EPRI | ELECTRIC POWER RESEARCH INSTITUTE

OCTOBER 2019

CONSUMER GUIDE TO ELECTRIC VEHICLE CHARGING

Photo courtesy of SRP

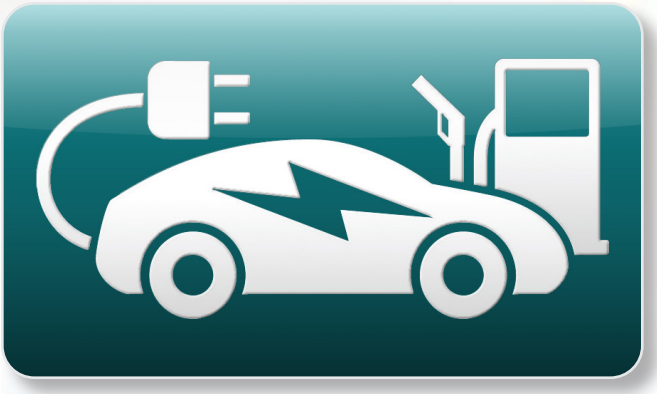
CHARGING 101

Electric cars are catching on across the country. New-car buyers are discovering that electric vehicles are fun to drive, safe and comfortable, and convenient to refuel. They also cost less to run. About 40 electric car models are available in the United States today and global automakers plan to offer more in coming years.

With electric vehicles, consumers change the way they refuel. Instead of going to a gas station, they plug into the electricity grid—at home, at work, or in public. Even with a growing public charging network, most drivers prefer to charge at home. It's more convenient, and it usually saves money.

Charging your electric car is as easy as charging your smart phone or computer. Simply plug it in—then carry on with life. Your car charges while you sleep, play or work.

This guide addresses the most commonly asked questions about electric vehicle charging. It includes information on where to charge, charging speeds, charging on the go and in the real world, charging station hardware, connectors, helpful apps, and installation considerations. It serves as a companion to "Consumer Guide to Electric Vehicles" March 2019 (EPRI Product ID 3002015368).



IN THIS GUIDE

WHERE TO CHARGE

You can charge your electric car at home, at work, or on the go at public charging stations.

HOME

Most charging occurs at home, where it is most convenient and cost-effective. You can plug into an up-to-date 120 VAC household outlet (also called Level 1) using the cord that comes with the car, or install a dedicated Level 1 charging station. A dedicated 240 VAC charging station (also called Level 2) charges faster. Drivers with dedicated parking simply park, plug in, and walk away. Apartment and condo dwellers with shared parking should coordinate with the building manager and neighbors. Drivers can program their electric car to start charging or to be finished charging by a certain time to take advantage of cheaper time-of-use utility rates.

WORK

The workplace, where many people spend several hours each day, is another convenient place to refuel. Charging at work enables drivers to extend their car's range during work hours, increasing the number of electric miles they can drive each day. Some companies offer electric car charging as an employee perk, and to demonstrate corporate sustainability. Most develop their own rules about charging station use.

ON THE GO

Many people have a "going to the gas station" mindset, so they (incorrectly) think public charging is the only (or best) charging option. It's neither. Public charging supplements home or workplace charging and provides another option to boost your car's range while you're on the go. The number of stations nationwide is growing rapidly, from shopping centers to stops along highways. Parking and payment arrangements vary. Availability is first-come, first-served.

Charging your car is as easy as charging your smart phone or computer. Simply plug it in—then carry on with life. Your car charges while you sleep, play or work.

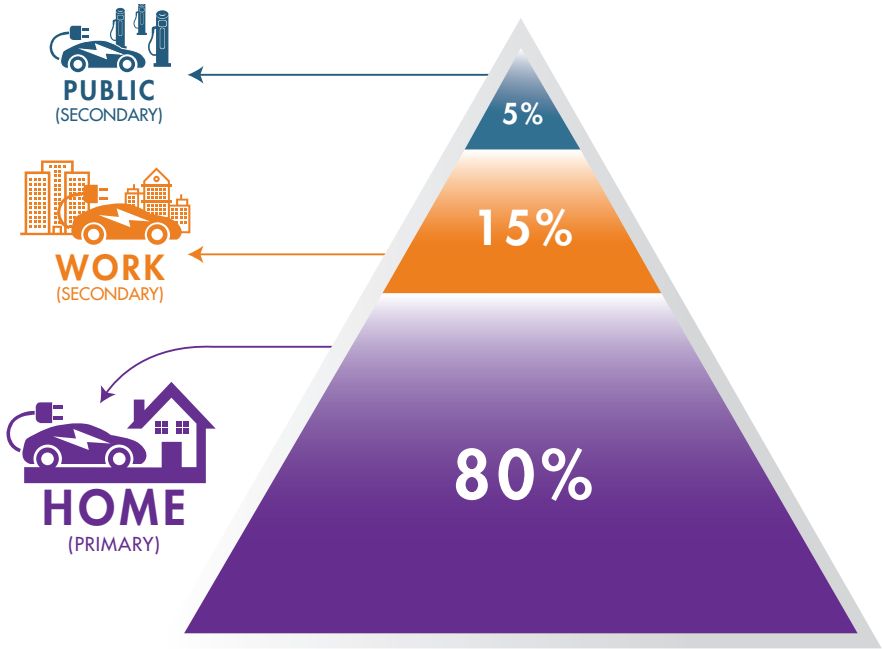


Figure 1 – Charging station usage varies by location. Approximately 80% of charging occurs at home, 15% at work, and 5% at public locations.

CHARGING LEVELS

Three factors determine how fast your car charges: how much electricity is delivered from the source, how much electricity the car can accept, and the size of the car's battery.

The terms, AC Level 1, AC Level 2, and DC Fast describe how energy is transferred from the electrical supply to the car's battery. Equipment on electric cars converts AC to DC to charge the batteries, which operate on DC. DC Fast charging delivers DC current directly to batteries in fast-charging capable cars.

AC Level 1 (commonly called Level 1) is the slowest charging speed. It's a popular choice for home charging, especially for plug-in hybrids with small batteries, because people park at home for longer periods. It requires only the charging cord that comes with every electric car, plugged into a new, up-to-date household outlet so there's no installation cost. A dedicated Level 1 charging station is also an option for home charging and is recommended for Level 1 charging at workplaces and in public.

AC Level 2 (commonly called Level 2) charging is faster than Level 1, usually requires a charging station, and uses higher grid voltage. Level 2 charging can occur at home, workplaces, and in public.

DC Fast charging occurs only in public due to its even higher grid voltage. Stations are increasingly available in strategic locations, near shopping centers and along highway corridors. All electric cars can charge at Level 1 and Level 2, but not all cars are equipped for DC Fast charging. As the name implies, it's much faster than the other two.

Table 1 – Charging levels and range replenished

CHARGING LEVEL; DESCRIPTION	LOCATION	MILES RANGE REPLENISHED[1]
AC Level 1; cord comes with car; three-prong outlet or charging station	Home, Work, Public	3–5 miles/hour
AC Level 2; charging station	Home, Work, Public	8–24 miles/hour, higher on some models
DC Fast; charging station[2]	Work, Public	
50 kW		2–3 miles/minute; charges 100-mile range car to 80% in 30 minutes
150 kW		6–9 miles/minute; charges 240-mile range car to 80% in 30 minutes
350 kW		12–18 miles/minute; charges 300-mile range car to 80% in 20 minutes

1 The amount of range replenished may vary beyond the numbers shown, depending on the charger type and vehicle.
2 Most current U.S. DC Fast chargers offer a maximum power level of 50 kW–150 kW charging (Tesla Superchargers offer 120 kW–150 kW). Tesla promises V3 Superchargers will deliver up to 250 kW, and other networks promise high-power (350 kW+) DC Fast chargers beginning in 2020 for future vehicles that can take advantage of them (Porsche will have the first).

CHARGING COST

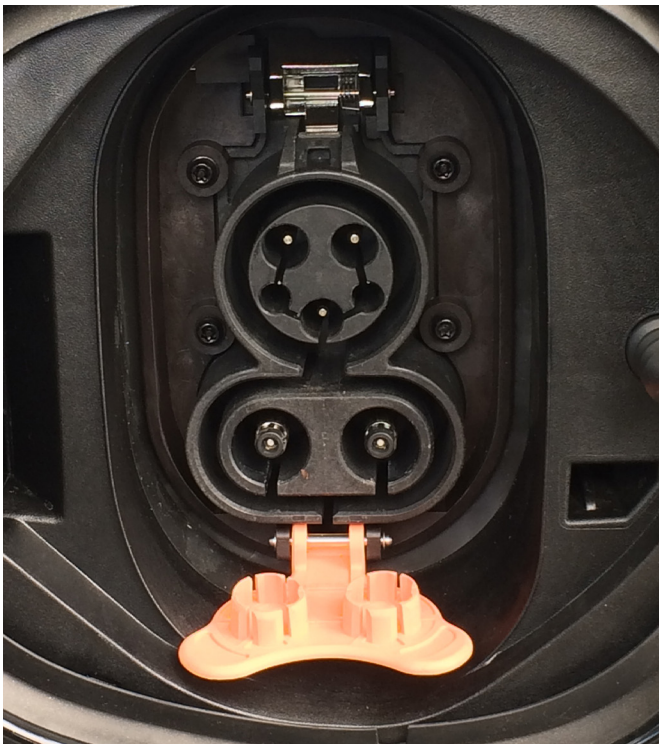
Charging cost depends on several factors: the price of electricity, your vehicle's efficiency (how much electricity it uses to travel one mile), and how many miles you drive. Home charging is the most economical—and the most convenient. Many utilities offer special time-of-use and electric vehicle rates for their residential customers.

Public charging costs vary by region and network provider. Some public charging stations are free and open to all, with electricity subsidized by the property owner. Some automakers offer free public charging in certain networks for a limited time. Some charging networks require a membership and charge a monthly fee plus usage, or a connection fee with a per-minute charge; they may also charge additional fees after a charging session is complete, to encourage drivers to move their cars. Charging on the go usually costs less than or equal to the cost of gasoline but more than that of home charging.

Table 2 – Average cost to drive 30, 100, or 200 miles using electricity (with home and public charging options) compared to gasoline

MILES DRIVEN	GASOLINE COST[1]	ELECTRICITY COST HOME CHARGING[2]	ELECTRICITY COST PUBLIC CHARGING LEVEL 2[3]	ELECTRICITY COST PUBLIC CHARGING DC FAST[4]
30	$3.90	$1.10	$2.30	$3.70
100	$13.00	$3.70	$7.90	$12.20
200	$26.00	$7.30	$15.80	$24.50

1 This calculation assumes average U.S. light-duty vehicle efficiency of 25 mpg and regular unleaded gasoline at $3.25/gallon.
2 This calculation assumes an average electric vehicle efficiency of 3.5 miles/kWh and a U.S. average residential electricity price of $0.125/kWh.
3 This calculation assumes an average electric vehicle efficiency of 3.5 miles/kWh and a U.S. Level 2 public charging network average electricity price of $0.27/kWh.
4 This calculation assumes an average electric vehicle efficiency of 3.5 miles/kWh and a U.S. DC Fast public charging network average electricity price of $0.42/kWh.



CHARGING ON THE GO

Most electric car drivers appreciate the convenience of plugging in at home and starting each day with a full charge. But not everyone has a dedicated parking space at home, and sometimes people need to drive beyond their electric car's range. In these cases, public charging is essential.

The number of public charging locations nationwide is growing. Some are connected to membership networks. Others are open access. The industry is developing software and standards to enable anyone to use any network's chargers regardless of membership. For more information, see page 10 for charging stations and page 12 for networks and apps.

Even with the growth in public charging locations, drivers may encounter range anxiety. What if a station shown on your charging app is in use by another electric vehicle, blocked by a gasoline car, or broken? Fear of being stranded will decline as more long-range electric cars become available and more people become comfortable with their car's actual range.

PUBLIC CHARGING ETIQUETTE

- Don't park at a charging station if you're not charging.
- Charge up, then move your car to open the space for the next driver.
- Don't unplug another car unless it's finished charging or has a note on the dashboard indicating when it's OK to unplug.
- Charge only when necessary.

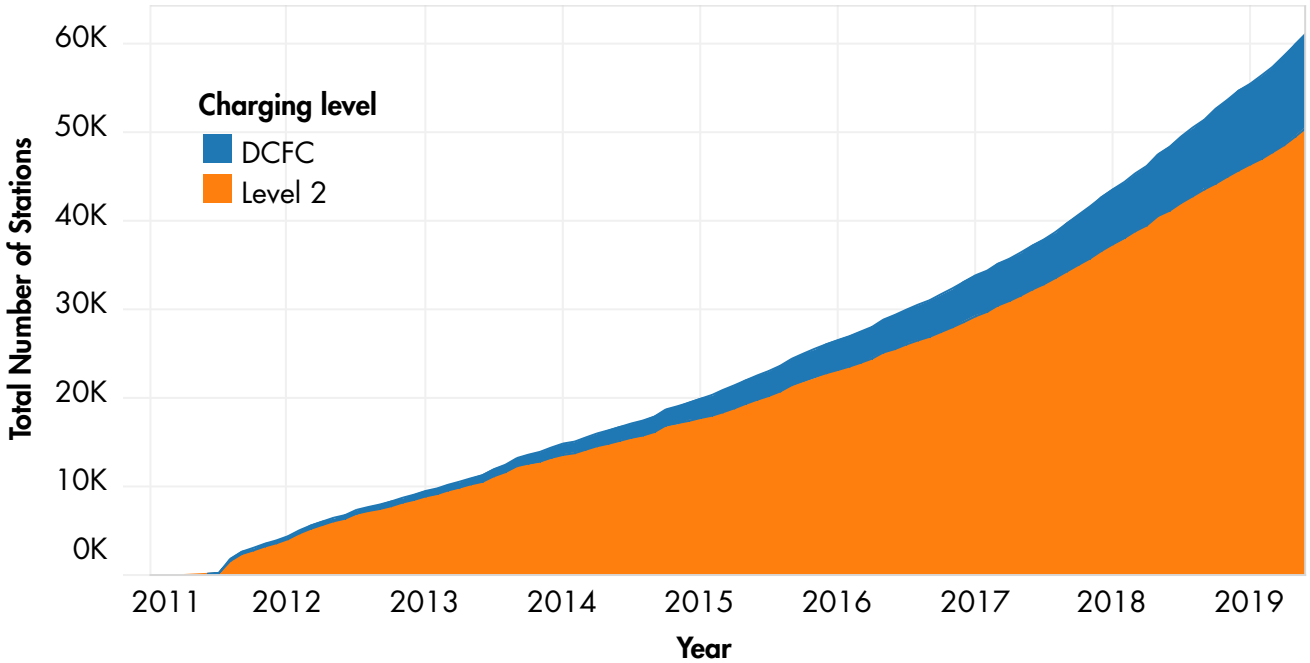


Figure 2 – Between January 1, 2018 and June 2019, the total number of public charging stations nationwide increased from roughly 45,000 to 64,000 or 41%. During the same period, the number of DC Fast charging stations increased from roughly 7,600 to 9,300 or 80%.
Source: Plugshare

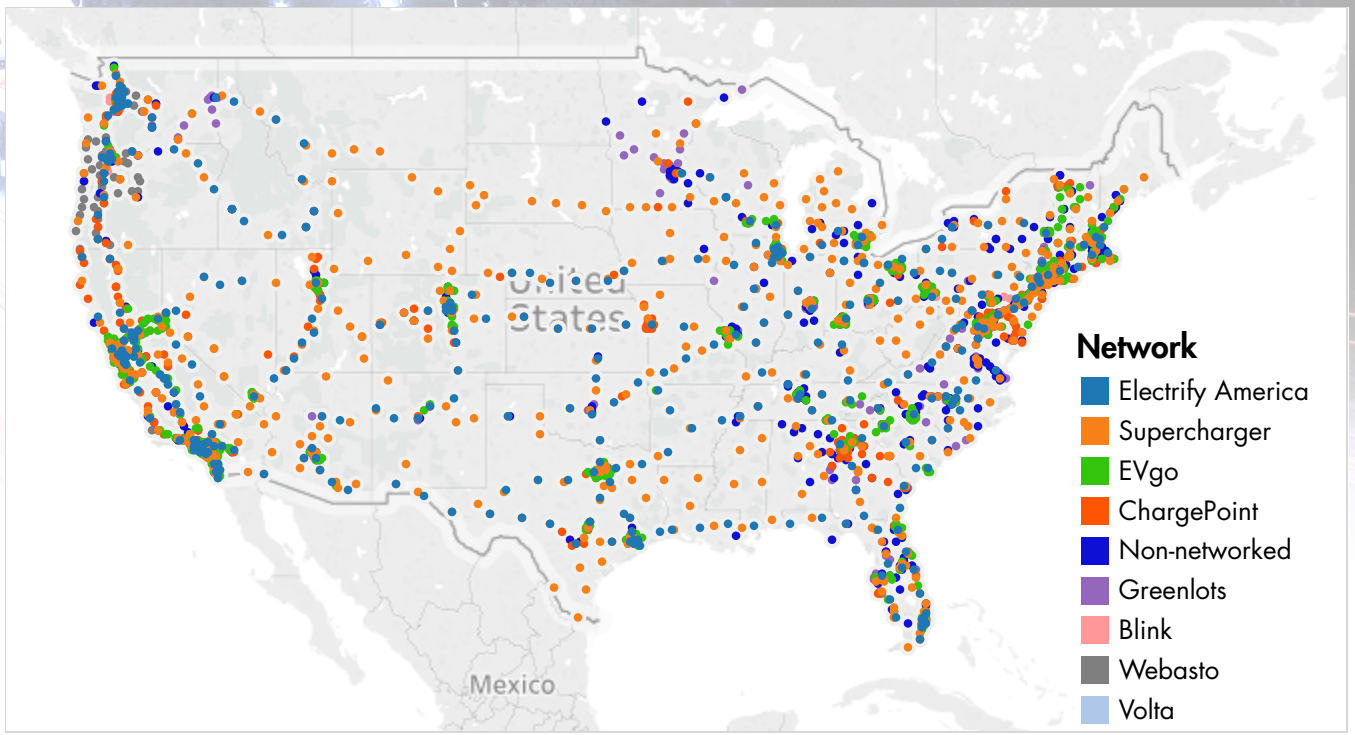


Figure 3 – Nationwide DC Fast charging stations as of June 2019; includes only networks with at least 15 stations
Source: Plugshare

FUTURE TECHNOLOGY

Very High-Power Charging. A few 350-kW DC Fast chargers are being tested in demonstrations. Cars that can accept that charging rate are expected in 2020 and later. Industry is also developing a standard for ultra-high-power fast charging—beyond 1 MW—to meet the charging demand expected from electric buses and electric big-rig trucks.

Wireless Charging. Available in some countries, and for commercial electric vehicle charging in the United States, the technology is not yet available here for consumers, and its market potential is uncertain.

Vehicle-to-Grid. Future technology may enable energy transfer from electric vehicle batteries to the electricity grid.

Vehicle-to-Home. Future technology may enable an electric vehicle to act as a backup generator for home, workplace, or other building electrical loads.

CHARGING IN THE REAL WORLD

Let's consider a few different electric vehicle drivers and their real-world driving needs.

AC LEVEL 1 AND 2 AT HOME

Robert used to charge his 238-mile electric car every other night when he drove a lot for work. Now retired, he drives shorter distances most days and only needs to charge every four or five days, or before family trips to the mountains.

Alberto ferries the kids around town in his plug-in hybrid. Its 26-mile electric range is enough for him to drive on electricity alone most days. If he drives farther, the gasoline engine kicks in. When he gets home every night, he plugs in to have a full battery the next morning.

AC LEVEL 1 AND 2 AT WORK

Photo courtesy of SRP

Sam commutes 35 miles each way and occasionally drives to meetings away from the office. Thanks to workplace charging, Sam can essentially double his older electric car's daily driving range, to about 160 miles.

Cindy can't always rely on accessing the charging station in her condo community. But since her employer has workplace charging and she only commutes 18 miles each way, her electric car with 124 miles of range meets her daily driving needs—even if she doesn't charge every day. Another perk: In her state, she can drive solo in the carpool lanes.

AC LEVEL 2 PUBLIC

Bonnie never knows how far she'll drive on a given day. She juggles a 55-mile roundtrip commute, daytime errands from work, evening choir practices, and kids' activities. She occasionally uses public chargers when parked, allowing her to arrive home at night with range to spare.

DC FAST PUBLIC

Nandini commutes 18 miles one-way to work, attends evening classes, and frequently drives 120 miles to the state capital for meetings. In a typical commute week, she charges her 200-mile electric car at home every other night to cover her daily driving needs. On longer travel days, she starts with a full charge from home and drives straight to the capital. Heading home, she stops at one of several DC Fast charging sites along the highway to supplement her range. The 20-minute charging stop allows her to catch up on email and texts or grab a quick snack.

HARDWARE: CHARGING STATIONS

The appliances that allow energy transfer to your electric car are usually called chargers or charging stations. (The official term is electric vehicle supply equipment or EVSE.) Their size, functionality, power needs, and costs vary. Choose a product that is Underwriters Laboratories (UL) certified.

Table 3 – Charging options and hardware

	HOME CHARGING	WORKPLACE CHARGING	PUBLIC CHARGING
AC LEVEL 1		 Photo courtesy of Hawaiian Electric	
Use Case	Sufficient for cars parked at home 8–10 hours overnight	Sufficient for cars parked at the office all day, 8–10 hours	Sufficient for cars parked for 8–10 hours or longer
Charging Rate	1.4 kW–3.3 kW	1.4 kW–3.3 kW	1.4 kW–3.3 kW
Circuit Capacity	Dedicated 110–120 VAC, 15- or 20-amp circuit	Dedicated 110–120 VAC, 15- or 20-amp circuit	Dedicated 110–120 VAC, 15- or 20-amp circuit
Purchase and Installation Cost	Free; cord comes with car, plugs into standard household outlet	Varies by location	Varies by location

	HOME CHARGING	WORKPLACE CHARGING	PUBLIC CHARGING
AC LEVEL 2		 Photo courtesy of SRP	
Use Case	Faster charging; many carmakers partner with electric vehicle charging networks; consumers can choose other providers; non-networked station is sufficient for most.[1]	Faster charging; allows employees to share charging stations; some employers offer free charging; others charge a fee or use a third-party network provider.[1]	Faster charging; some public charging is free or subsidized by carmakers; some locations charge a fee or use a third-party network provider.[1]
Charging Rate	3.8 kW–19.2 kW	3.8 kW–19.2 kW	3.8 kW–19.2 kW
Circuit Capacity	Dedicated 240 VAC, 30–100-amp circuit	Dedicated 208–240 VAC, 30–100-amp circuit	Dedicated 208–240 VAC, 30–100-amp circuit
Cost	Installation costs vary; purchase cost: $200–$2,200	Installation costs vary; purchase cost: $200–$2,200	Installation costs vary; purchase cost: $200–$2,200

	HOME CHARGING	WORKPLACE CHARGING	PUBLIC CHARGING
DC FAST			
Use Case	Not applicable for home charging	Uncommon in typical workplace setting, unless it is also a public venue.	Located along U.S. travel corridors and in some shopping destinations.
Charging Rate	Not applicable	Not applicable	50 kW, 150 kW, 350 kW[2]
Circuit Capacity	Not applicable	Not applicable	Dedicated 480 VAC, 60-amp circuit Dedicated 480 VAC, 180-amp circuit Dedicated 480 VAC, 420-amp circuit
Purchase and Installation Cost	Not applicable	Not applicable	Cost is borne by the service provider or site host; equipment and installation costs vary.

1 Most drivers find networked stations unnecessary for home charging, since many cars come with their own remote-control features and apps. Employers and property managers may want network functionality for energy monitoring, usage analysis, access control, a payment system, cellular/Wi-Fi communications, and back-office support.

2 Most current U.S. DC Fast chargers offer a maximum power level of 50 kW–150 kW charging (Tesla Superchargers offer 120 kW–150 kW). Tesla promises V3 Superchargers will deliver up to 250 kW, and other networks promise high-power (350 kW+) DC Fast chargers beginning in 2020 for future vehicles that can take advantage of them.

HARDWARE: CONNECTORS

The connector is the plug that you plug into the car. It delivers current from the electrical service to charge the car's battery. It also facilitates communication between the car and the charging station, so the charging process is automatic once the car is plugged in.

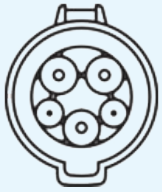
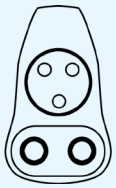
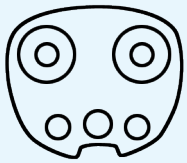
For AC Level 1 and AC Level 2 charging, all electric vehicles except Tesla use a standard connector known as J1772. Many new connectors come with charging cords that will work with both 120 VAC (Level 1) and 240 VAC (Level 2), via "pigtails" that can be swapped to use one plug or the other.

There are two standard connectors for DC Fast charging: Combined Connector Standard (known as the combo connector or CCS), and CHAdeMO, each adopted by different automakers. Most new fast-charging stations offer cables with both connector types, but some older stations only have one. You cannot use the charging cord that comes with the car for DC Fast charging.

Tesla uses its own connector for AC Level 2 and DC Fast charging and offers adaptors so U.S. Tesla drivers can use non-Tesla charging stations. Only Tesla vehicles can charge at Tesla charging stations.

Today's charging apps typically identify the number and type of available connectors at each public charging station. More on apps and networks on page 12.

Table 4 – Electric vehicle charging connectors

					
CONNECTOR DESCRIPTION	J1772 standard connector for all electric vehicles except Tesla; used with Level 1 or Level 2 charging station, or with 120 VAC cord that comes with the car	CCS connector used with charging station for cars that are fast-charging capable	CHAdeMO connector used with charging station for cars that are fast-charging capable	Tesla connector used only with Tesla vehicles	Tesla connector used only with Tesla vehicles
CHARGING LEVEL	AC Level 1, AC Level 2	DC Fast	DC Fast	AC Level 2	Supercharger
POWER	1.4 kW – 19.2 kW	50 kW – 350 kW[1]	30 kW – 50 kW	10 kW – 20 kW	120 kW – 250 kW[2]

1 Fast-charging station speeds vary. Most currently available DC Fast chargers offer a maximum power level of 50 kW–150 kW charging. High-power (350 kW+) DC Fast chargers will be introduced beginning in 2020 for future vehicles that can take advantage of them.

2 Current Tesla Superchargers charge at 120 kW–150 kW; V3 Superchargers promise up to 250 kW.

NETWORKS AND APPS

One of the most convenient features of driving electric is the connectivity offered by different charging networks and apps.

NETWORKS

Electric vehicle charging networks are private companies that offer different options to meet drivers' varying charging needs. Although most networks operate on a membership basis—you sign up online, provide a credit card, download a mobile app, and get a charging card or key fob—the industry is working to improve access to all drivers regardless of membership.

Some networks allow a simple credit card swipe at the charging station. Others have a toll-free number that non-members can call to pay for a charging session via credit card.

Carmakers and networks are now working to develop "plug-and-charge" capability using secure digital communication between the car's onboard software and the charger. The driver plugs in the car and walks away, the network identifies the car (owner data is hidden), and billing is handled in the background.

APPS

Apps help electric vehicle drivers locate charging stations, plan trips based on available charging stations, and remotely manage charging or cabin conditioning. Most automakers provide their own apps to display their chosen charging networks on the car's screen or on the driver's smartphone.

Several independent companies offer apps that show all charging options, regardless of network. These are important because they show the widest array of charging sites. Some let drivers upload tips and photos to help other drivers find the chargers.

TYPICAL CHARGING NETWORK FEE STRUCTURES

- Free network access with membership; cost to charge depends on individual location
- Monthly flat rate for all-you-can-charge
- Pay-as-you-go, per-minute or per-kWh charging fee
- Monthly membership fee + per-minute or per-kWh charging fee
- Session fee + per-minute or per-kWh charging fee + idle fee (to encourage you to disconnect and move your car when it's fully charged)

INSTALLATION CONSIDERATIONS

The following considerations apply whether you're installing a charging station or a simple 120 VAC outlet.

01 TALK TO YOUR UTILITY.

Research your utility's rate plans and do the math. Driving on electricity can be much cheaper than gasoline—when you choose the right rate.

Ask your utility for information on charging network services, licensed local contractors, and additional local resources such as incentives.

02 LOOK FOR LOCAL, STATE, AND FEDERAL INCENTIVES.

Some charging infrastructure incentives are available. See Additional Resources, page 14.

Consult your tax advisor or accountant.

03 DECIDE ON YOUR CHARGING NEEDS.

Level 1 (standard 120 VAC outlet or dedicated charging station)?

Level 2 (dedicated charging station)?

04 HIRE AN ELECTRICIAN AND ASSESS AVAILABLE POWER.

Level 1 = 120 VAC, dedicated 15- or 20-amp circuit.

If you're DIY, research local permitting requirements.

Level 2 = 240 VAC, dedicated 30- to 100-amp circuit (most are 40 amps; higher amperage accommodates higher power, faster chargers).

05 IF YOU WANT A LEVEL 2 HOME CHARGING STATION, CONSIDER THESE OPTIONS.

Physical size; some are quite large and heavy.

Wall-mount vs. pedestal.

Cable length; 25 ft. cable recommended.

Networked or non-networked.

Choose a UL-certified product.

06 CONSIDER COSTS.

$0 for existing dedicated 120 VAC outlet in your garage (nothing needs to be done).

$200 – $2,200 to purchase and install a Level 2 charging station; equipment and installation costs vary.

07 INSTALL STATION.

Charging stations can be hardwired or can use a plug. Pros and cons include portability, cost, adaptability, and appearance.

If possible, locate the station close to the electrical panel,for simplicity and savings.

Mount it so the cable can reach the front or back of a car. Charge ports are located in different places on every car, and you may want to charge outside your garage.

CONTACT YOUR UTILITY

Electric utilities are committed to serving customers and the growing numbers of electric vehicle owners. They typically offer special electric vehicle programs or rates. Some also have charging infrastructure incentives. Visit your local utility's website and call customer service to learn about electric vehicle programs in your community.

Over the last 10 years, University of California, Davis researchers have conducted a series of market studies about consumer awareness of electric vehicles. One survey of more than 4,000 electric vehicle drivers found that only 5% talked to their utility before buying their electric car. Another survey of car-owning households found fewer than 20% had heard about incentives available from their electric utility.

ADDITIONAL RESOURCES

YOUR LOCAL UTILITY
Contact your utility for information about electric vehicle rates, and local and regional resources.

EPRI
Consumer Guide to Electric Vehicles, March 2019
EPRI Product ID: 3002015368
https://www.epri.com/#/pages/product/3002015368/?lang=en-US

Interoperability of Public Electric Vehicle Charging Infrastructure, August 2019
EPRI Product ID: 3002017164
https://www.epri.com/#/pages/product/3002017164/?lang=en-US

ELECTRIC DRIVE TRANSPORTATION ASSOCIATION
Electric vehicle incentives
www.goelectricdrive.org/you-buy/incentives

Electric vehicle charging 101, products, station locator
www.goelectricdrive.org/owning-ev

U.S. DOE ALTERNATIVE FUELS DATA CENTER
www.afdc.energy.gov/fuels/electricity.html

Charging infrastructure
https://afdc.energy.gov/fuels/electricity_infrastructure.html

Charging infrastructure for multi-unit dwellings
https://afdc.energy.gov/fuels/electricity_charging_multi.html

Charging infrastructure for workplaces
https://afdc.energy.gov/fuels/electricity_charging_workplace.html

U.S. DOE VEHICLE TECHNOLOGIES OFFICE
https://www.energy.gov/eere/vehicles/vehicle-technologies-office

U.S. DOE AND U.S. DOT FUNDING AND FINANCING GUIDE FOR CHARGING STATIONS
https://goo.gl/J8sVsq

U.S. DOE EV EVERYWHERE WORKPLACE CHARGING CHALLENGE
www.energy.gov/eere/vehicles/ev-everywhere-workplace-charging-challenge

PLUG IN AMERICA
www.pluginamerica.org

VELOZ
Resources on workplace and multi-unit charging
https://www.veloz.org/pevc-resources/

PLUG-IN CARS
Guides on electric vehicles, buying, charging, etiquette, etc.
www.plugincars.com/guides.html

INSIDE EVS
Enthusiasts' blog with electric vehicle charging guide
https://insideevs.com/news/348050/electric-vehicle-charging-guide/

MYEV.COM
Enthusiasts' blog with numerous articles on charging
https://www.myev.com/research/

GLOSSARY OF TERMS

AC, DC

Alternating current, direct current. The U.S. electricity grid operates on AC. A typical household outlet is 110–120 VAC (volts alternating current). Large home appliances use 240 VAC. Electric car batteries operate on DC.

CHARGING LEVEL

The terms, AC Level 1, AC Level 2, and DC Fast describe how energy is transferred from the electrical supply to the car's battery. Level 1 is the slowest charging speed. DC Fast is the fastest. Charging rate varies within each charging level, depending on a variety of factors including the electrical supply and the car's capability.

CONNECTOR

The plug that connects the electricity supply to charge the car's battery. J1772 is the standard connector used for Level 1 and Level 2 charging. CCS or "Combo" connector is used for DC Fast charging most American and European model cars. CHAdeMO is the connector used to DC Fast charge some Japanese model cars.

EVSE

Electric vehicle supply equipment. An industry term for the charging appliance. Most people say chargers or charging stations. Charging station once referred to just the appliance but now is also being used to describe a location with multiple chargers (think: gas station).

EVSP

Electric vehicle service providers. Companies that make and operate charging station networks.

KW

Kilowatt. 1 kW = 1,000 watts of power. Relates to both the speed of power delivered from the electrical supply and the car's ability to accept that power. A car capable of 120 kW charging will charge faster than a car capable of 80 kW charging. Likewise, a 150-kW charging station delivers more power to a car's battery in less time than a 50-kW station. Home charging rates typically range from 1.4 kW–7 kW but may go up to 19.2 kW.

KWH

Kilowatt-hour. A unit of energy; the amount of power used in one hour. The metric electric utilities use to measure and bill for customers' electricity usage. Charging a car at home at power level 3.3 kW for one hour uses 3.3 kWh. Average U.S. household electricity rate is 12.5 cents/kWh and varies by region and time of day.

MW

Megawatt. 1 MW = 1,000 kW.

For more information about EPRI Electric Transportation research activities contact:

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