity generation, PHEVs and EVs have substantial life cycle emissions advantages over similar conventional vehicles running on gasoline or diesel. In regions that depend heavily on conventional fossil fuels for electricity generation, plug-in vehicles may not demonstrate as strong a life cycle benefit. Even in these areas, however, consumers may have the option of purchasing renewable energy.

Vehicle Safety

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. Their battery packs meet testing standards that subject batteries to conditions such as overcharge, vibration, extreme temperatures, short circuit, humidity, fire, collision, and water immersion. Manufacturers design vehicles 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*).

Maintenance Requirements

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. 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, their electrical systems require little to no regular maintenance and their brake systems benefit from regenerative braking. In addition, EVs often have far fewer moving parts and fewer fluids to change.


Life cycle emissions of PHEVs and EVs depend on the source of electrical power used for charging. In regions that use high percentages of renewable energy to generate electricity, emissions benefits are substantial. Photos from iStock 13782143 (left); NYPA, NREL 26486 (right)

Fuel Costs

Fuel costs for HEVs, PHEVs, and EVs are generally lower than for similar conventional vehicles. Electric drivetrains are about four times more efficient than internal combustion engines, and electricity prices are less volatile than gasoline and diesel fuel prices. HEVs and PHEVs typically use significantly less gasoline/diesel than their conventional counterparts. Over the life of the vehicle, HEV, PHEV, and EV 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. ■

Download the Alternative Fueling Station Locator iPhone app from the App Store

Learn More Find additional information on HEVs, PHEVs, and EVs on the AFDC at *afdc.energy.gov/vehicles/electric.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** The fuel savings of driving a Honda Civic Hybrid versus a conventional Civic is about 36% in the city and 11% on the highway.	**Better than similar HEVs and conventional vehicles** Most PHEVs achieve combined fuel economy ratings higher than 90 miles per gasoline gallon equivalent*.	**Better than similar HEVs and conventional vehicles** Most EVs achieve fuel economy ratings higher than 100 miles per gasoline gallon equivalent*.
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, annual fuel cost savings range from $400 to $1,000, relative to their conventional counterparts.	**Less expensive to run than an HEV or conventional vehicle** In electric-only mode, PHEV fuel costs can range from about $0.02 to $0.04 per mile. On gasoline only, fuel costs range from about $0.05 to $0.10 per mile. For conventional sedans, costs range from about $0.10 to $0.15 per mile.	**Less expensive to run than conventional vehicles** EVs run on electricity only. Fuel costs for a typical EV range from $0.02 to $0.04 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: Alternative Fuels Data Center (afdc.energy.gov), FuelEconomy.gov

* *PHEVs and EVs 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 (such as electricity) with the same energy content as a gallon of gasoline.*

U.S. DEPARTMENT OF ENERGY

Energy Efficiency & Renewable Energy

Clean Cities Technical Response Service
800-254-6735 • *technicalresponse@icfi.com*

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DOE/GO-102014-4350 • May 2014

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post consumer waste.

Prepared by the National Renewable Energy Laboratory (NREL), a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy; NREL is operated by the Alliance for Sustainable Energy, LLC.