LOOK AT HISTORY OF ELECTRIC VEHICLES

Electric drive vehicles have been around for **a long time**. Early automobiles were **mostly electric or steam powered**. “Steamers” were the most common until the late 1800s.

In 1900, 38 percent of the cars sold were electrically powered; the others ran on **steam or gasoline**. **Starting the engine and changing gears were the most difficult things** about driving a gasoline-powered vehicle.

Driving electric vehicles is easy since it did not need to be manually cranked to get going and had no need for a transmission or change of gears.

These were the primary reasons the public accepted electric drive over the gasoline vehicles. **However, the internal combustion engine became popular because it allowed a vehicle to travel great distances**, achieve a decent high speed, and was much less expensive to buy.

■ From 2004 to present many hybrid vehicles have been produced and are being sold at great numbers.

■ In 2008, the Lotus Elise-based, Lithium Ion Tesla Roadster went on sale.

■ In 2010, Chevrolet introduced an “extended range” BEV called the Volt, this car was named car of the year in 2011.

■ In 2010, Nissan released a BEV called the Leaf and some mid-sized hybrids. Also, Mitsubishi released a BEV called the Mi-MEV.

■ In 2011, many new BEVs and plug-in hybrids were introduced including the TESLA Model S; Honda Fit; Ford Escape, Fusion, Focus, and C-MAX; Smart ED; and Toyota Prius Plug-in and a Tesla-powered Toyota RAV4.

■ All of these will make the near future the busiest years in electric cars since early in the twentieth century.

ZERO-EMISSIONS VEHICLES

BEVs use electrical energy stored in batteries to power the traction motors **(Figure 36–2)** . **BEVs have zero emissions**.

The only emissions related to a BEV are those released when coal, oil, or natural gas are used in power plants to generate the electrical energy required to recharge the batteries.

The use of hydroelectric, wind, sunlight, or other renewable sources to generate electricity would eliminate all emissions associated with EVs. It is impossible to have zero emissions from an internal combustion engine.

Fuel cell electric vehicles (FCEVs) are also zero emission electrically-powered vehicles but they rely on hydrogen as the fuel. There is no infrastructure for dispensing hydrogen, although fuel reformers can be used to extract hydrogen from other fuels. The use of reformers does cause the release of some emissions.

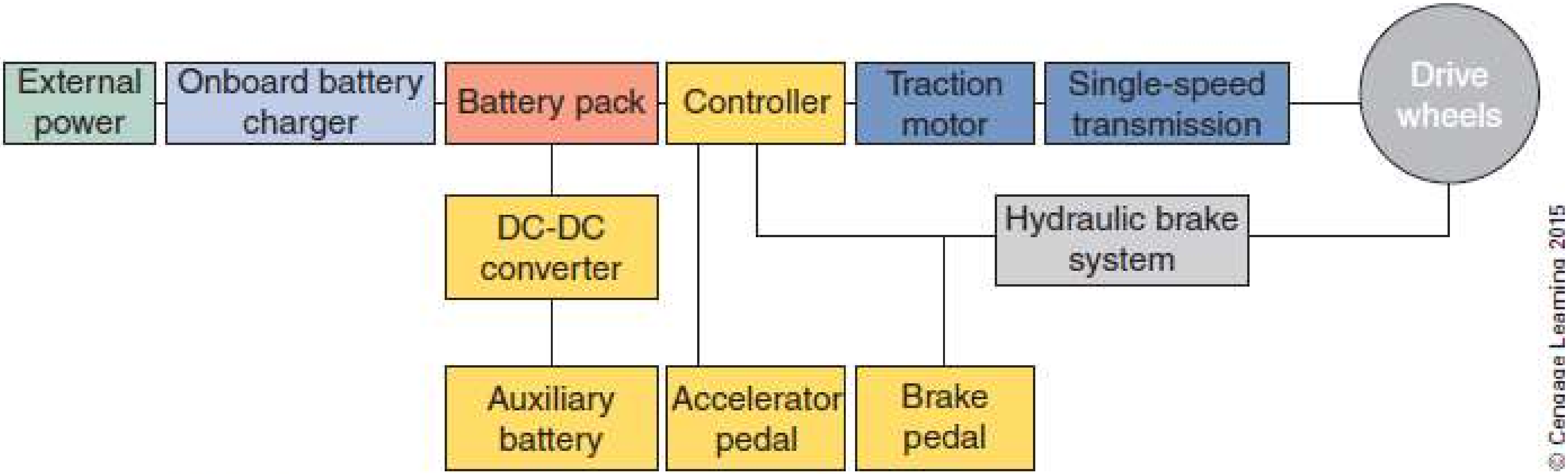


Figure 36-2 The major components of a BEV.

Because of the limited range, BEVs are ideal for commuting or traveling **within a limited area**. Studies have shown that 80 percent of commuters travel fewer than 40 miles per day; this is well within the range of most BEVs.

Cost

The initial cost of a BEV tends to be **higher than a conventional vehicle**. This is due to their limited availability and the cost of the batteries. Current estimates put the cost of a typical EV battery at $ 10,000 to $ 15,000 .

New batteries developed to extend the range of a BEV are, unfortunately, more expensive.

However, as more BEVs are produced and sold, their cost should decrease. The initial cost of an EV is reduced by a federal tax break that lowers the cost by $ 7,500 , and some states offer further subsidies.

	Chevy Volt	Mitsubishi MiEV	MiEV Sport	Tesla Roadster	Opel Flextreme	Aptera
Estimated Production Date	2010	2010	2010	2008	2010	2008
Estimated Price		30000		98000		26900 for EV, 29900 for Hybrid
Estimated Initial Production #	60000	1000		650		
Body Style	4-5 Passenger Sedan	4 Passenger Sedan	2+2 Passenger Sedan	2 Passenger Roadster	3 Door Liftback	2 Door
Vehicle Class	Compact Car	Sub-Compact Car	Sub-Compact Car	Compact Car	Compact Car	Micro Car
Battery Type	Li-Ion	Li-Ion	Li-Ion	Li-Ion	Li-Ion	
Peak Power	130 - 140 kW	47 kW	87 kW	185 kW	120 kW	
Continuous Power	45 kW					19 kW
Generator Power	54 kW	n/a		n/a	53 kW	12 kW
Recharge Time @ 110V	6 - 6.5 hours	13+ hours	17 hours	3.5 hours	6 hours	
0-60 time	8 - 8.5 seconds			4 seconds		< 10 seconds
Weight	3140 pounds	2380 pounds		2700 pounds		850 pounds
Full EV Range	40 miles	99 miles	124 miles	245 miles	34.17 miles	120 miles
Extended Range	640 miles	n/a	n/a	n/a	444 miles	600 - 700 miles
Peak Power / Weight Ratio	34.6	19.7		68.5		

The motor in an EV has few moving parts. The armature or rotor of the motor is the only moving part.

On the other hand **combustion engine has hundreds of moving parts**, each requiring clean lubrication and are subject to wear.

The rotor in a motor is normally mounted on sealed bearings and requires little, if any, additional lubrication throughout its life.

The **controller** and battery charger are electronic units and **require little or no maintenance.**

The batteries also are sealed and maintenance free.

All of these reasons explain why a BEV has very low maintenance costs.

The **true cost** of driving a BEV depends on the **cost of electricity per kilowatt/hour (kWh)** and the efficiency of the vehicle. Actual operating costs are reduced by making the cars lighter, more aerodynamic, and with less rolling resistance.

Disadvantages

Perhaps the biggest **disadvantage** of a BEV is the very **limited driving range**.

The **typical range** between recharging the batteries is **50 to 150 miles**. Although some new battery designs have extended this range, long-distance travel in a BEV is still not practical.

It is important to understand that a battery's size and amount of power it stores does not directly determine the range of an EV.

Remember, the **smallest, lightest, and most aerodynamic** electric vehicles will provide the longest range, with the same battery.

Long recharge times are also a problem.

In the **problem of where they can be recharged**. If the owner is at home, the charger can be connected to the electrical system of the house.

Most EV manufacturers offer special home charging stations that shorten the required charge time.

MAJOR PARTS

The basic systems in a BEV are:

- **a high-voltage battery pack,**
- **battery management system,**
- **the motor(s) and supporting system,**
- **12-volt system:** supplies the electrical power for the vehicle's accessories.
- **converter and/or inverter:** convert AC to DC and DC to AC electricity and to charge the 12-volt battery and to provide power to the low-voltage systems
- **the driver's displays and controls (Figure 36–3)** .

The propulsion system has a traction motor that provides the power to rotate the drive wheels and a controller to control the power output of the motor.

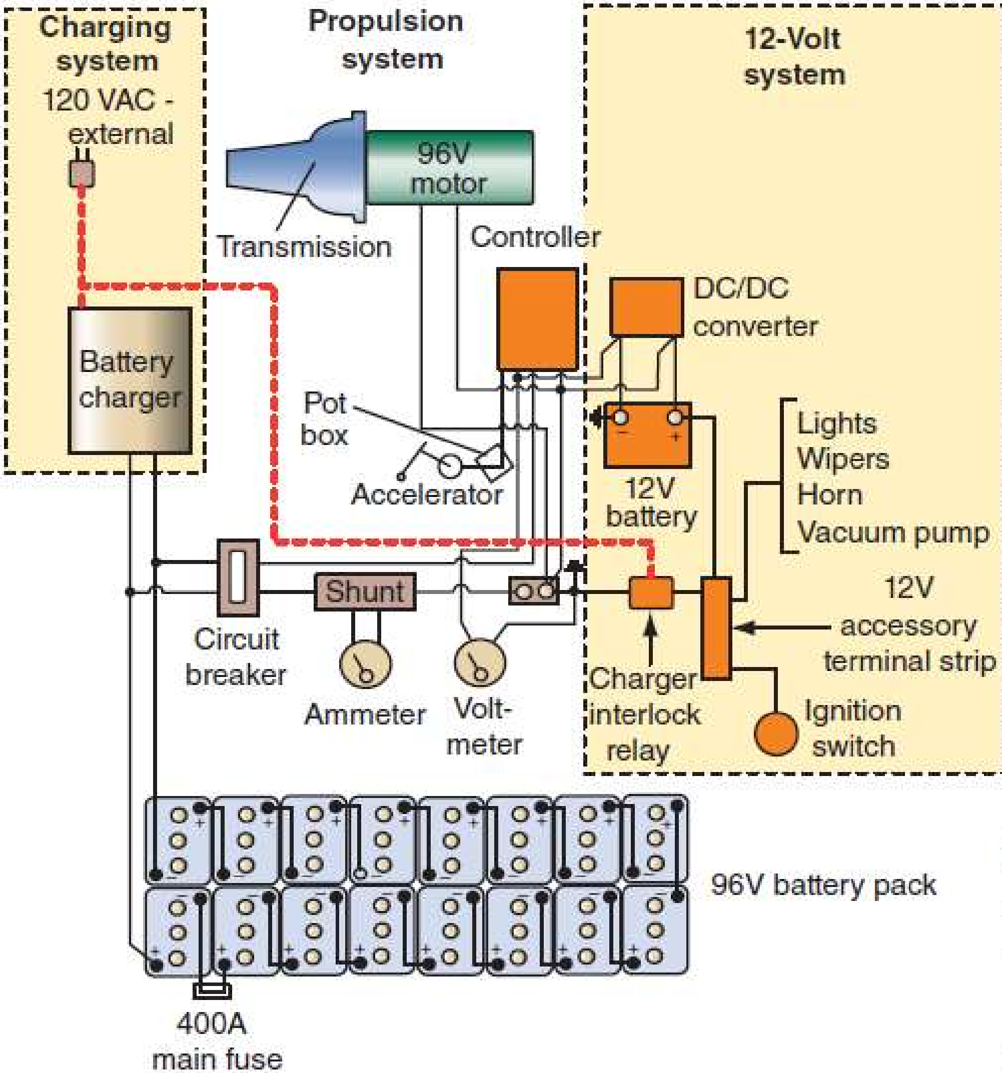


Figure 36-3 A basic wiring diagram of an electric vehicle.

Energy and Power

You may recall that **energy is the ability to do work** and **power is the rate at which work is done**.

A common automotive **expression of power is horsepower**. Although this term is used when discussing the motor in an electric vehicle, the correct way to express power is using the term kilowatt.

One **kilowatt (kW)** is the international unit to **measure power (not only electrical)**; a kilowatt is 1,000 watts.

One kW equals 1.34 horsepower and 746 watts equals 1 horsepower. Therefore, a 149 kW motor can provide about 200 hp .

Electric motors provide a maximum torque when it is spinning at zero rpm. So, it is very hard to compare the power output of an electric motor to a gasoline-powered engine that produces a maximum amount of torque at a much higher engine speed **(Figure 36–4)** .

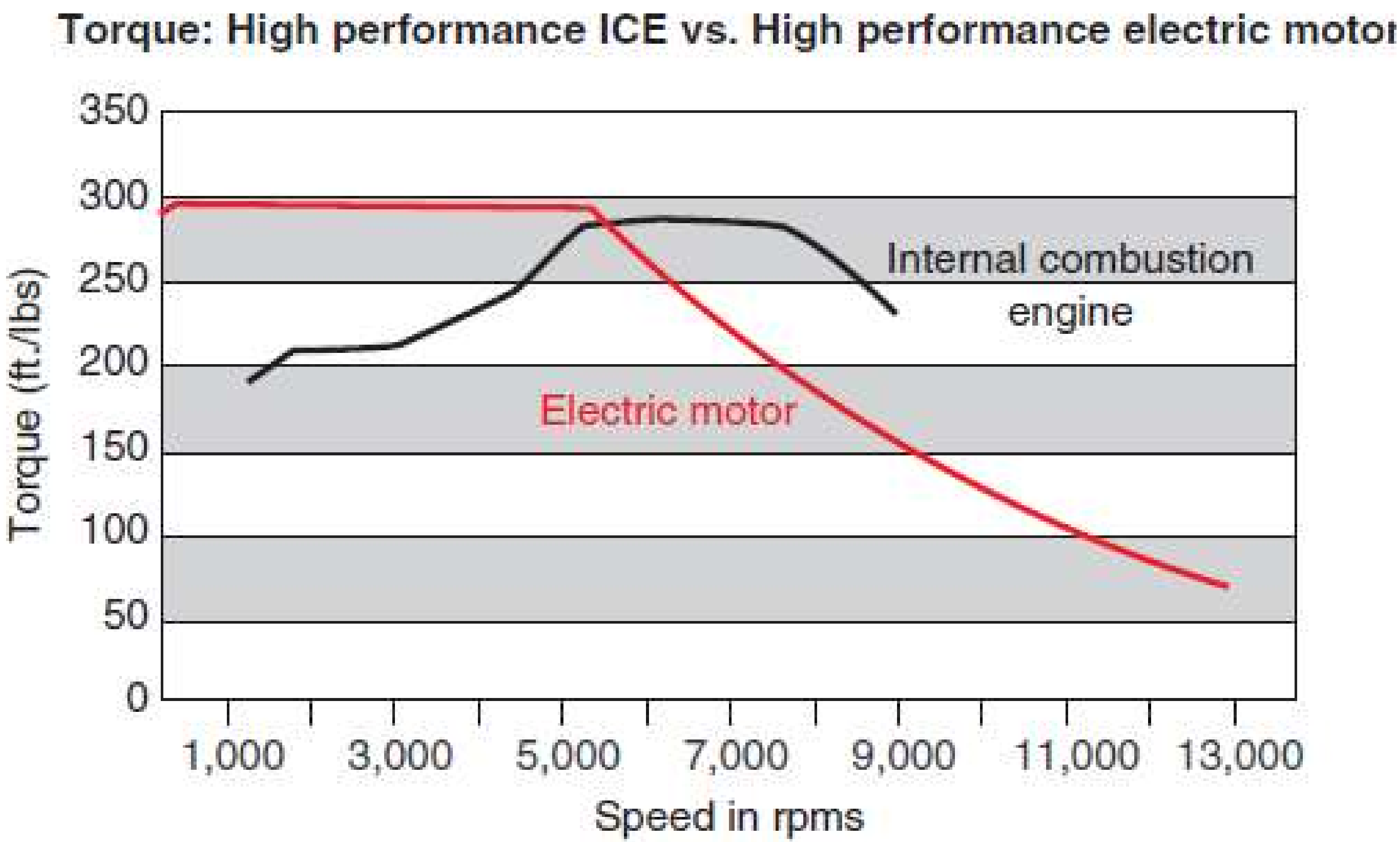


Figure 36-4 A comparison of the amount of torque produced by a gasoline engine and an electric motor.

The **power rating of an electric motor** (or gasoline engine) indicates how quickly energy can be changed into work, such as acceleration.

A motor relies on the energy stored in a battery or some other source. **The amount of energy available is expressed in kilowatt hours (kWh).** Kilowatt hours express what can be accomplished by 1 kilowatt acting for 1 hour.

For example, when a light bulb with a power rating of 100W has been on for 1 hour, it has used 100 watt-hours (0 .1 kWh) .

This is the same amount of energy used to keep a 50W light bulb on for 2 hours.

When comparing systems and the available power of a battery, it is important that a battery's rating is looked at in regards to the system's voltage. If a battery has a rating of 100 amp-hours and the battery provides 12 volts, the amp-hours should be multiplied by the voltage to determine the total energy available. In this case, the energy source can provide 1,200 watt-hours (1 .2 kWh) .

So if we look at a 300V battery pack rated at 24 kWh , the battery can provide 80 amps at 300 volts for 1 hour.

Keep this in mind when looking at the ratings of batteries and battery chargers. Also, do not be fooled by the manufacturers' estimates.

Nissan says the 24 kWh pack in a Leaf provides for a 100-mile drive range.

That means 240 watts are needed to provide enough energy for 1 mile of travel. So, theoretically the battery should supply enough energy for 100 miles of travel. This number is close to what the EPA has estimated as the driving range of the Leaf **(Figure 36–5)** .

The traction motors are either AC or DC motors and are specifically designed for this use.

Most production BEVs use AC motors and FCEVs (Fuel Cell Electric Vehicles) and many conversion EVs use a DC motor.

The latter is a consequence of cost. DC motors can be powered directly by the batteries, whereas AC motors require inverters to change the DC voltage stored in the batteries into the AC required by the motors.

FCEVs have a DC motor because the electricity generated is not AC; therefore, there is no need for an inverter or other similar conversion equipment.

The cost of high-voltage batteries has declined through the years.

For example, the Nissan Leaf has a 24 kWh battery. If batteries cost $ 1,000 per kWh, the battery in a Leaf would cost $ 24,000 and would make it nearly impossible for Nissan to sell the car for $ 32,800 before incentives.

At $ 400 per kilowatt hour, the battery would only cost $ 9,600 .

This has been a focus of the U.S. Department of Energy that has set a goal of providing car batteries for $ 250 a kilowatt hour.

Electric Motor

In most EVs, there is **no transmission** because the rotary motion of the motor can be applied directly to the differential gears.

A motor is capable of providing enough torque throughout its speed range to move the vehicle without torque multiplication. With an electric motor, instant torque is available at any speed.

The entire rotational force of a motor is available the instant the accelerator pedal is pressed. Peak torque stays constant to nearly 6,000 rpm, and then it begins to slowly decrease.

The wide torque band eliminates the need for multispeed transmissions. There is no need for a reverse gear either, since by switching the polarity of the stator will cause the rotor to turn in reverse. The absence of a typical transmission saves weight and makes the power train much less complex.

Controller

The controller in a BEV controls the voltage and current to the traction motor(s) in response to the driver’s input.

The controller may also reverse the current flow to the motor when reverse gear is selected. In electric vehicles with DC motors, a simple variable-resistor-type controller can be used to regulate the speed of the motor.

With this type of controller, full current and power is drawn from the battery all of the time.

At slow speeds, when full power is not needed, a high resistance in the resistor reduces current flow to the motor. With this type of system, a large percentage of the energy from the battery is wasted as an energy loss (heat) at the resistor. High speeds are the only time all of the available power is used.

Modern controllers adjust motor speed through pulse width modulation (PWM).

Pulse width is the length of time, in milliseconds, that a component is energized.

Controllers rely on transistors to rapidly interrupt the flow of electricity to the motor.

High electrical power (during high speed, acceleration, and/or heavy loads) is available when the intervals that the current is stopped are short.

During slow speeds, little power is needed and the intervals of no current flow are longer **(Figure 36–6)** .

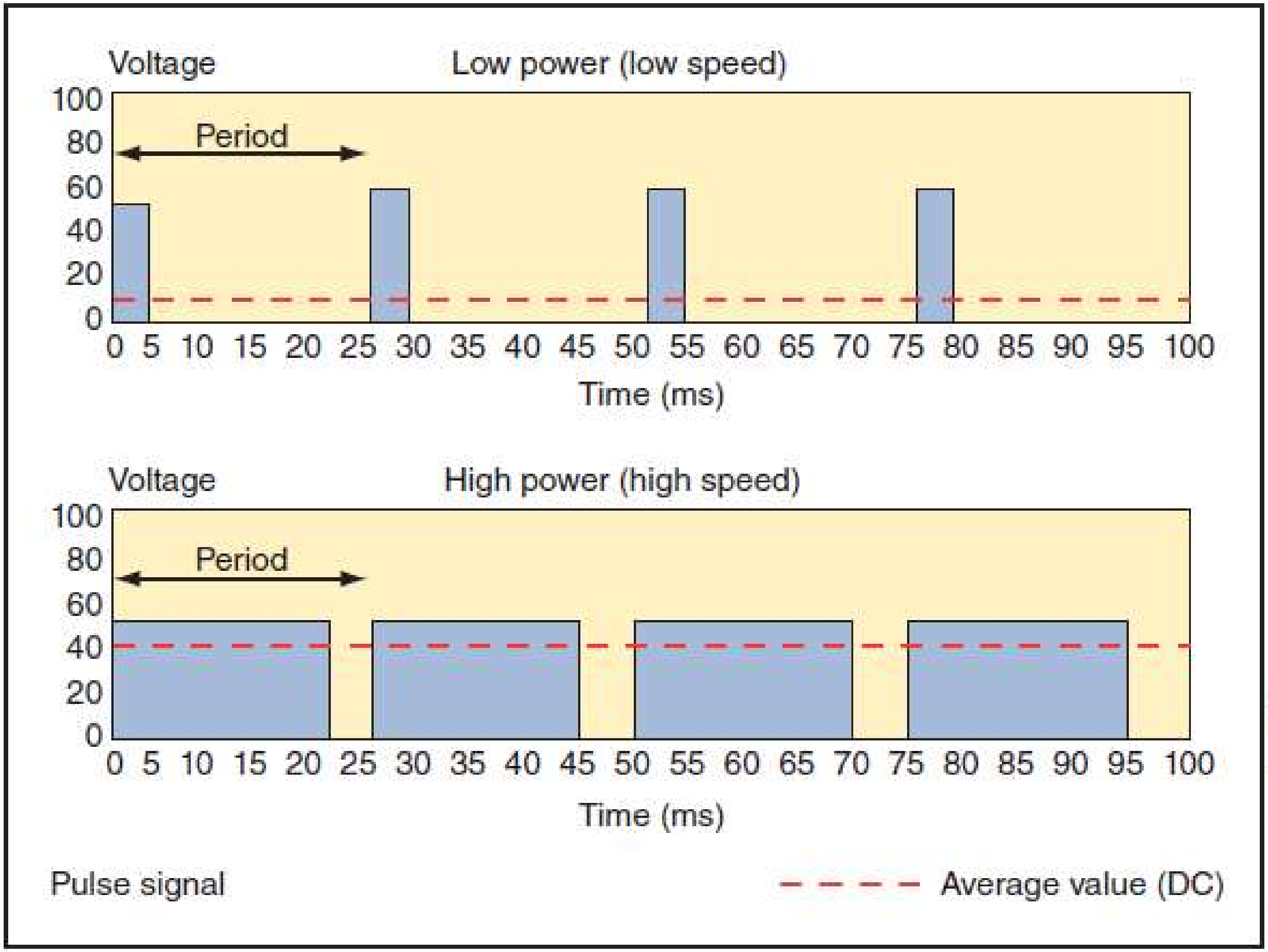


Figure 36-6 An explanation of pulse width modulation at low and high speeds.

Inverter/Converter

An AC power inverter converts the battery's DC voltage into three-phase AC voltage to power the traction motor.

The output voltage varies according to the demands of the driver and the vehicle. Normally the inverter is controlled by an electronic control module.

The output from a typical inverter is constantly being calculated using input signals from the accelerator pedal, the motor's shaft speed sensor, the motor's direction sensor, and the brake pedal.

The inverter is liquid-cooled and the heat from the inverter can be used to supplement the passenger compartment's heater to save energy. This is done automatically whenever the controls are set for heat.

BATTERY CHARGING

Refueling a BEV simply means charging the batteries. Recharging involves connecting a battery charger to a source of electricity and connecting the charger to the battery pack.

Battery chargers **(Figure 36–7)** may be internal (in the vehicle) or external (at a fixed location).

There are advantages and disadvantages to both. An on-board charger allows the batteries to be recharged wherever there is an electrical outlet.

The disadvantage of on-board chargers is their added weight and bulk. To minimize this, manufacturers normally equip the vehicles with low power chargers that require long charge times.

External chargers, however, force the driver to charge the batteries at specific locations but offer more power and decrease the time required to charge the batteries. Some BEVs with offboard chargers also have a convenience charger. These onboard chargers plug into standard 110-volt outlets and allow the driver to recharge batteries wherever electricity is available.

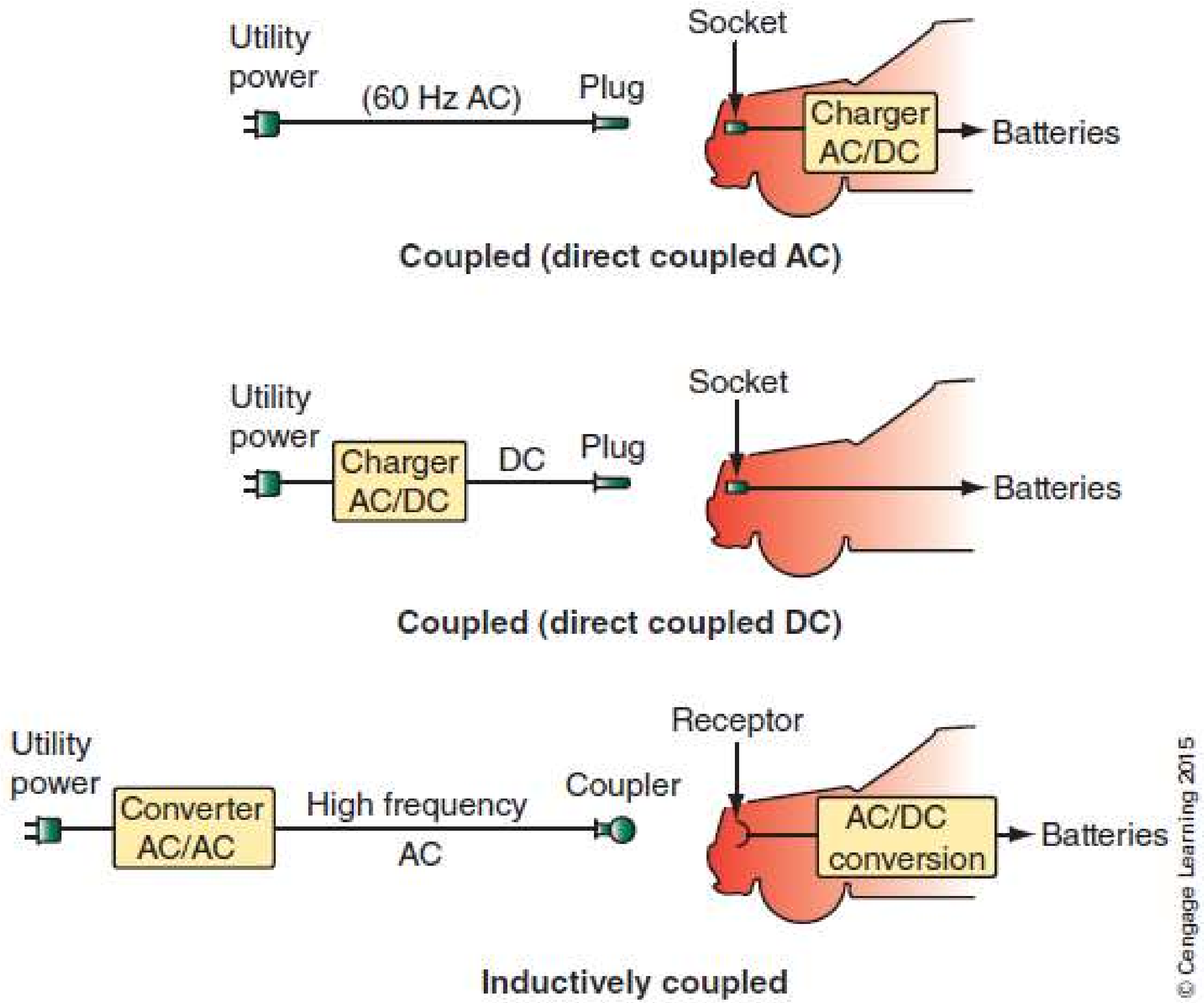


Figure 36-7 EV battery chargers may be internal (onboard) or external (offboard).

Most EVs have an on-board charger that uses a rectifier circuit to transform AC from the electrical grid to DC, which is necessary for recharging the battery pack.

The rectifier can only handle a certain amount of power and develops a great amount of heat while it is changing AC to DC.

Rectifiers can be built to handle more power and heat, but they would cost quite a lot.

Based on these concerns, most conventional charging stations in North America and Japan are based on 240V/30A service.

This power level seems to be a safe limit for the rectifiers. But, charging at these levels takes several hours to recharge the battery pack.

The required time varies with the size and type of battery and battery charger.

A solution to these problems is to use an external charging station capable of delivering DC directly to the vehicle's battery pack.

Doing this would call for dedicated chargers at permanent locations. These new chargers may be able to recharge a battery in less than 20 minutes.

They use sophisticated electronics to monitor the cells and regulate the charging voltage and current.

Being able to quickly charge the batteries would certainly make an electric vehicle more practical.

The charging setup using high voltage and high-current is called a DC Fast Charge and is also referred to as level-3 charging **(Figure 36–8)** .

VOLTAGE TYPE	CHARGE LEVEL	MAX. VOLTAGE	PEAK CURRENT
AC	1	120 VAC	16A
AC	2	240 VAC	32A (2001)/ 80A (2009)
DC	1	450 VDC	80A
DC	2	450 VDC	200A
DC	3	600 VDC	400A

Figure 36-8 Current standards for the various charging levels.

Charger to Vehicle Connectors

There are two basic ways a BEV is connected to an external source of electricity for charging.

One is the traditional plug, called a conductive coupling. The coupling is plugged into a receptacle on the vehicle where it connects into the wiring for the batteries.

The other type of coupling is called an inductive coupling. Inductive charging transfers electricity from a charger to the vehicle using magnetic principles. To charge the batteries, a weatherproof paddle is inserted into the vehicle's charge port **(Figure 36–9)** .

The paddle and charge port form a magnetic coupling. The external charging unit sends current through the primary winding inside the paddle. The resulting magnetic flux induces an alternating current in the secondary winding, which is in the charge port. The connection is basically a transformer with the primary winding in the paddle and the secondary winding in the vehicle.

The induced AC is then converted to DC (within the vehicle) to recharge the batteries.

There is no metal-to-metal contact between the charge paddle and the charge port of the vehicle.

This system provides a safe and easy-to-use way to recharge the batteries.

Inserting the paddle begins the charging process. The insertion of the paddle completes a communication link between the charger and the vehicle. The charger displays what percent of charge remains in the batteries and an estimate of the time needed to fully charge the batteries.

This link also allows the charging unit to enter into self-diagnostics and prevents the vehicle from being driven while the paddle is inserted in its port. If the charging cable becomes damaged or cut, power will shut off within milliseconds. The charging process ends immediately after the paddle is removed from the port.

Conductive Charging With a conductive charger, a connector safely makes the link between the power supply and the vehicle's charge port. The connector makes a weatherproof direct electrical connection to the vehicle's charge port.

The connector has multiple pins that carry data. This data is used to control the action of the charger based on the conditions of the battery pack. External chargers are available in many different sizes and can be wall or pedestal mounted **(Figure 36–10)** .

Conductive charging can be accomplished with a fuel nozzle looking connector called the ODU **(Figure 36–11)** .

The connector has many round male pins that mate to female ends in the vehicle. Similar to adding fuel to the vehicle, the connector is placed into an opening on the vehicle and refueling or recharging can take place.

Figure 36-10 An on-the-wall charging unit with a special circuit box (load center) installed to handle the high voltage.

Figure 36-11 An ODU connected to an electric vehicle.

Recharging Standards and Regulations

Like nearly everything designed for an automobile, there are standards and regulations that pertain to charging a high-voltage battery pack.

The most recognized standard is the North American standard for electrical connectors for electric vehicles as defined by the Society of Automotive Engineers (SAE). This standard is referred to as the "SAE Surface Vehicle Recommended Practice J1772, SAE

Electric Vehicle Conductive Charge Coupler." Basically this standard covers the basic physical, electrical, communication protocol, and performance requirements for an EV's conductive charge system and coupler. The purpose of the standard is to ensure EVs from different manufacturers will not need special or unique chargers or charging connectors.

With the advent of improved chargers, and the desire to charge with AC and DC voltage, new specifications for the J1772 ODU have been released.

Using AC and DC at the same time to charge a battery is faster than the previous regulated process.

Therefore the new J1772 standards allows for a single inlet in the vehicle and a single plug to be used for both AC and DC charging.

The new J1772 standard incorporates AC Levels 1 and 2 (up to 80 amps), and DC Levels 1 and 2 (up to 200 amps).

The new “combo” connector is similar to the first-generation J1772 plug but also has pins to fit into the lower portion of the inlet.

The first-generation J1772 plug fits into the upper part of the inlet, while DC charging takes place across two dedicated pins across the bottom of the connector.

Above these pins is a round receptacle that has five pins **(Figure 36–13)** . These pins complete the circuit from the electric grid to the vehicle through AC power Line 1 and AC power Line 2 pins and a designated ground pin.

The two other pins are for Proximity Detection and the Control Pilot. The Proximity Detection feature prevents the car from moving while it is connected to the charger.

The Control Pilot is the communication line used to transfer information between the charger and vehicle in order to safely and efficiently charge the battery.

Figure 36-13 The female connections for a SAE J1772 connector.

When the male and female halves of the connector are not mated, there is no voltage at the pins, and charging does not begin until it is commanded by the vehicle.

This combination connector allows for DC-fast charging and has been endorsed by Audi, BMW, Chrysler, Daimler, Ford, General Motors, Porsche, and Volkswagen.

Their goal is to provide a way for consumers to charge their EVs in 15 to 20 minutes.

CHAdeMO Protocol The new SAE standard offers a number of advantages over the competing CHAdeMO standard **(Figure 36–14)** .

However, CHAdeMO (short for "charge and move") is already well established in Japan, and is also used by most existing vehicles and chargers in the North American market.

In spite of CHAdeMO's current dominance, there is strong support for J1772. The connector currently used for DC-fast charging on the Nissan Leaf and Mitsubishi i vehicles is based on the CHAdeMO standard.

Some Asian EV models have two vehicle electric inlets, one for CHAdeMO DC charging and one for J1772 AC charging **(Figure 36–15)** .

Figure 36-14 A CHAdeMO on-vehicle connector.

Figure 36-15 The Nissan Leaf has receptacles for a CHAdeMO and SAE J1772 connector.

Charging Precautions

There are three primary things that affect the required time to recharge the batteries:

- the current state of charge of the battery,
- the chemicals used inform the cells of the battery,
- and the type of charger used.

Each EV has a specific charging procedure. These procedures vary with the type of charger, charger coupling, and battery. Always follow the procedure for the vehicle being worked on. The following are some general guidelines to follow:

■ Make sure the gear selector is in the park position and the parking brake is applied before charging.

■ Before charging, make sure the motor switch is off and the key is removed.

■ To avoid getting an electric shock, never operate the charger with wet hands.

■ Avoid charging under high temperatures or direct sunlight.

■ Never touch the terminals of the conductive terminals on the vehicle or coupler; you may get an electric shock.

■ Do not modify the charge coupler.

■ The charge coupler should be firmly installed without any tension on the cable.

■ If the charge coupler is damaged, repair or replace it as soon as possible.

■ Make sure water, dirt, or other foreign objects do not enter the charge port on the vehicle.

■ Do not disconnect the charge coupler until the batteries are fully charged, unless it is necessary to prematurely stop charging.

ACCESSORIES

Some systems, such as the radio, lights, and horn, operate the same way as they do in a conventional vehicle.

Other systems, such as the power steering and power brakes, require additional small electric motors, which have an impact on the vehicle’s driving range.

Because all accessories and auxiliary systems operate on electricity, their electrical power needs reduce the capacity of the battery.

HVAC

To meet federal safety standards, all vehicles must be equipped with passenger compartment heating and windshield defrosting systems.

Vehicles with an internal combustion engine use the heat of the engine’s coolant to warm the passenger compartment. In a BEV, there is no engine and therefore there is no direct source for heat. The heat must be provided by an auxiliary heating system. Some electric vehicles use an electric resistance heater with a fan.

Other BEVs have liquid heaters. Water, or a mixture of water mixed with ethylene glycol, is held in a tank. The liquid in the tank is kept heated by a resistive heating element submerged in the tank.

When the driver turns on the heating system, a small pump circulates the heated liquid through a heater core in the passenger compartment. A fan moves air over the core to provide heated air.

BEV air-conditioning systems also have a significant impact on the driving range. In many cases, the air-conditioning system uses a high-voltage motor to rotate the compressor. Obviously, the energy used to power the air conditioning puts a drain on the battery pack.

The amount of energy consumed by the air-conditioning system depends on how often it is used, the outside temperature, and the selected temperature for the passenger compartment.

Power Brakes

Many power brake systems use engine vacuum and atmospheric pressure to multiply the effort applied to the brake pedal during braking. Because there is no engine in a BEV, there is no direct vacuum source. However, normal vacuum assist power brake systems can be used if fitted with an electric vacuum pump.

These pumps are similar to those used on diesel engine vehicles. The pump may be connected to a storage tank. The tank reduces the time the pump needs to operate and therefore minimizes the effect the pump has on driving range.

Another type of power brake system uses hydraulic pressure, from a pump, to reduce the pedal effort required to apply the brakes. Some BEVs use an electric pump to provide the necessary hydraulic pressure **(Figure 36–16)** .

These systems are called electro-hydraulic brake systems. Because both types of power brake systems for BEVs operate on electrical power, brake boost is available at all times.

Figure 36-16 The master cylinder and pump assembly for an electro-hydraulic brake system.

Power Steering

Hydraulic pressure is often used to reduce steering effort. This pump can be driven by an electric motor, which is how some BEVs are equipped.

The control for the pump can be programmed to provide more assist at lower speeds, and less at higher speeds. The system can also be programmed to only run the pump when it is needed; this reduces the effect power steering has on the driving range. These systems are called electro-hydraulic steering systems.

Many power steering systems are purely electrical and mechanical systems. An electric motor moves the steering linkage. These systems are programmable and the energy consumed by the motor depends on the amount the steering wheel is turned. While driving straight, the motor may not run. However, when the steering wheel is fully turned, the motor is drawing its maximum current.

DRIVING A BEV

Driving a BEV is like driving any other vehicle but with some notable exceptions. There is still a steering wheel, a brake pedal, and an accelerator pedal. A BEV typically has adequate acceleration and can travel at highway speeds.

The biggest difference for the driver is that attention must be paid to the consumption of energy. Failure to minimize consumption and carefully plan travel routes can lead to reduced power and a need to recharge the batteries at inconvenient locations or times. If the batteries are not charged, the vehicle will not move.

Starting

The biggest adjustment a driver needs to make when preparing to drive a BEV is starting it or getting it ready for action. A BEV has no noise or vibration when it is ready to go.

The driver must look at the instrument cluster to determine it is ready. Make sure the gear lever is in the PARK position and that the parking brakes are on.

The accelerator should never be depressed during starting.

The ignition (motor) switch has several positions:

- One is “lock,” during which the traction motor is off and the steering wheel is locked. The key can be removed only at this position.
- “Accessories” allows some accessories to work but the traction motor is off.
- “START” actually gets the traction motor ready to work,
- “ON” is the normal position for driving.

Never leave the switch in the ON position when the vehicle is not in use.

To turn on the traction motor, turn and hold the motor switch to START with the brake pedal depressed until the READY light in the instrument cluster comes on **(Figure 36–17)** .

On some vehicles, a buzzer will sound when this happens. Once the READY lamp is lit, the motor switch can be released to allow it to move to the ON position.

At this point, the traction motor will run when the accelerator is depressed and all accessories are ready to operate.

If the READY light does not illuminate during the start process, there is a problem with the traction motor or its circuit, or the auxiliary battery is discharged

Figure 36-17 The instrument panel displays for a typical EV.

Driving and Braking

Most BEVs have a single-speed automatic transmission and the gearshift lever has five positions **(Figure 36–18)** .

Normally the shift lever can only be shifted out of “P” when the motor switch is in the ON position.

When moving out is important that the accelerator is not depressed when shifting gears. Doing this can cause the vehicle to unsafely and quickly move and can cause damage to the motor. Once the shift lever has been moved and with the brake pedal still depressed, the parking brake can be released.

To begin moving, press the accelerator. Drive normally with the realization that the accelerator is the only thing that controls vehicle speed. When the accelerator is released, vehicle speed will decrease because the wheels are now turning the motor that just became a generator.

To back up, bring the vehicle to a complete stop. Then depress the brake pedal and move the shift lever into the “R” position.

It is important to keep in mind that a BEV can accelerate just as quickly in reverse as it does in drive.

However, it is more difficult to steer any vehicle in reverse therefore the accelerator should be gently pressed when backing up.

To park and shut down the vehicle, come to a complete stop. Then apply the parking brake. While depressing the brake pedal, move the shift lever to the “P” position. Now turn the motor switch to the LOCK position and remove the key.

Maximizing Range

The driving range of a BEV is reduced by cold weather (requiring use of heater), warm weather (requiring use of the air conditioner), and the condition and age of the battery. There are certain other things a driver can do to extend the range and the life of the batteries.

■ Avoid high-speed driving. Maintain a moderate speed on highways.

■ Avoid driving up inclines.

■ Avoid frequent speed increases or decreases. Attempt to drive at a steady pace.

■ Avoid unnecessary stopping and braking.

■ Avoid full throttle acceleration, accelerate slowly and smoothly.

■ The vehicle should be well maintained, including proper tire inflation pressure.

■ Unnecessary weight in the vehicle will shorten the driving range.

FORD FOCUS

The Ford Focus Electric **(Figure 36–19)** uses a 23 kWh, liquid-cooled lithium-ion battery pack that provides an all-electric range of about 100 miles (160 km) .

It relies on a synchronous PM electric motor rated at 107 kW (143 h p) and 184 ft.-lb of torque. The motor's output is transferred to the front wheels through a single-speed transmission.

The L-shaped battery pack is located under the rear seat and between the rear wheels. The battery uses a liquid cooling and heating thermal management system to precondition and regulate the temperature of the battery. The thermal management system heats or chills a coolant before passing it through the battery's cooling system.

The Focus has a 6 .6 kW on-board charger. A full recharge is possible after 3 to 4 hours. This requires plugging into Ford's 240 volt, 32 amp Level 2 home recharging unit with a J1772 connector **(Figure 36–20)** .

The Focus also is equipped with a 120-volt cord that allows the charger to be connected to a standard household outlet. At 120 volts, the battery pack can be recharged in close to 20 hours.

Figure 36-20 An at-home high-voltage charger for a Focus EV.

The instrument cluster allows the driver to monitor energy consumption. There is a smartphone application that allows the driver to remotely track the car's charging status.

Ford also provides a 2.5 kilowatt rooftop solar panel system through the solar system manufacturer SunPower.

The solar panels can produce an average of 3,000 kWh annually, theoretically enough to accommodate a customer who drives 12,000 miles a year.

The charging port is in the left front fender **(Figure 36–21)** . The port illuminates when the charger's cord connector is plugged into the charge port. A blue light indicates GO and that the charger is connected and charging.

Figure 36-21 The charging port on a Focus is on the left front fender.

Figure 36-22 A Nissan Leaf.

NISSAN LEAF

The Nissan Leaf **(Figure 36–22) is a true ZEV with zero tailpipe emissions**.

It is rated at **106 MPGe for city driving** and 92 MPGe on the highway and 99 MPGe for combined city and highway driving.

The Leaf is equipped with an AC synchronous motor that can provide up to 107 hp (80 kW) and 207 pounds-feet of torque to the front drive wheels. The EPA estimates the driving range for a Leaf with a full battery is 73 miles (117 km) , although Nissan advertises a range of 100 miles (161 km) .

Power from the motor moves through a single speed reducer-type transmission. But through electronic controls,

there are two optional forward drive modes:

- **Drive** provides quicker acceleration, but uses a great amount of the battery's reserve.
- **Eco** extends the driving range by limiting acceleration and reducing the power to the climate control system. It also provides additional brake regeneration, causing the car to decelerate more rapidly, but also adding electrons to the battery.

The battery is a 24 kWh lithium manganese (Li-Ion) that is capable of delivering up to 90 kW of power.

The battery pack **(Figure 36–23)** is made up of 48 modules and each module contains four laminated flat cells, arranged in three stacks. The 192 stacked laminar cells have lithium manganate cathode. The battery weighs about 660 pounds (272 kg) , and is located under the floor pan directly beneath the front and rear rows of seats. The battery pack is air cooled (and heated when necessary) to protect the cells.

Figure 36-23 The battery pack in a Leaf.

Charging time varies with the type of charging used. Customers can purchase a 240V home charging station through Nissan. Some Leaf models have a Quick Charge Port with a 3.3 kW on-board charger. With this charger, the battery can be fully recharged by a 220/240 volt 30 amp within 8 hours.

The Leaf ’s charging port at the front of the car has two charging inlets **(Figure 36–24)** . One is a standard J1772 connector for Level 1 and 2 recharging. The other is a Level 3 DC connector that uses the CHAdeMO protocol.

Figure 36-24 The Leaf's charging port at the front of the car and the two charging inlets.

The Leaf also has an auxiliary 12-volt lead-acid battery that provides power for the basic systems and accessories in the car, such as the sound system, headlights, and windshield wipers.

An interesting touch is that some models of the Leaf have a small solar panel on the rear spoiler **(Figure 36–25)** to help trickle charge this auxiliary battery.

Figure 36-25 The solar panel built into the spoiler on some models of the Leaf.

Telematics

The Nissan Leaf uses an advanced telematics system called Carwings. Carwings is connected any time the car is within the range of a cell tower and provides information to the driver, such as the car's position, remaining range, and the location of charging stations available within that range.

The system also monitors and compiles information about distances traveled and the amount of energy consumed **(Figure 36–26)** . It also provides daily, monthly, and annual reports of those and that information can be viewed on the car's digital screens.

Through Carwings, cell phones can be used to remotely turn on the air conditioner and heater and reset all charging functions.

Figure 36-26 The "carwings" display in a Leaf.

Pedestrian Sounds

Because BEVs emit very little noise while they are moving, the Leaf is programmed to emit digital warning sounds, one for forward motion and another for reverse, to alert pedestrians, the blind, and others that it is moving close to them.

This is called the Vehicle Sound for Pedestrians (VSP) system. This sound system moves from 2.5 kHz at the high end to a low of 600 Hz , which makes it audible for all age groups.

The sound stops when the Leaf reaches 19 mph and begins again when the Leaf slows to less than 16 mph . The VSP system is controlled by a computer and synthesizer and the sound is emitted from a speaker in the driver's side front wheel well.

MITSUBISHI i-MiEV

The Mitsubishi i-MiEV (*Mitsubishi innovative Electric Vehicle*) is an EV hatchback **(Figure 36–27)** .

The car has a PM synchronous motor mounted on the rear axle. The water-cooled 49 kW motor can provide 66 hp and 145 pound-feet of torque.

The motor is placed above the rear axle and the 16 kWh lithium-ion battery pack and the motor control unit is under the floor. The motor's output is sent to the rear wheels through a single-speed fixed reduction transmission.

The EPA initially rated this Mitsubishi capable of providing a combined fuel mileage rating of 112 MPGe. The estimated driving range in the city is 98 miles (158 km) .

The 16 kWh SCiB battery pack uses lithium-titanate oxide in the anode, which provides increased safety and decreased charging times.

The battery pack is made up of two 4 - cell modules placed vertically at the center of the pack and ten 8 - cell modules placed horizontally, these are connected in series. These 88 cells provide 330 V .

Figure 36-27 A Mitsubishi i-MiEV (Mitsubishi innovative Electric Vehicle).

It is estimated that it takes 22 hours to recharge the battery with a 110 –volt power supply and 7 hours with 220 volts.

And, if the Level 3 480 -volt quick-charging station with CHAdeMO charging technology is available, the battery can be recharged to about 80 percent of full capacity in about 15 minutes, about 50 percent in 10 minutes, and about 25 percent in 5 minutes.

This is much less than the required charge time for a typical Li-Ion battery charged under the same conditions. The SCiB also generates little heat while recharging, eliminating the need for a complex system, and power robbing system, to cool the battery module.

The system offers three distinct driver-selected drive modes: “D,” “Eco,” and “B.”

Each has been designed to provide the best performance for different driving conditions.

- D mode is the default position and is the best mode for driving on highways and interstates.
- The Eco mode limits the motor’s output to increase the range by decreasing the amount of power available for acceleration.
- The B mode adds more regenerative braking when the car is coasting to a stop or braking on downhill stretches to more aggressively

recharge the battery.

TESLA

Tesla Motors in California is an independent auto manufacturer. Their focus is to manufacture high-technology EVs.

The company has been strongly supported by its founder and other investors, and is dedicated to providing fun and practical EVs.

This effort was further helped by the U.S. government when Tesla was granted investment dollars. Tesla's first car available to the public was its Roadster.

This was actually a proof of concept vehicle, as it demonstrated the advantages and disadvantages of an EV.

The Tesla Roadster was a BEV produced by Tesla Motors in California **(Figure 36–28)** . It was a mid-engine, rear-wheel drive car based on the Lotus Elise.

220 volts. And, if the Level 3 480-volt quick-charging station with CHAdeMO charging technology is available, the battery can be recharged to about 80 percent of full capacity in about 15 minutes, about 50 percent in 10 minutes, and about 25 percent in 5 minutes. This is much less than the required charge time for a typical Li-Ion battery charged under the same conditions. The SCiB also generates little heat while recharging, eliminating the need for a complex system, and power robbing system, to cool the battery module.

Figure 36-27 A Mitsubishi i-MiEV (Mitsubishi innovative Electric Vehicle).

Figure 36-28 The Tesla Roadster is an EV based on the gasoline-powered Lotus Elise.

It had a 248 hp (185 kW) 3 - phase 4 - pole AC induction motor **(Figure36-29)** powered by a 53 kWh lithium-ion battery.

The roadster has a single speed fixed gear transmission. The EPA's estimated range for the roadster is 244 miles. Tesla calls its battery pack the Energy Storage System (ESS).

This battery has 6,831 lithium-ion cells arranged into sheets and bricks. Each brick has 69 cells connected in parallel and each sheet has 9 bricks connected in series.

Each of the cells is similar to those used as batteries for laptop computers. The battery weighs 990 pounds, stores 56 kWh of electric energy, and can deliver as much as 215 kW of power. Coolant is pumped continuously through the battery when the car is running.

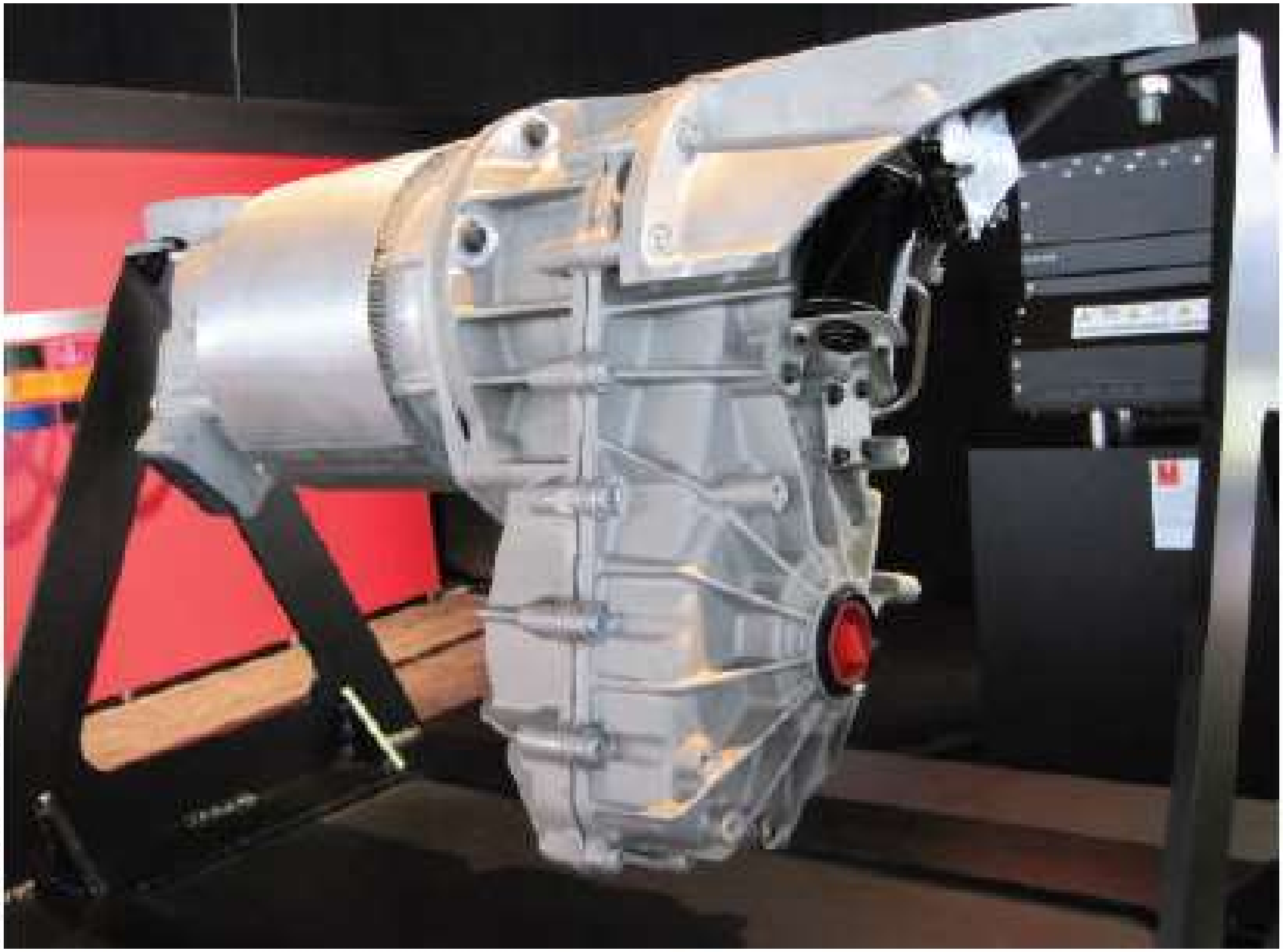


Figure 36-29 The motor and transmission in a Tesla Roadster.

Smart ED

The Smart ForTwo electric drive (or Smart ED) is a BEV version of its normal model **(Figure 36–34)**.

During the development of this EV, Smart developed and tested three different generations of this variant.

The first version was powered by a rear-mounted 41 hp (30 kW) motor that drove the rear wheels. It had a sodium-nickel chloride (Zebra) battery pack with an output of 13.2 kWh . The estimated range was 68 miles (109 km) and had a top speed of 75 mph . Eight hours were needed to totally recharge the batteries with a 240 V source.

The second generation used a lithium-ion battery supplied by Tesla Motors with capacity of 16.5 kWh . This increased the range to 84 miles (135 km) . However, a 27 hp (20 kW) motor was used which lowered the top speed of the car to 62 mph . The battery pack needed 3 hours to charge from 20 to 80 percent of its capacity **with a standard 240 V outlet**.

Figure 36-34 A Smart EV.

The third generation has a more powerful electric motor, 74 hp (55 kW) 96 ft.-lb (129 Nm) .

The car now has a top speed of 75 mph . It also uses a new lithium-ion battery pack that increases the range to 87 miles (140 km) .

FUEL CELL VEHICLES

A fuel cell vehicle (FCV) or fuel cell electric vehicle (FCEV) is a type of electric vehicle which uses a fuel cell.

Fuel cells in vehicles generate electricity to power the motor, generally using oxygen from the air and compressed hydrogen.

Most fuel cell vehicles are classified as zero-emissions vehicles that emit only water and heat.

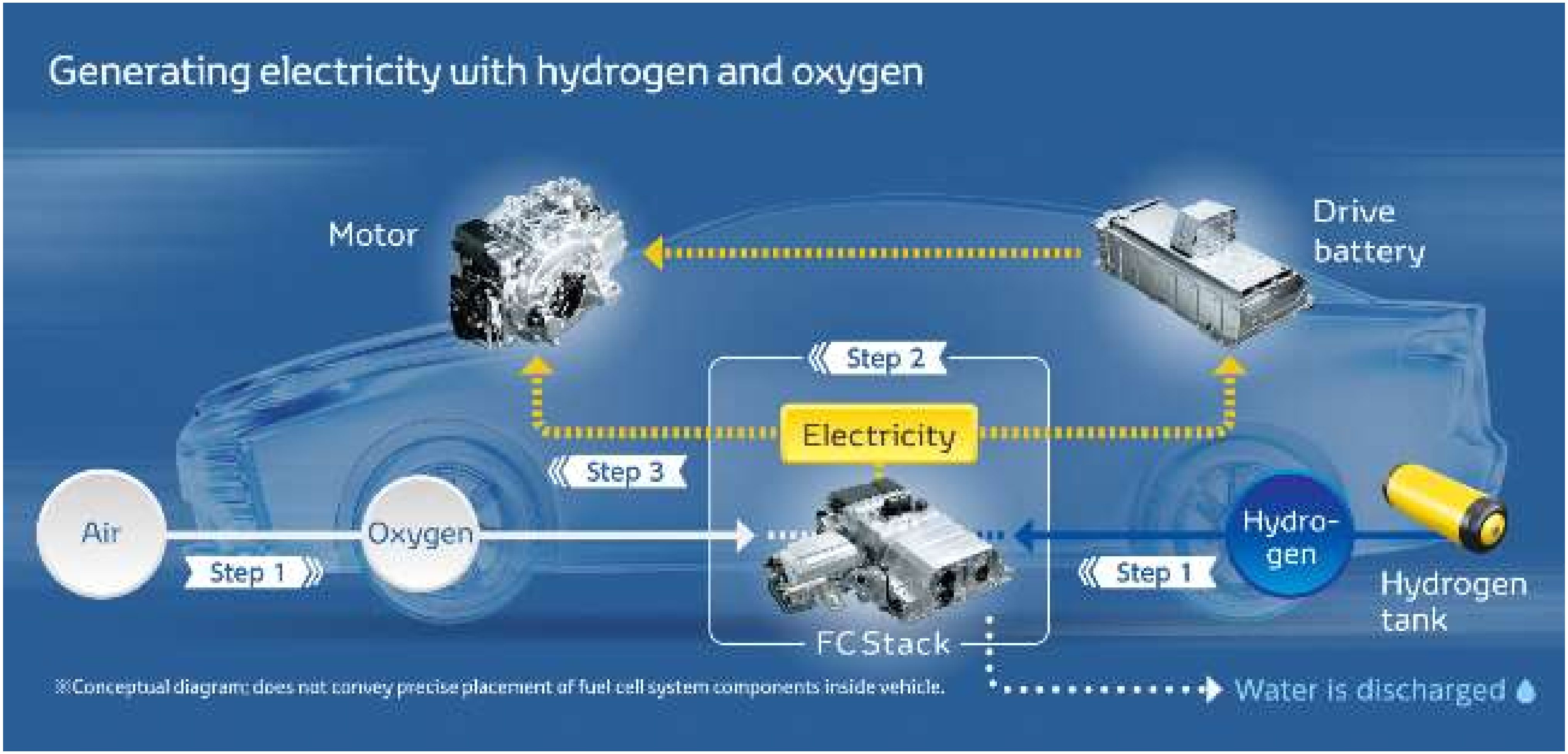
As compared with internal combustion vehicles, hydrogen vehicles centralize pollutants at the site of the hydrogen production, where hydrogen is typically derived from reformed natural gas.

FUEL CELL VEHICLES

2015 Toyota Mirai

2017 Honda Clarity Fuel Cell

2018 Hyundai Nexo



Generating electricity with hydrogen and oxygen
Motor
Drive battery
Step 2
Electricity
Step 3
Air
Oxygen
Step 1
Hydro-gen
Step 1
Hydrogen tank
FC Stack
※Conceptual diagram: does not convey precise placement of fuel cell system components inside vehicle.
Water is discharged