U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Plug-In Electric Vehicle Handbook

for Fleet Managers

Clean Cities

U.S. Department of Energy

Photo from Kathy Boyer, Triangle Clean Cities Coalition, NREL/PIX 18520

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Clean Cities Helps Deploy PEVs and Charging Infrastructure

Successfully deploying plug-in electric vehicles (PEVs) and charging infrastructure requires unique knowledge and skills. If you need help, contact your local Clean Cities coalition. Clean Cities is the U.S. Department of Energy's flagship alternative-transportation deployment initiative. It is supported by a diverse and capable team of stakeholders from private companies, utilities, government agencies, vehicle manufacturers, national laboratories, and other transportation-related organizations. These stakeholders, organized into nearly 100 Clean Cities coalitions nationwide, are ready to help fleets with specific PEV deployment challenges. Contact your local coalition by visiting the Clean Cities website at *www.cleancities.energy.gov*.

Disclaimer

Introduction

You've heard the buzz about the new light-duty plug-in electric vehicles (PEVs) like the Chevy Volt and Nissan Leaf, and you're wondering whether they could benefit your fleet. Or perhaps your fleet is looking to reduce petroleum use, and you're curious whether PEVs are a good solution. Maybe you'd like to know about advanced medium- and heavy-duty PEV options that cut fuel costs and eliminate tailpipe emissions in your fleet. If so, this handbook is for you. It's designed to answer your basic questions about PEVs and charging infrastructure and point you to additional information so you can make the best decisions for your fleet.

The PEV concept isn't new. More than 100 years ago, all-electric vehicles (EVs) held much of the U.S. car market, but their popularity waned as the interest in conventional cars with internal combustion engines (ICEs) rose. At that time, the ICE vehicle had a longer driving range, petroleum fuel costs were declining, and the introduction of the electric starter and manufacturing assembly line improved the affordability and usability of conventional vehicles with an ICE. Gasoline- and diesel-powered ICE vehicles ended up dominating transportation in the 20th century.

Concerns about the environmental impacts of ICE vehicles sparked a PEV renaissance at the end of the 20th century. In 1990, California passed the nation's first zero emission vehicle mandate, putting the state at the forefront of that decade's deployment of PEVs, such as the General Motors EV1, Chrysler EPIC, Ford Electric Ranger, and the Toyota RAV4 EV. Although many vehicles from this generation were discontinued in the early 2000s, California's vision helped set the stage for the next generation of PEVs.

Today, PEVs are back and ready to compete with—and complement—the ubiquitous ICE technology. Advances in electric-drive technologies enabled commercialization of hybrid electric vehicles (HEVs), which integrate an ICE with batteries, regenerative braking, and an electric motor to boost fuel economy. Continued technological advances have spawned plug-in HEVs (PHEVs), which integrate small ICEs and large, grid-chargeable batteries that enable all-electric driving ranges of 10 to 40 miles or more. Advanced technologies have also enabled manufacturers to introduce a new breed of PEVs that don't use an ICE at all.

Key Acronyms

EVs (all-electric vehicles) are powered only by one or more electric motors. They receive electricity by plugging into the grid, and they store it in batteries. They consume no petroleum-based fuel while driving and produce no tailpipe emissions.

EVSE (electric vehicle supply equipment) delivers electrical energy from an electricity source to charge a PEV's batteries. It communicates with the PEV to ensure that an appropriate and safe flow of electricity is supplied.

HEVs (hybrid electric vehicles) combine an ICE or other propulsion source with batteries, regenerative braking, and an electric motor to provide high fuel economy. They rely on a petroleum-based or alternative fuel for power and are not plugged in to charge. HEV batteries are charged by the ICE or other propulsion source and during regenerative braking.

ICEs (internal combustion engines) generate mechanical power by burning a liquid fuel (such as gasoline, diesel, or biofuels) or a gaseous fuel (such as compressed natural gas). They are the dominant power source used in on-road vehicles today.

PEVs (plug-in electric vehicles) derive all or part of their power from electricity supplied by the electric grid. They include EVs and PHEVs.

PHEVs (plug-in hybrid electric vehicles) use batteries to power an electric motor, plug into the electric grid to charge, and use a petroleum-based or alternative fuel to power an ICE or other propulsion source.

Only a few light-, medium-, and heavy-duty PEV models are available today. But because of the benefits they offer, PEV market penetration and availability are growing quickly. PEVs are as good as or better than conventional vehicles in some performance categories. They are safe, convenient, and can slash your fleet's operating costs while demonstrating your community leadership.

PEV Basics

What makes PEVs unique is their ability to charge from an off-board electric power source. In other words, PEVs can be "plugged in." This feature distinguishes them from HEVs, which supplement power from an ICE or other propulsion source with battery power but cannot be plugged in. There are two basic types of PEVs: EVs and PHEVs.

Under the hood of a Nissan Leaf. An EV contains no ICE. Instead, the battery supplies electricity to the electric motor. *Photo from Margaret Smith, DOE, NREL/PIX 18215*

All-Electric Vehicles (EVs)

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 an electric power source. EVs can also be charged in part by regenerative braking, which generates electricity from some of the energy normally lost when braking. EVs use no petroleum-based fuel while driving and therefore produce no tailpipe emissions (see the *PEV Benefits* section for more information about emissions).

Today's EVs typically have a shorter range than conventional vehicles have. Most light-, medium-, and heavy-duty EVs are targeting a range of about 100 miles on a fully charged battery. The range depends in part on driving conditions and habits (see the *Factors That Affect All-Electric and Hybrid Electric Vehicle Efficiency and Range* section).

The time required to fully charge depleted batteries—which can range from less than 30 minutes to almost a full day—depends on the size and type of the batteries, as well as the type of charging equipment used. Learn more about charging in the *Charging PEVs* section.

Neighborhood electric vehicles (NEVs), also called low-speed vehicles, are a type of EV with range and speed limitations. NEVs are commonly used for neighborhood commuting, light hauling, and delivery. They are often limited to use on roads with speed limits up to 35 miles per hour, making them ideal for college campuses and similar applications. There are also specialty EVs, such as airport ground support equipment and personal transporters, which are not intended for road use. Although these types of vehicles are valuable for the niches they serve, this handbook focuses on EVs designed for highway use.

Plug-In Hybrid Electric Vehicles (PHEVs)

PHEVs (sometimes called extended range electric vehicles, or EREVs) use batteries to power an electric motor and use another fuel, such as gasoline or diesel, to power an ICE or other propulsion source. Some heavy-duty PHEV concepts use a microturbine or fuel cells for onboard power generation, instead of using an ICE. Powering the vehicle some of the time with electricity from the grid cuts petroleum consumption and tailpipe emissions compared with conventional vehicles. When running on gasoline, PHEVs, like HEVs, consume less fuel and typically produce lower emissions than similar ICE vehicles.

PHEVs have larger battery packs than HEVs, providing an all-electric driving range of about 10 to 40-plus miles for current light-duty models. During typical urban driving, most of a PHEV's power can be drawn from stored electricity. For some urban fleet applications, a PHEV could be driven on all-electric power all day and

In all-electric mode, PEVs produce no tailpipe emissions. PEV lifecycle emissions are minimized when their source of electricity comes from nonpolluting resources like wind and sunlight. *Photo from Atlantic County Utilities Authority, NREL/PIX 18311*

then charged at night or even during a down time like lunch. The ICE powers the vehicle when the battery is mostly depleted, during rapid acceleration, or when intensive heating or air conditioning is required. Some heavy-duty PHEVs work the opposite way, with the ICE used for driving to and from a job site and electricity used to power the vehicle's equipment or control the cab's climate while at the job site. Because the vehicle would otherwise be idling at the job site to power equipment or climate control systems, this PHEV strategy can result in significant fuel savings.

PHEVs can be plugged into the grid and charged, but the time required to charge depleted batteries is typically shorter for PHEVs than EVs, because most have smaller battery packs. In addition, when in use, PHEV batteries are charged by their ICEs and regenerative braking.

PHEV fuel consumption depends on the distance driven between battery charges. For example, if the vehicle is never plugged in to charge, fuel economy will be about the same as for a similarly sized HEV. If the vehicle is driven a shorter distance than its all-electric range and plugged in to charge, it may be possible to use only electric power.

PHEV System Designs

There are two categories of PHEV systems, which differ in how they combine power from the electric motor and the engine.

- **Parallel** PHEVs connect the engine and the electric motor to the wheels through mechanical coupling. Both the electric motor and the engine can drive the wheels directly.
- **Series** PHEVs use only the electric motor to drive the wheels. The ICE is used to generate electricity for the motor. The Chevy Volt uses a slightly modified version of this design: the electric motor drives the wheels almost all of the time, but the vehicle can switch to work like a parallel PHEV at highway speeds and/or when the battery is depleted.

Factors That Affect Plug-In Electric and Hybrid Electric Vehicle Efficiency and Range

The efficiency and driving range of PEVs varies substantially based on driving conditions and driving habits. Extreme outside temperatures tend to reduce range because more energy must be used to heat or cool the cabin. Cold batteries do not provide as much power as warm batteries do. The use of electrical equipment, such as windshield wipers and seat heaters, can reduce range. High driving speeds reduce range because more energy is required to overcome increased air resistance. Rapid acceleration reduces range compared with smooth acceleration. Hauling heavy loads or driving up significant inclines also reduces range. The Nissan Leaf website (*www.nissanusa.com/leaf-electric-car*) provides examples of driving conditions and resulting ranges for the Leaf, as well as tips to help you maximize your range.

With PHEVs, the ICE is activated when driving demands exceed the capacity of the all-electric propulsion system, resulting in operation similar to that of HEVs. The effects of this hybrid mode of operation vary substantially based on vehicle type, route, duty cycle, and cargo load. In general, HEVs provide the largest fuel economy advantage over conventional ICE vehicles during stop-and-go "city" driving. This is because HEVs can take advantage of the electric motors' ability to stay highly efficient across broad ranges of motor speed and frequent changes in acceleration, keeping the engine running more smoothly at a more efficient speed than in a conventional vehicle. In addition, the HEV's regenerative braking recaptures and uses some of the energy normally lost during braking. Examples of light- and medium-duty hybrid versus conventional vehicle operation are shown in Figure 1.

Training your drivers about the optimal ways to operate PEVs can maximize the efficiency and range of your fleet's vehicles. Check with your PEV manufacturers about the availability of training materials.

PEV Benefits

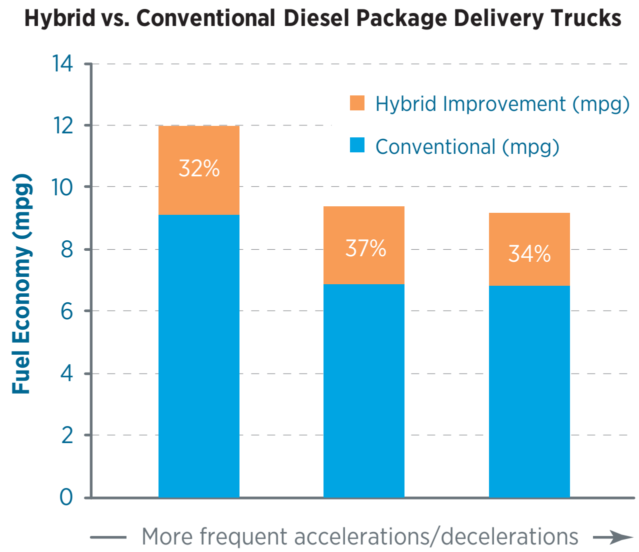
What can PEVs do for your fleet? They can lower your operating costs and help you comply with government policies while demonstrating your commitment to environmental protection and energy security.

High Fuel Economy, Low Operating Cost

PEVs can reduce your fleet's fuel costs dramatically because of the low cost of electricity versus conventional fuel. Because PEVs rely in whole or part on electric power, their fuel economy is measured differently than in conventional vehicles. You might see it stated as miles per gallon of gasoline equivalent (mpge). Or it may be broken down by kilowatt-hours (kWh) per 100 miles for EVs and the electric mode of PHEVs, and miles per gallon (mpg) for the ICE mode of PHEVs. Depending on how they're driven, today's EVs (or PHEVs in electric mode) can exceed 100 mpge.

Powering a light-duty PEV with electricity costs only 3 to 5 cents per mile. In contrast, fueling a gasoline car that has a fuel economy of 27.5 mpg costs about 14 cents per mile. If 15,000 miles are driven per year, driving the PEV in all-electric mode instead of driving the conventional gasoline car could save $1,300 to $1,600 in annual fuel costs.[1] The fuel economy of medium- and heavy-duty vehicles is highly dependent on the load carried and the duty cycle, but PEVs maintain a strong fuel-cost advantage in this category of vehicles as well.

1 *Fuel cost savings depend on electricity and gasoline prices as well as vehicle types and driving patterns. This illustration compares a gasoline car with a fuel economy of 27.5 mpg (combined city and highway) assuming a gasoline cost of $3.75/gallon versus PEVs operated in electric mode at 3 cents to 5 cents per mile (which assumes an electricity cost of 11 cents/kWh).*



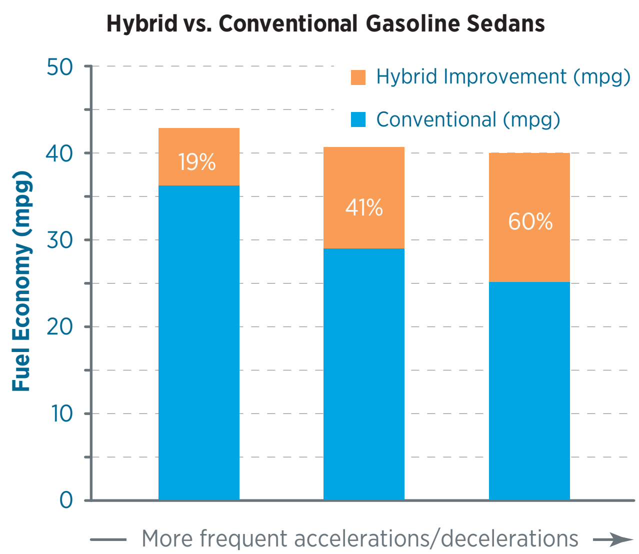


Figure 1. Examples of light- and medium-duty hybrid versus conventional vehicle operation. *Sources: Sedan data from FuelEconomy.gov, comparison of model year 2011 hybrid electric and conventional Honda Civics; package delivery truck data from Twelve-Month Evaluation of UPS Diesel Hybrid Electric Delivery Vans,* www.nrel.gov/docs/fy10osti/44134.pdf. *Graphs by Dean Armstrong, NREL*

If your utility offers lower electricity rates for charging during off-peak times, such as at night, you may be able to reduce your PEV fuel costs even further by charging during these times. Learn more from Idaho National Laboratory's report *Comparing Energy Costs per Mile for Electric and Gasoline-Fueled Vehicles* (*http://avt.inel.gov/pdf/fsev/costs.pdf*). Notably, electricity prices are typically less volatile than gasoline and diesel prices, making it easier for fleets to predict fuel costs over time.

PEVs can help regulated fleets comply with government requirements. *Photo from Richard Bogacz, New West Technologies, LLC, NREL/PIX 19665*

The reduced maintenance requirements of PEVs compared with conventional vehicles may also lower your operating costs. See the *Vehicle Maintenance* section for more information.

Compliance with Fleet Requirements

The Energy Policy Act (EPAct) of 1992 and subsequent federal regulatory activities require certain fleets owned or operated by federal and state agencies or alternative fuel providers to acquire alternative fuel vehicles or reduce petroleum consumption in other ways. Electricity is an EPAct-defined alternative fuel, so PEVs help covered fleets meet EPAct requirements. For more information, see the EPAct Transportation Regulatory Activities website (*www.eere.energy.gov/vehiclesandfuels/epact*). PEVs can also help fleets comply with state and local alternative transportation policies; find relevant policies on the Alternative Fuels and Advanced Vehicles Data Center (AFDC) Incentives and Laws database (*www.afdc.energy.gov/afdc/laws*).

Community Leadership

Some fleets are required to minimize their petroleum use or emissions. Others do so voluntarily to meet their organizations' environmental or energy-security objectives, demonstrate community leadership, improve their public image, and differentiate themselves from competitors. Fleets that are highly visible—such as transit and school buses, law-enforcement vehicles, and taxis—are particularly well suited to project a positive image through the use of PEVs.

High Performance

Today's PEVs are state-of-the-art highway vehicles ready to match or surpass the performance of their conventional gasoline and diesel counterparts. However, some medium- and heavy-duty vehicles have a limited maximum speed (e.g., 50 to 75 miles per hour) appropriate to their vocation. In addition, PEVs in all-electric mode are much quieter than conventional vehicles and, unlike conventional vehicles, produce maximum torque and smooth acceleration from a full stop. This low-end torque can be especially useful when hauling heavy loads. In fact, this torque is the reason locomotives use electric motors, powered by diesel ICE generators, to cover long distances.

Flexible Fueling

Depending on how your fleet operates, you may fuel vehicles at fleet facilities, public fueling stations, or both. Like conventional vehicles, PEVs are well suited to any of these fueling options. Charging stations at fleet facilities enable PEVs to be recharged overnight and during idle times (see the *Charging PEVs* section). In addition, a network of public PEV charging stations is beginning to be established, which will enable PEVs to charge when idle for a few hours away from their home base. The old "gas station" concept will remain an option as well—with an electric twist. Along major transportation corridors, governments and businesses are establishing public fast-charging stations, which can significantly boost PEV batteries in less than 30 minutes. Of course, PHEVs will be able to fuel with gasoline or diesel (or possibly other fuels in the future) at fueling stations when necessary.[2]

Low Emissions

PEVs can have significant emissions benefits over conventional vehicles. Vehicle emissions can be divided into two general categories: air pollutants, which contribute to smog, haze, and health problems; and greenhouse gases (GHGs), such as carbon dioxide and methane, which contribute to climate change. Both categories of emissions can be evaluated on a direct basis and on a life cycle basis. Direct emissions are emitted through the tailpipe, as well as through evaporation from the vehicle's fuel system and during the fueling process. EVs

2 *In the future, PHEVs may be capable of fueling with alternative fuels such as E85 (a fuel composed of 51% to 83% ethanol, and gasoline), compressed natural gas, or hydrogen.*

produce zero direct emissions. PHEVs produce zero tailpipe emissions when they are in all-electric mode, but they do produce evaporative emissions. And when using the ICE, PHEVs do produce tailpipe emissions. However, their direct emissions are typically lower than those of comparable conventional vehicles.

Life cycle emissions include all emissions related to fuel and vehicle production, processing, distribution, use, recycling, and disposal. In the case of gasoline, emissions are produced while extracting petroleum from the earth, refining it, distributing the fuel to stations, and burning it in vehicles. In the case of electricity, most electric power plants produce emissions, and there are additional emissions associated with the extraction, processing, and distribution of the fuels they use. For all types of vehicles, emissions are also produced when extracting raw materials for vehicle production; manufacturing, distributing, maintaining, and operating the vehicles; and recycling and disposing of vehicles and their components, including batteries. As such, the life cycle emissions associated with any vehicle are significant.

The life cycle emissions associated with a PEV depend on the source of electricity used to charge it. In geographic areas that use relatively low-polluting energy sources for electricity generation, PEVs typically have a life cycle emissions advantage over similar conventional vehicles running on gasoline or diesel. In regions that depend heavily on conventional fossil fuels for electricity generation, PEVs may not demonstrate a life cycle emissions benefit. Use the GREET Fleet Footprint Calculator (*http://greet.es.anl.gov/carbon_footprint_calculator*) to explore the GHG and petroleum-saving benefits of adding PEVs to your fleet.

Energy Security

PEVs can help make the United States more energy independent. Today, our cars and trucks—and the way of life they support—depend almost entirely on petroleum. The U.S. transportation sector accounts for two-thirds of our petroleum consumption. With much of the world's petroleum reserves located in politically volatile countries, our reliance on petroleum makes us vulnerable to price spikes and supply disruptions. PEVs help reduce this threat because almost all U.S. electricity is produced from domestic coal, nuclear energy, natural gas, and renewable sources. From a local standpoint, PEVs help reduce the impacts of gasoline and diesel price volatility on your fleet.

Buying the Right PEVs

As with any vehicle purchase, before choosing a PEV you should assess your fleet's driving requirements, applicable mandates or policies, and budget. Then, you can compare your needs with the available PEVs.

Today's EVs can typically travel about 100 miles on a full charge, more than enough for the daily driving needs of many fleet applications. *Photo from Margaret Smith, DOE, NREL/PIX 19545*

Driving Requirements

Your fleet has specific operating needs which must be met. Additional factors must be considered when deciding whether to purchase PEVs for your fleet. For example, do you have a need for an EV, which typically drives about 100 miles on electricity? Or do you need a PHEV, which may have a much shorter all-electric range but can use another fuel for extended driving range? This depends largely on the vehicle's route, opportunities for charging, and the availability of charging stations. For vehicles that drive less than 100 miles per day and can plug in at night, an EV might be suitable. If charging is available during the vehicle's idle periods, an EV could go beyond the 100-mile daily range. Otherwise, a PHEV might be the best choice for extended driving. Compare the fuel economy and range of light-duty PEVs and conventional vehicles using FuelEconomy.gov (*www.fueleconomy.gov*).

Availability

As of this writing, only a few light-duty PEV models are commercially available. PEV technology is just beginning to make inroads into the U.S. vehicle market, but the number of available vehicles is predicted to grow quickly. For comparison, only two HEV models were available in the late 1990s, compared with 29 models in 2011. To find currently available PEVs, use the AFDC Light-Duty Vehicle Search (*www.afdc.energy.gov/afdc/vehicles/search/light*). Learn about anticipated PEV introductions from the Electric Drive Transportation Association (*www.electricdrive.org/index.php?ht=d/sp/i/11551/pid/11551*) and FuelEconomy.gov (*www.fueleconomy.gov/feg/phevnews.shtml* and *www.fueleconomy.gov/feg/evnews.shtml*).

A larger number of medium- and heavy-duty PEV models are currently available, most of which are EVs. Applications include delivery trucks, step vans, transit and shuttle buses, and utility trucks. To find currently available medium- and heavy-duty PEVs, use the AFDC Heavy-Duty Vehicle and Engine Search (*www.afdc.energy.gov/afdc/vehicles/search/heavy*).

In addition to limited availability of PEV models, early PEV introductions (starting in 2010) have been limited to select geographic areas to match dealer and service preparation. However, it is expected that at least some PEVs will be available from select dealerships in all 50 states by the end of 2011. Because of the popularity and limited initial production of PEVs, there may be a wait time involved in obtaining these vehicles.

Some PEVs are now available to federal fleets from the U.S. General Services Administration (GSA). See GSA's Alternative Fuel Vehicles page (*www.gsa.gov/portal/content/104211*) for a list of the latest offerings.

Prices and Incentives

Purchase prices for today's PEVs are considerably higher than for similar conventional vehicles, although prices are likely to decrease as production volumes increase. Fleets can reduce the cost of owning PEVs through lower operating costs (see the *PEV Benefits* section) and government incentives.

Example Light-Duty PEV Prices, 2011[1]

Chevy Volt (PHEV) $40,280

Nissan Leaf (EV) $32,780

Example Medium- and Heavy-Duty PEV Prices, 2011

Ford Transit Connect EV
(Class 3 van)[2] $57,400

Navistar eStar
(Class 3 van)[3] $150,000

SEV Newton
(Class 5 vocational truck)[4] $123,600

ZeroTruck
(Class 5 van/vocational truck)[4] . . $155,500

1. *Manufacturer's suggested retail prices, before incentives.*
2. *As reported in The New York Times, Dec. 7, 2010, "Ford Starts to Ship an Electric Delivery Van."*
3. *As reported in Autoblog Green, May 15, 2010.*
4. *As reported in the U.S. General Services Administration (GSA) 2011 Model Year Alternative Fuel Vehicle Guide. Note that GSA prices may not be available to non-GSA-supported fleets.*

The federal Qualified Plug-In Electric Drive Motor Vehicle Tax Credit is available for PEV purchases through 2014 (or until PEV manufacturers meet a certain level of mass production). It provides a tax credit of $2,500 to $7,500 for new PEV purchases, with the specific credit amount determined by the size of the vehicle and the capacity of its battery. It is limited to vehicles with a gross vehicle weight rating up to 14,000 pounds. As of December 2011, all of the available light-duty PEVs qualified for the credit. Some of the available medium-duty EVs also qualified for a credit.

Depending on your fleet's location, you may also be eligible for PEV incentives from your state, city, or utility. To find relevant incentives, search the AFDC's Federal and State Incentives and Laws database (*www.afdc.energy.gov/afdc/laws*). For even more information about incentives in your area, contact your local Clean Cities coalition (*www.afdc.energy.gov/cleancities/progs/coalition_locations.php*) or state energy office (*www.naseo.org/members/states/default.aspx*).

Conversions

It is possible to convert conventional vehicles and HEVs into PHEVs by adding battery capacity and onboard charging equipment. Conventional vehicles can also be converted into EVs by removing the engine and adding a battery pack, electric motor, charging equipment, and control equipment. When considering these conversions, be sure to do your homework: In some cases, conversions can affect the vehicle's factory warranty. In addition, some companies have offered PHEV conversions without obtaining the required national certifications from federal and state regulatory agencies, such as the U.S. Environmental Protection Agency and the California Air Resources Board. Therefore, it is critical to make sure that companies performing conversions on your vehicles have received the necessary approvals. For links to companies that provide light-, medium-, or heavy-duty PHEV conversions, visit the AFDC's PEV conversions page (*www.afdc.energy.gov/afdc/vehicles/electric_conversions.html*).

A variety of medium- and heavy-duty PEVs are available.
Photo by Trish Cozart, NREL/PIX 19544

Driving and Maintaining PEVs

PEVs are at least as easy to operate and maintain as conventional vehicles, but some special considerations apply.

Vehicle Maintenance

Because PHEVs have ICEs, maintenance requirements for this system are similar to those in conventional vehicles. However, the PEV electrical system (battery, motor, and associated electronics) likely will require minimal scheduled maintenance. Because of regenerative braking, brake systems on PEVs typically last longer than on conventional vehicles. In general, EVs require less maintenance than conventional vehicles do, because there are usually fewer fluids to change and far fewer moving parts.

Battery Life

Like the ICEs in conventional vehicles, the advanced batteries in PEVs are designed for extended life but will wear out eventually. Currently, Nissan and General Motors are offering eight-year/100,000-mile warranties for the batteries in the Leaf and the Volt. PEV dealerships will have specific information about battery life and warranties. Although manufacturers have not published pricing for replacement batteries, if the batteries need to be replaced outside the warranty, it is expected to be a significant expense. However, battery prices should decline as the benefits of technological improvements and economies of scale are realized.

Safety

PEVs must undergo the same rigorous safety testing and meet the same safety standards required for conventional vehicles sold in the United States. In addition, a PEV-specific standard sets requirements for limiting chemical spillage, securing batteries during a crash, and isolating the chassis from the high-voltage system to prevent electric shock.

PEV manufacturers have designed their vehicles with safety features that deactivate the high-voltage electric system in the event of a collision. EVs tend to have a lower center of gravity than conventional vehicles, making them less likely to roll over and often improving ride quality.

One safety concern specific to PEVs is their silent operation: Pedestrians may be less likely to hear a PEV than a conventional vehicle. The National Highway Traffic Safety Administration is studying ways to address this issue, such as requiring PEVs to emit audible sounds at low speeds. This option is already available on some PEVs, including the Volt and the Leaf. In any case, PEV drivers should be trained to use extra caution in pedestrian areas.

Figure 2. A Chevy Volt charges up with public Level 2 EVSE at Los Angeles International Airport. *Photo from Coulomb Technologies*

Charging PEVs

Charging a PEV requires plugging in to electric vehicle supply equipment (EVSE). EVs must be charged regularly, and charging PHEVs regularly will minimize the amount of gasoline or diesel they consume. There are various types of EVSE—which differ based on how quickly they can charge a vehicle—and EVSE can be installed at your fleet facility or accessed in public (Figure 2).[3] This section describes the EVSE options so you can choose what's best for your fleet.

Types of Charging Equipment (EVSE)

EVSE is the equipment used to deliver electrical energy from an electricity source (such as the electricity running to your fleet facility's outlets) to a PEV. EVSE communicates with the PEV to ensure that an appropriate and safe flow of electricity is supplied.

EVSE for PEVs is classified into several categories by the rate at which the batteries are recharged. Two types—Level 1 and Level 2—provide alternating-current (AC) electricity 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. Charging times range from less than 30 minutes to 20 hours or more, based on the type of EVSE, as well as the type of battery, how depleted it is, and its energy capacity. EVs generally have more battery capacity than PHEVs, so charging a fully depleted EV takes longer than charging a fully depleted PHEV.

Many medium- and heavy-duty PEV manufacturers are adopting light-duty charging standards or commercially available standards developed for other uses. However, some manufacturers are introducing alternative charging configurations in their medium- and heavy-duty PEVs, so EVSE options and performance may be different for these vehicles.

Typical Charging Rates

The rate at which charging adds range to a PEV depends on the vehicle, the battery type, and the type of EVSE. The following are typical rates for a light-duty vehicle:

Level 1: 2 to 5 miles of range per hour of charging

Level 2: 10 to 20 miles of range per hour of charging

DC fast charging: 60 to 80 miles of range in 20 minutes of charging

3 Home EVSE is another PEV charging option. For more information, see the Clean Cities Plug-In Electric Vehicle Handbook for Consumers (www.afdc.energy.gov/afdc/pdfs/51226.pdf).

Level 1

Level 1 EVSE provides charging through a 120-volt (V) AC plug and requires a dedicated branch circuit. Most, if not all, PEVs will come with a Level 1 EVSE cord set so that no additional charging equipment is required. On one end of the cord is a standard, three-prong household plug (NEMA 5-15 connector). On the other end is a J1772 standard connector (see the *Connectors and Plugs* section on the next page), which plugs into the vehicle.

Level 1 is typically used for charging when there is only a 120-V outlet available. Depending on the battery type and vehicle, Level 1 charging adds about 2 to 5 miles of range to a PEV per hour of charging time.

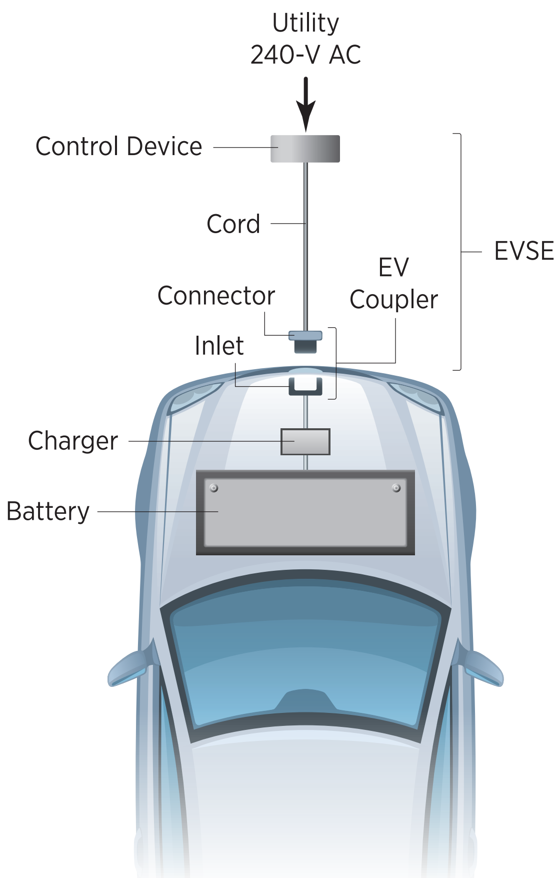


Figure 3. Level 2 charging schematic.

Source for both figures: eTec (2010), Electric Vehicle Charging Infrastructure Deployment Guidelines for the Oregon I-5 Metro Areas of Portland, Salem, Corvallis and Eugene. EV Project publication, www.theevproject.com/documents.php*. Illustrations by Dean Armstrong, NREL*

Level 2

Level 2 EVSE offers charging through a 240-V (typical in residential applications) or 208-V (typical in commercial applications) AC plug and requires installation of charging equipment and a dedicated electrical circuit (Figure 3). Because Level 2 EVSE can easily charge a typical EV battery overnight, this will be a common installation for fleet facilities. Level 2 equipment uses the same connector on the vehicle as Level 1 equipment. Based on the battery type, charger configuration, and circuit capacity, Level 2 charging adds about 10 to 20 miles of range to a PEV per hour of charging time.

DC Fast Charging

DC fast-charging EVSE (480-V AC input to the EVSE) enables rapid charging at sites such as heavy traffic corridors and public fueling stations (Figure 4). A DC fast charger can add 60 to 80 miles of range to a light-duty PEV in 20 minutes.

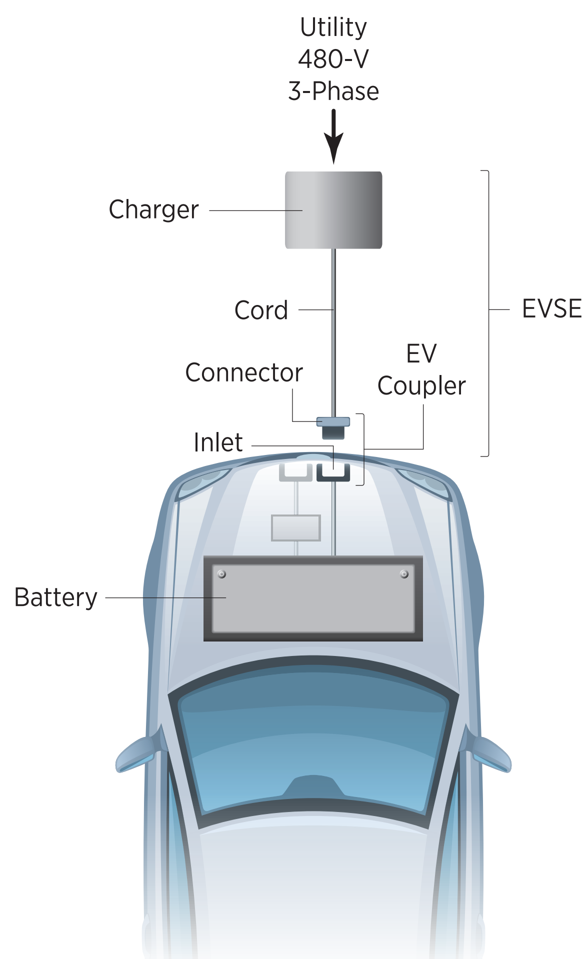


Figure 4. DC fast charging schematic.

Figure 5. The standard EVSE connector fits into the standard receptacle. *Photo by Andrew Hudgins, NREL/PIX 17634*

Figure 6. The standard J1772 receptacle (right) can receive charge from Level 1 or Level 2 equipment. The CHAdeMO DC fast charge receptacle (left) uses a different type of connector. *Photo by Andrew Hudgins, NREL/PIX 19558*

Inductive Charging

Inductive-charging EVSE uses an electromagnetic field to transfer electricity to a PEV without a cord. It is still being used in some areas where it was installed for EVs in the 1990s. Currently available PEVs cannot use inductive charging, although SAE International is working on a standard that may apply to PEVs in the future.

Connectors and Plugs

Most modern EVSE and PEVs have a standard connector and receptacle (Figure 5). This connector is based on the SAE J1772 standard developed by SAE International. Any vehicle with this plug receptacle can use any Level 1 or Level 2 EVSE. All major vehicle and charging system manufacturers support this standard, which should eliminate drivers' concerns about whether their vehicles are compatible with available infrastructure. To receive DC fast charging, most currently available PEVs are using the CHAdeMO connector, developed in coordination with Tokyo Electric Power Company, which is not standard in the United States. Manufacturers may offer the CHAdeMO DC fast charge receptacle (Figure 6) as an option on vehicles until a standard is in place. SAE International is also working on a "hybrid connector" standard for fast charging that adds high-voltage DC power contact pins to the J1772 connector, enabling use of the same receptacle for all levels of charging.

Charging at a Fleet Facility

If your fleet uses PEVs, Level 2 EVSE—and possibly DC fast charging—might be appropriate to install at a facility where your fleet vehicles can charge. Figure 7 (next page) summarizes the process for installing fleet EVSE, and the following sections address considerations related to installing and operating EVSE at a fleet facility.[4] As Figure 7 shows, it is important to consult with your utility, electrical contractor, PEV provider, and EVSE provider early in the EVSE installation process. For additional details about installing EVSE, see the *Clean Cities Plug-In Electric Vehicle Handbook for Electrical Contractors.*

Planning

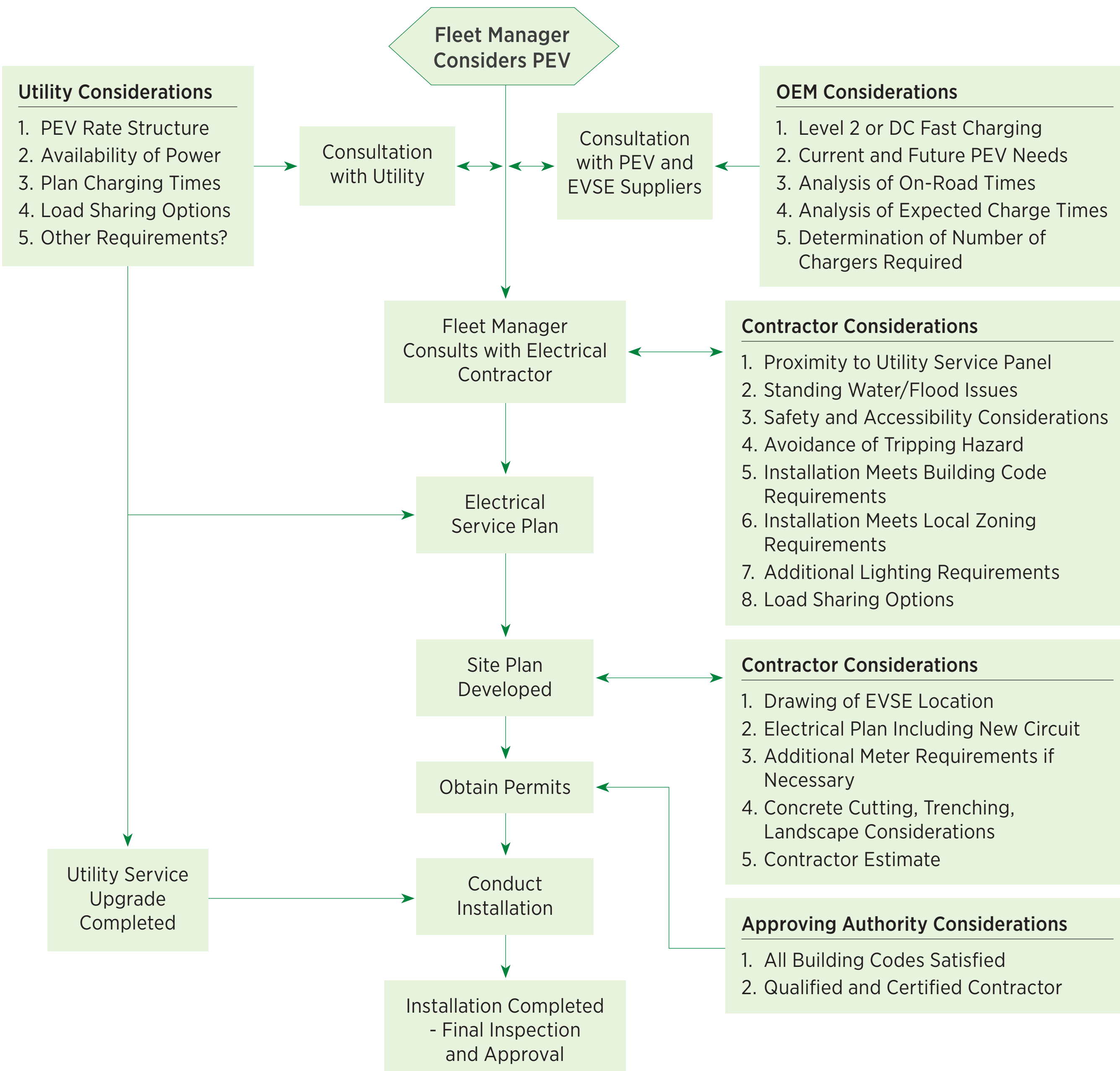
Thorough planning is essential to successful installation of fleet EVSE. The following are important considerations.

- **Number and Type of EVSE Units:** Determine your EVSE requirements by estimating your fleet's needs over at least the next several years. This should include projected PEV acquisitions and potential changes in PEV technologies and charging requirements (e.g., switching from PHEVs to EVs). If you are considering eventual expansion of your PEV fleet, consider adding extra circuits, electrical capacity, and conduit from the electrical panel to future EVSE locations. It is usually less expensive to install extra panel and conduit capacity during initial construction than to modify the site later. Analyze your

4 *These recommendations are primarily summarized from PG&E's Electric Vehicle Supply Equipment Installation Manual (*http://evtransportal.org/evmanual.pdf*) and eTec's Electric Vehicle Charging Infrastructure Deployment Guidelines for the Oregon I-5 Metro Areas of Portland, Salem, Corvallis and Eugene (*www.theevproject.com/documents.php*).*

fleet's electricity and charging-time needs by plotting electricity-use and time requirements for all of your PEVs. This will enable you to assess electrical-upgrade needs and choose the appropriate number and type of EVSE units, in consultation with your utility and the manufacturers of the PEVs and EVSE you are using. Note that Level 2 EVSE typically requires one unit per vehicle (to enable overnight charging of all vehicles), whereas DC fast charging can serve multiple vehicles. This presents a tradeoff: Level 2 equipment is less expensive than DC fast charging equipment, but DC fast charging may reduce land use and installation labor costs compared with Level 2. Further, DC fast charging may be required for PEVs that drive more than 100 miles in a day. Before you install DC fast charging for your fleet, check that using it regularly doesn't void your fleet's PEV warranties.

Figure 7. General process for installing EVSE at a fleet facility. *Source: eTec (2010), Electric Vehicle Charging Infrastructure Deployment Guidelines for the Oregon I-5 Metro Areas of Portland, Salem, Corvallis and Eugene. EV Project publication,* www.theevproject.com/documents.php.



- **Convenience:** Locate EVSE and associated PEV parking as close as possible to the electric service while accommodating other activities within your fleet's facility. Keep in mind that PEVs can be parked for hours at a time for charging.

- **Avoiding Hazards:** Cords and wires associated with EVSE should not interfere with pedestrian traffic or present tripping hazards. PEV charging spaces should not be located near potentially hazardous areas.

- **Ventilation:** Although most of today's advanced batteries do not require ventilation during charging, some older types emit gases during charging. If PEVs are charged with these types of batteries in an enclosed space, there must be adequate ventilation, which may include installation of fans, ducts, and air handlers. Depending on the installation, the National Electrical Code may also require ventilation. Verify the requirements with the PEV manufacturer's documentation.

- **Battery Temperature Limits:** Because some PEV batteries have operating- and charging-temperature limits, EVSE may need to be located within an enclosed, climate-controlled area in extreme climates.

- **Pooled Water and Irrigation:** EVSE is designed to operate safely in wet areas. However, users will be more comfortable if it is not located where water pools or where irrigation systems spray.

- **Preventing Impact:** Curbs, wheel stops, and setbacks should be used to prevent PEVs from colliding with EVSE. However, accessibility issues must also be considered when using these strategies.

- **Vandalism:** Assess the risk of vandalism and minimize risk through use of preventive strategies, such as motion detectors, security lighting, tamper alarms, and locked enclosures.

- **Signage:** Use signs that can be seen over parked vehicles to designate PEV-only parking spaces.

- **Accessibility:** Evaluate and address requirements for complying with the Americans with Disabilities Act, as well as state, local, and organizational accessibility policies. Compliance measures may include adjusting connector and receptacle heights, cutting curbs, and providing handicap-accessible parking spaces.

PEVs are suitable for many applications, including military cargo delivery. *Photo from Smith Electric Vehicles, NREL/PIX 17631*

Choosing an EVSE Provider and Electrical Contractor

Several companies manufacture and sell EVSE. Some have partnered with a PEV manufacturer to become a "preferred EVSE provider," so one way to choose EVSE is to use the company recommended by your PEV manufacturer or dealer. You can also discuss EVSE options with your electrical contractor and utility. If you choose an EVSE provider before choosing an electrical contractor, you can discuss potential electrical contractors with your EVSE provider—they likely will have a preferred-contractor list for your area. Find links to EVSE provider websites on the AFDC's Related Links page (*www.afdc.energy.gov/afdc/related_links.html*).

Engineering and Construction

Because EVSE installations involve specialty equipment and electrical work—in addition to standard civil engineering work—select well-qualified contractors with experience in the relevant engineering and construction areas. The condition and location of existing electrical equipment will determine the complexity of the required electrical installations. If the existing electrical system does not support the required EVSE input voltage range, an isolation transformer is required to step electricity down to Level 2 or up to DC fast-charging voltage. To learn more about the types of considerations contractors must address, see the *Clean Cities Plug-In Electric Vehicle Handbook for Electrical Contractors.*

Corporate fleets use PEVs to reduce fuel costs and demonstrate their environmental commitments.
Photo by Trish Cozart, NREL/PIX 19543

Complying with Regulations

EVSE installations must comply with local, state, and national codes and regulations, and installation requires a licensed contractor. Your contractor should know the relevant codes and standards and obtain approval from the local building, fire, environmental, and electrical inspecting/permitting authorities before installing EVSE.

You can learn about codes and standards typically used for U.S. PEV and infrastructure projects on the AFDC's Codes and Standards Resources page (*www.afdc.energy.gov/afdc/codes_standards.html*). To determine which codes and standards apply to your fleet's project, identify those that are in effect within the local jurisdiction of the project—many jurisdictions have unique ordinances or regulations.

Consult PEV manufacturer guidance for information about the required EVSE and learn the specifications before purchasing equipment and electric services. Rocky Mountain Institute's Project Get Ready has more information about EVSE codes and standards (*http://projectgetready.com/resources/other/underwriters-labs-ev-standards*).

In many areas, a site installation plan must be submitted to the permitting authority for approval before EVSE installation can proceed. A plan describes the use and locations of elements, such as electrical system components, hazardous materials, EVSE, lighting, vehicle and pedestrian traffic flow, ventilation, signage and striping, safety and accessibility measures, and landscaping. You may want to work with your contractor to develop the plan.

Electric Rates

If your fleet must charge PEVs during peak electricity demand periods, this may move you into a higher rate category and result in higher electricity costs. Conversely, special reduced rate structures may be available for fleets charging PEVs; you may need to purchase new meters to take advantage of these rate structures. It is important to research this issue carefully and discuss with your utility the effects of charging on electricity rates and loads. The advanced capabilities of some EVSE products can be useful for optimizing load management, helping you maximize charging during low-rate periods and minimize it during high-rate periods.

Installation Costs

EVSE installation costs vary considerably, so be sure to do your homework and get a number of price quotes before moving forward. The City of Houston reported installation costs varying from $860 to $7,400 per unit, not including the cost of the EVSE units themselves.[5] Factors affecting the cost (and installation time) include the number of circuits and EVSE units installed, indoor versus outdoor installation, required electrical upgrades, required ventilation, and the use of DC fast charging EVSE. If required, trenching and adding electrical service/panels incur the most cost.

According to the Rocky Mountain Institute/Project Get Ready, the cost of a Level 2 EVSE unit, not including installation costs, is approximately $1,000 to $7,000 (before incentives) depending on the level of sophistication.[6] DC fast charging EVSE units are projected to cost $20,000 to $50,000, but manufacturers are working to decrease costs substantially.

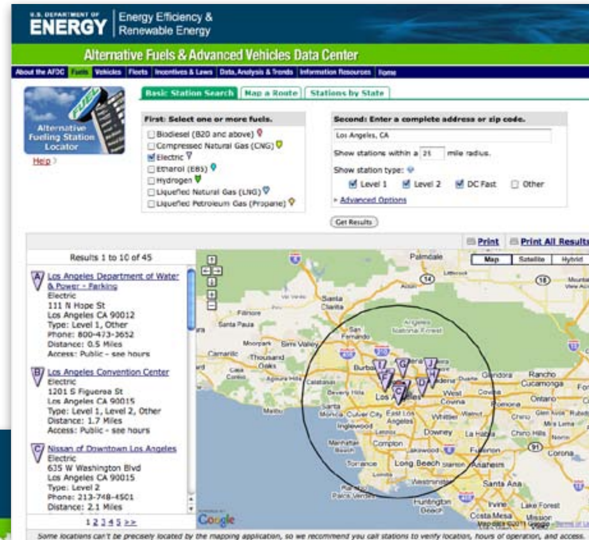
Discounts and incentives can lower infrastructure costs. Your fleet may be eligible for incentives from the state, city, or utility. To find current incentives, search the

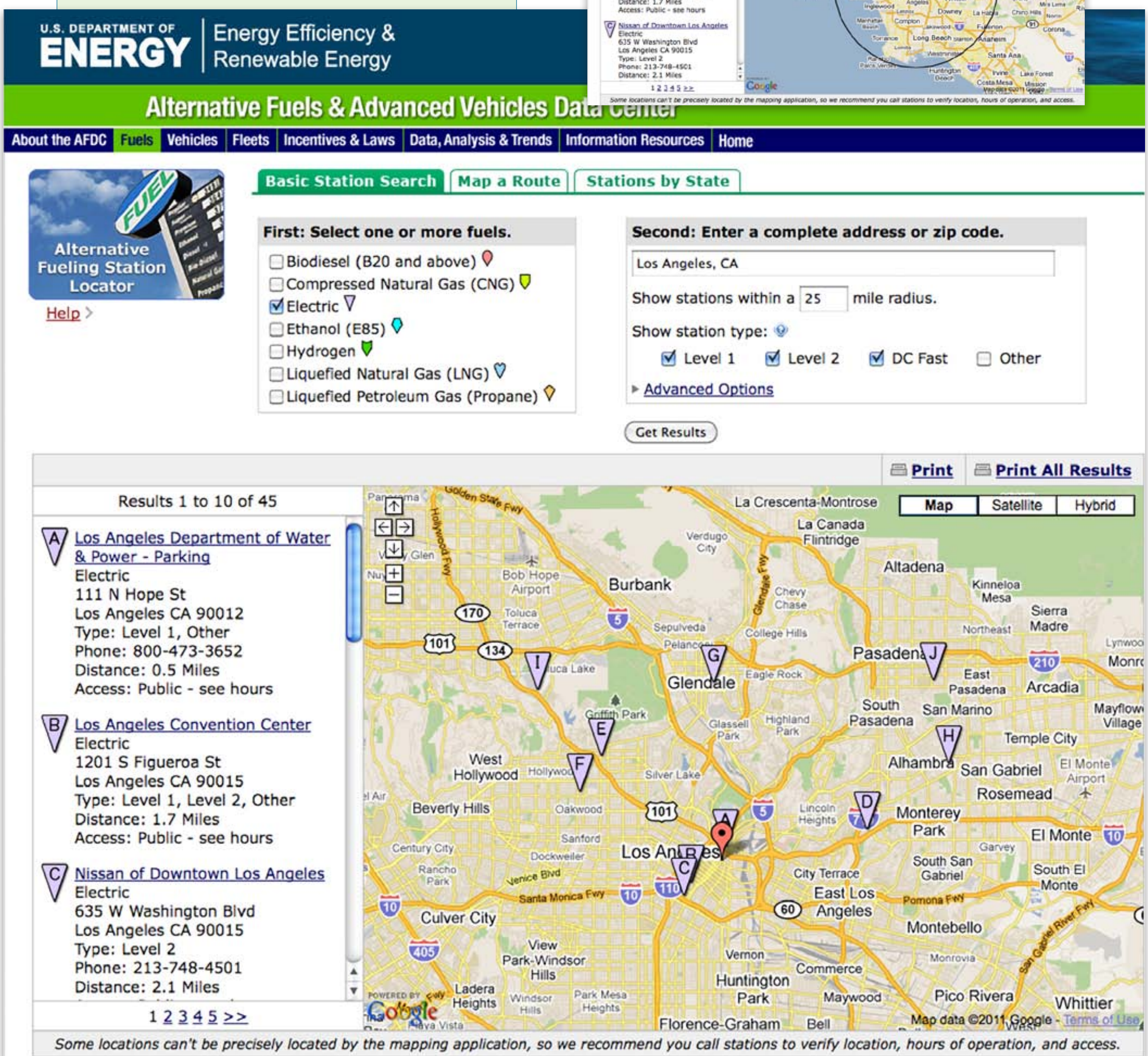
5 *See EVSE installation cost estimates on the Project Get Ready website (*http://projectgetready.com/resources/infrastructure/charging-station-installation-costs*).*

6 *From Rocky Mountain Institute. (2009). Plugging In: A Stakeholder Investment Guide for Public Electric-Vehicle Charging Infrastructure.* http://projectgetready.com/resources/infrastructure/plugging-in-a-stakeholder-investment-guide-for-public-electric-vehicle-charging-infrastructure.

Alternative Fueling Station Locator

The AFDC's Alternative Fueling Station Locator (*www.afdc.energy.gov/afdc/fuels/stations.html*) helps fleet drivers find charging stations along their routes or near a specific location. Simply select "Electric" from the list of fuels, enter the location or route, and specify the type of EVSE you're looking for. The locator generates a map of station locations and provides information for each station, including operating hours, phone numbers, and driving directions.





Fleets can play a major role in stimulating the adoption of PEVs in the United States.
Photo from Richard Bogacz, New West Technologies, NREL/PIX 19664

AFDC's Federal and State Incentives and Laws database (*www.afdc.energy.gov/afdc/laws*). As described in the *PEV Benefits* section, operating costs are lower for PEVs than for conventional vehicles, which also helps offset EVSE costs.

EVSE Maintenance

Typically, there are relatively few EVSE maintenance requirements. In general, charging cords should be securely stored so they are not damaged. Be sure to check the accessible EVSE parts periodically for wear and keep the system clean. See the EVSE manufacturer's guidelines for specific requirements. Periodic inspection, testing, and preventive maintenance by a qualified electrician may be recommended.

Charging in Public

Public charging stations make PEVs even more convenient. They increase the useful range of EVs and reduce the amount of gasoline or diesel consumed by PHEVs. Although the current availability of public charging stations is limited, it is increasing rapidly. Publicly and privately funded projects are accelerating the deployment of public stations, including several projects supported by the U.S. Department of Energy. For more information, visit the AFDC's Deployment page (*www.afdc.energy.gov/afdc/vehicles/electric_deployment.html*). To find charging stations near you, visit the AFDC's Alternative Fueling Station Locator (*www.afdc.energy.gov/afdc/fuels/stations.html*), or access the locator with a mobile device at *www.afdc.energy.gov/afdc/locator/m/stations*.

Most public charging will use Level 2 to enable charging at locations where vehicles are highly concentrated, such as shopping centers, city parking lots and garages, airports, hotels, government offices, and other businesses. Today, many charging stations offer free charging to encourage early adopters of PEVs. However, most public stations will evolve toward a pay-for-use system as PEVs become more mainstream. A number of payment models are being considered, all designed to make paying for charging simple and convenient. In the near future, drivers might subscribe to a charging service, swipe a credit card, enter a charging account number, or even insert coins or bills to charge their PEVs. In many cases, drivers may only be charged a single fee for parking and charging.

Choosing Electric

You now know the basics about PEVs, which should help you decide if they are right for your fleet. In a time of volatile petroleum prices and growing environmental concerns, PEVs offer a way to reduce operating costs, demonstrate your environmental responsibility, and comply with fleet policies. What's more, the number of available PEV models and the public charging station network are expanding rapidly—making PEVs a better choice every day. To keep up with all the new developments, visit the AFDC (*www.afdc.energy.gov/afdc/vehicles/electric.html*) and FuelEconomy.gov (*www.fueleconomy.gov*) frequently.

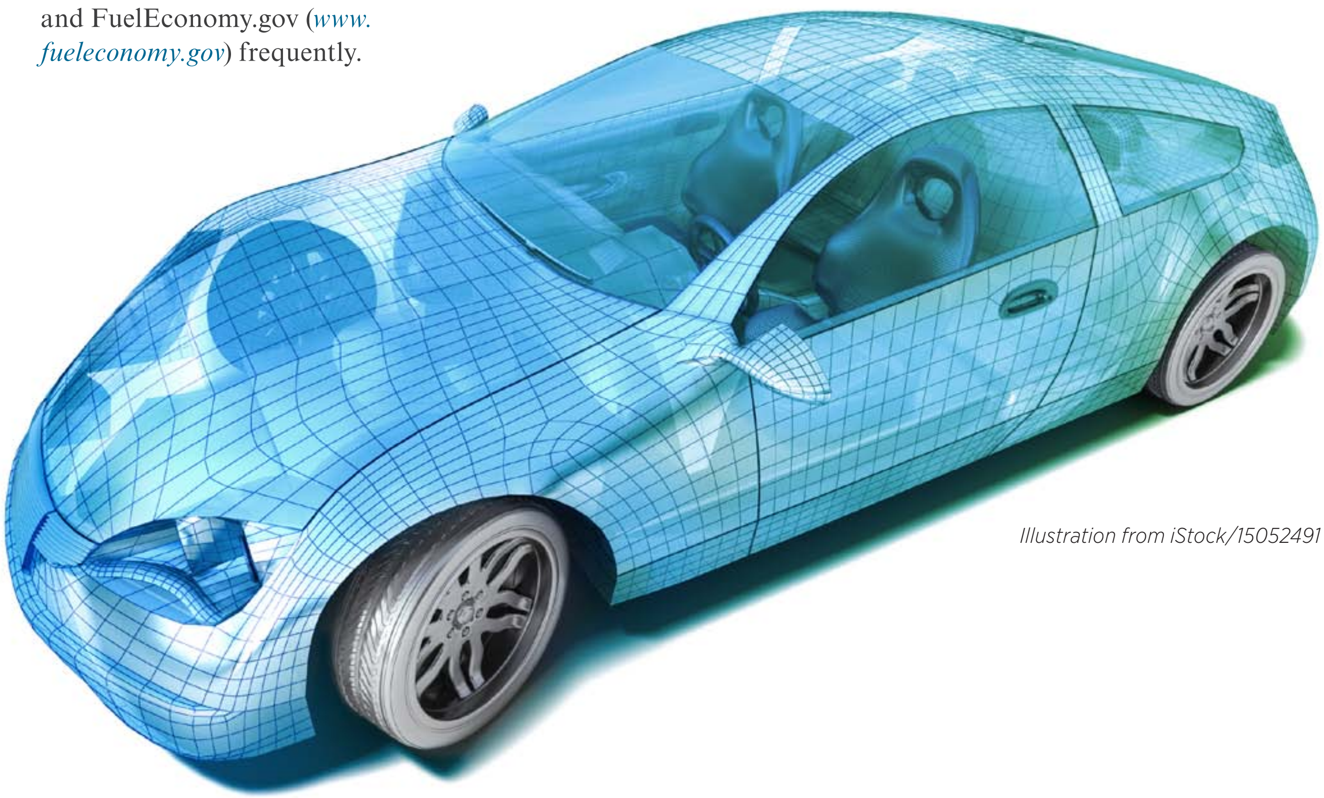


Illustration from iStock/15052491

Clean Cities Can Help

If you need assistance with your PEV projects, contact your local Clean Cities coordinator by visiting *www.cleancities.energy.gov*.

U.S. DEPARTMENT OF
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Energy Efficiency &
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Clean Cities Technical Response Service
800-254-6735
technicalresponse@icfi.com

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