ABES ENGINEERING COLLEGE, GHZIABAD
FME (BME 101)
UNIT 2
LECTURE NOTES PART-2 (ELECTRIC & HYBRID VEHICLE)

1. Electric Vehicles

Electric vehicles (EVs) use an electric motor for traction, and chemical batteries, fuel cells, ultracapacitors, and/or flywheels for their corresponding energy sources. The electric vehicle has many advantages over the conventional internal combustion engine vehicle (ICEV), such as an absence of emissions, high efficiency, independence from petroleum, and quiet and smooth operation. The operational and fundamental principles in EVs and ICEVs are similar, there are, however, some differences between ICEVs and EVs, such as the use of gasoline tanks vs. batteries, ICE vs. electric motor, and different transmission requirements. This chapter will focus on the methodology of power train design and will investigate the key components including traction motor and energy storages.

2. Components and Configurations of Electric Vehicles

The EV was mainly converted from the existing ICEV by replacing the internal combustion engine and fuel tank with an electric motor drive and battery pack while retaining all the other components, as shown in Figure 1. Drawbacks such as its heavy weight, lower flexibility, and performance degradation have caused the use of this type of EV to fade out. In its place, the modern EV is built based on original body and frame designs. This satisfies the structure requirements unique to EVs and makes use of the greater flexibility of electric propulsion. A modern electric drive train is conceptually illustrated in Figure 2. The drive train consists of three major subsystems: electric motor propulsion, energy source, and auxiliary. The electric propulsion subsystem is comprised of a vehicle controller, power electronic converter, electric motor, mechanical transmission, and driving wheels. The energy source subsystem involves the energy source, the energy management unit, and the energy refuelling unit. The auxiliary subsystem consists of the power steering unit, the hotel climate control unit, and the auxiliary supply unit.

Based on the control inputs from the accelerator and brake pedals, the vehicle controller provides proper control signals to the electronic power converter, which functions to regulate the power flow between the electric motor and energy source. The backward power flow is due to the regenerative braking of the EV and this regenerated energy can be restored to the energy source, provided the energy source is receptive. Most EV batteries as well as ultracapacitors and flywheels readily possess the ability to accept regenerated energy. The energy management unit cooperates with the vehicle controller to control the regenerative braking and its energy recovery. It also works with the energy refuelling unit to control the refuelling unit, and to monitor the usability of the energy source. The auxiliary power supply provides the necessary power at different voltage levels for all the EV auxiliaries, especially the hotel climate control and power steering units.

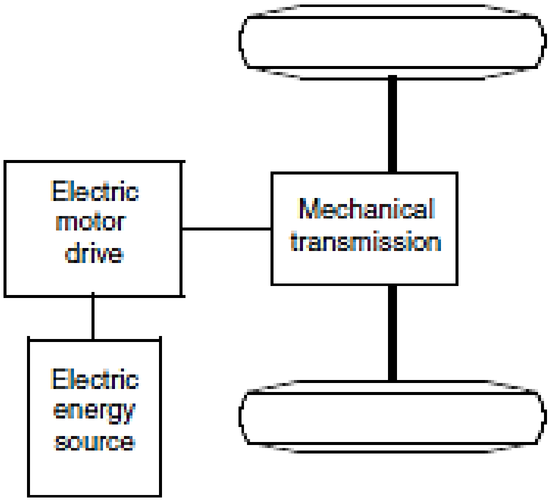


FIGURE 4.1
Primary electric vehicle power train

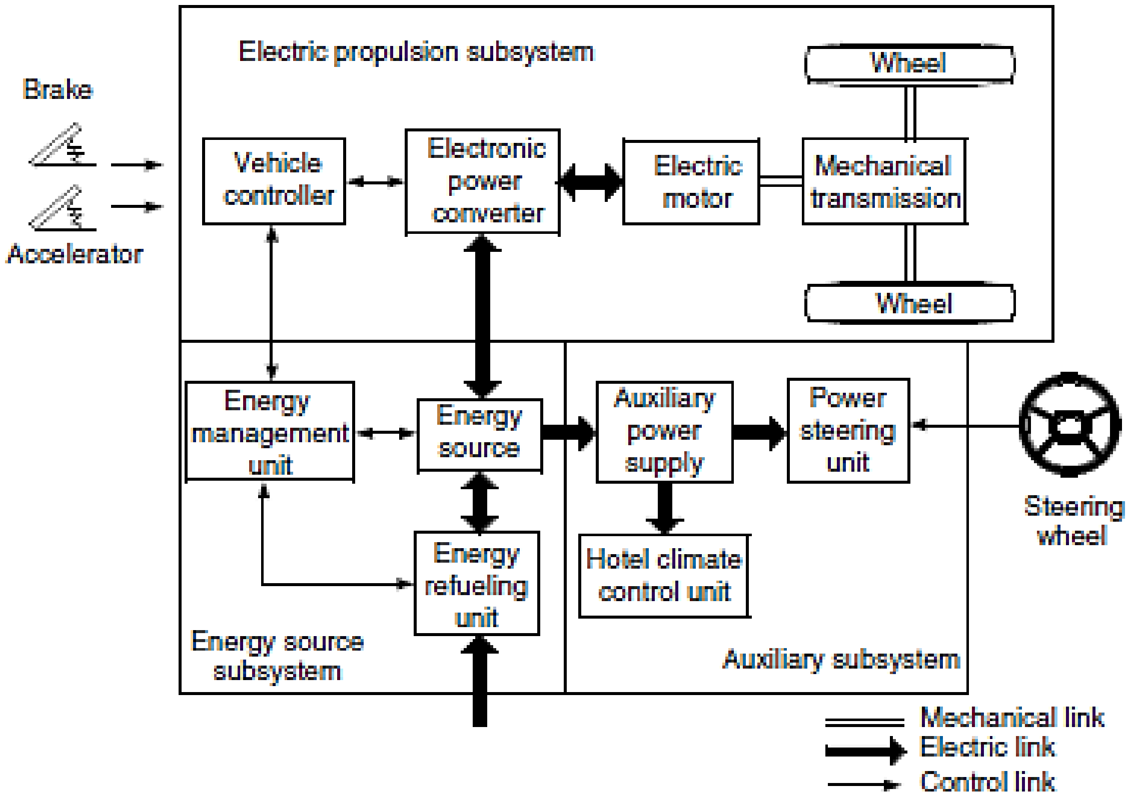
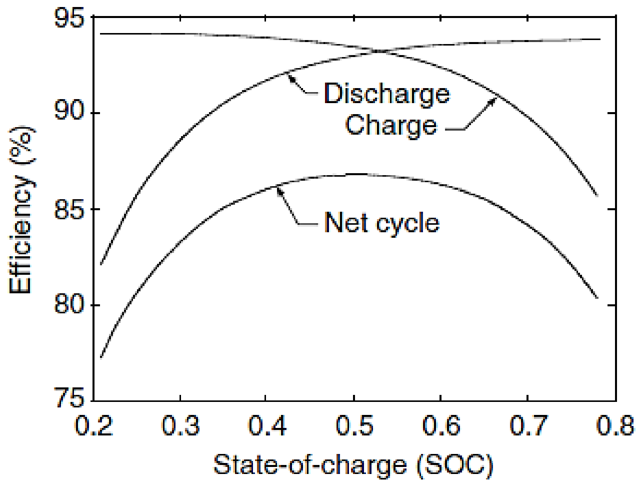


FIGURE 4.2
Conceptual illustration of general EV configuration

3. EV Batteries

The viable EV and HEV batteries consist of the lead-acid battery, nickel-based batteries such as nickel/iron, nickel/cadmium, and nickel–metal hydride batteries, and lithium-based batteries such as

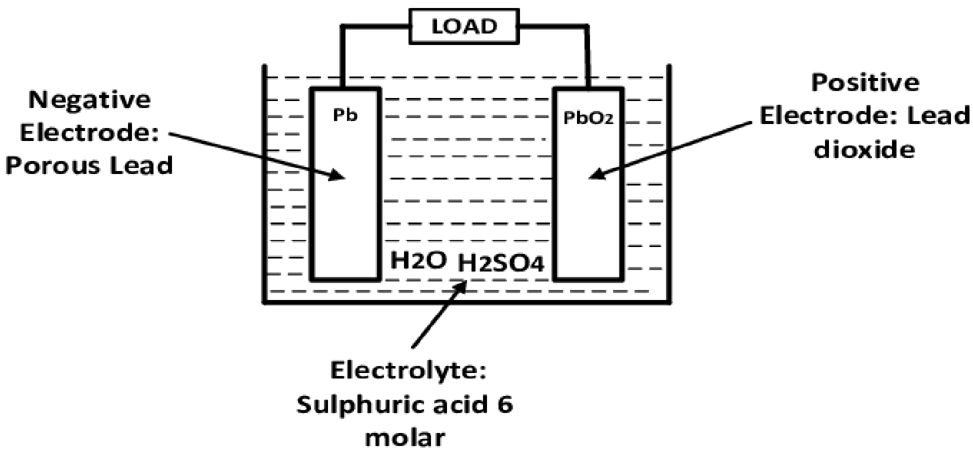
lithium polymer and lithium-ion batteries. In the near term, it seems that lead-acid batteries will still be the major type due to its many advantages. However, in the middle and long term, it seems that cadmium- and lithium-based batteries will be
major candidates for EVs and HEVs.



Typical battery charge and discharge efficiency

Lead-Acid Batteries

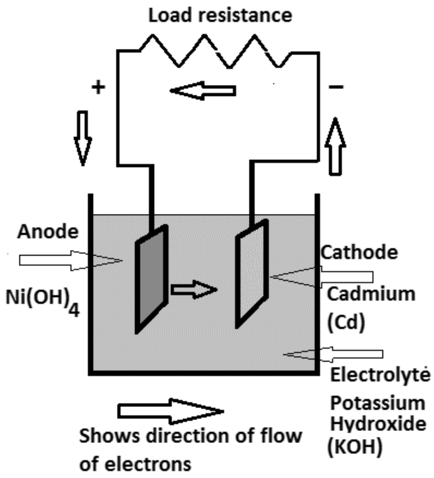
The lead-acid battery has been a successful commercial product for over a century and is still widely used as electrical energy storage in the automotive field and other applications. Its advantages are its low cost, mature technology, relative high-power capability, and good cycle. These advantages are attractive for its application in HEVs where high power is the first consideration. The materials involved (lead, lead oxide, sulfuric acid) are rather low in cost when compared to their more advanced counterparts. Lead-acid batteries also have several disadvantages. The energy density of lead-acid batteries is low, mostly because of the high molecular weight of lead. The temperature characteristics are poor.2 Below 10°C, its specific power and specific energy are greatly reduced. This aspect severely limits the application of lead-acid batteries for the traction of vehicles operating in cold climates.



Different lead-acid batteries with improved performance are being developed for EVs and HEVs. Improvements of the sealed lead-acid batteries in specific energy over 40 Wh/kg, with the possibility of rapid charge, have been attained. One of these advanced sealed lead-acid batteries is Electrosource's Horizon battery. It adopts the lead wire woven horizontal plate and hence offers the competitive advantages of high specific energy (43 Wh/kg), high specific power (285 W/kg), long cycle life (over 600 cycles for on-road EV application), rapid recharge capability (50% capacity in 8 min and 100% in less than 30 min), low cost (US$2000–3000 an EV), mechanical ruggedness (robust structure of horizontal plate), maintenance-free conditions (sealed battery technology), and environmental friendliness. Other advanced lead-acid battery technologies include bipolar designs and microtubular grid designs. Advanced lead-acid batteries have been developed to remedy these disadvantages. The specific energy has been increased through the reduction of inactive materials such as the casing, current collector, separators, etc. The lifetime has been increased by over 50% — at the expense of cost, however. The safety issue has been addressed and improved, with 310 Modern Electric, Hybrid Electric, and Fuel Cell Vehicles electrochemical processes designed to absorb the parasitic releases of hydrogen and oxygen.

Nickel-based Batteries

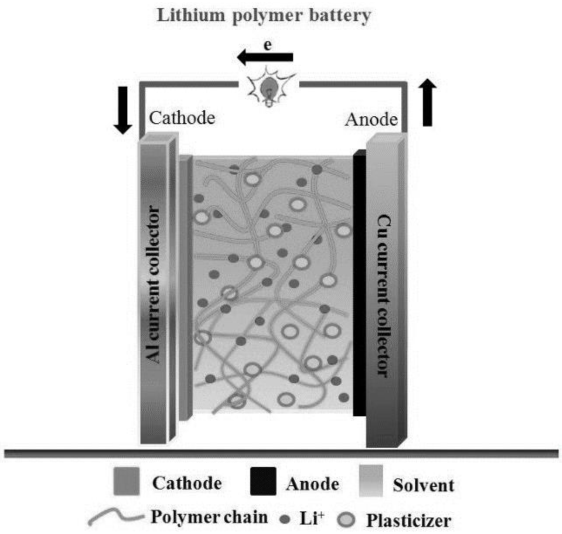
Nickel is a lighter metal than lead and has very good electrochemical properties desirable for battery applications. There are four different nickel-based battery technologies: nickel–iron, nickel–zinc, nickel–cadmium, and nickel–metal hydride.



Nickel Cadmium Battery

Lithium-Based Batteries

Lithium is the lightest of all metals and presents very interesting characteristics from an electrochemical point of view. Indeed, it allows a very high thermodynamic voltage, which results in a very high specific energy and specific power. There are two major technologies of lithium-based batteries: lithium–polymer and lithium-ion.



4. Electric propulsion/Transmission systems

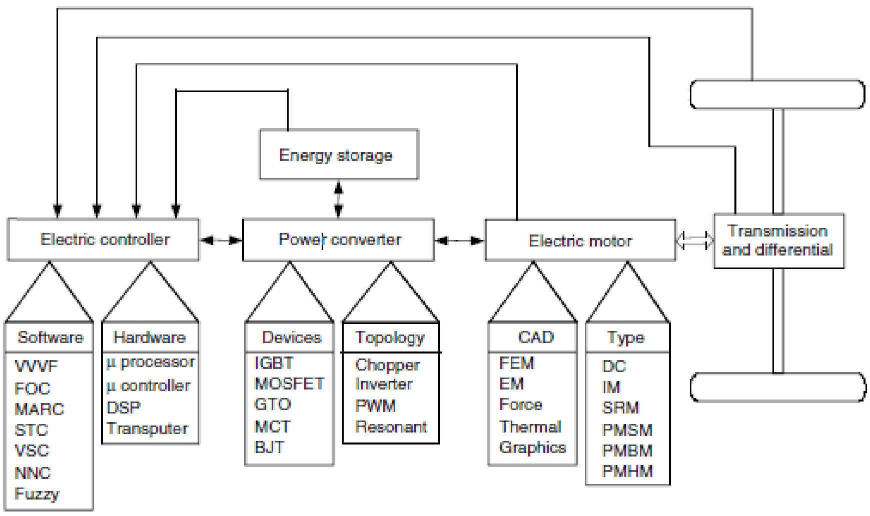
Electric propulsion systems are at the heart of electric vehicles (EVs) and hybrid electric vehicles (HEVs). They consist of electric motors, power converters, and electronic controllers.

The electric motor converts the electric energy into mechanical energy to propel the vehicle, or, vice versa, to enable regenerative braking and/or to generate electricity for the purpose of charging the onboard energy storage.

The power converter is used to supply the electric motor with proper voltage and current.

The electronic controller commands the power converter by providing control signals to it, and then controls the operation of the electric motor to produce proper torque and speed, according to the command from the drive.

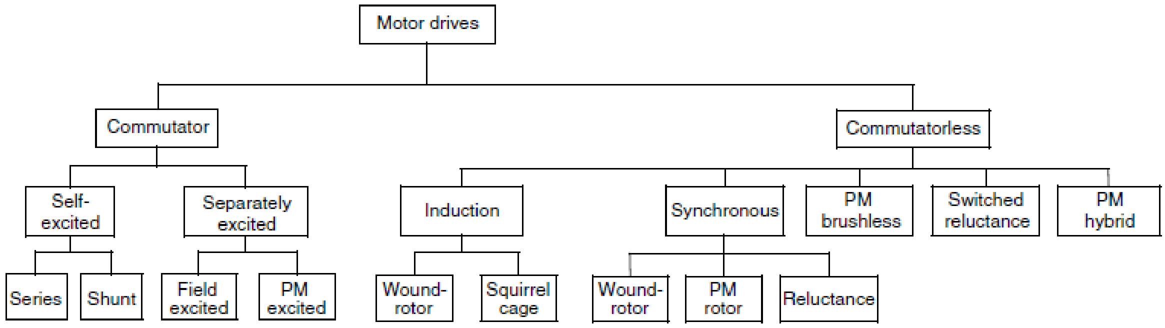
The electronic controller can be further divided into three functional units — sensor, interface circuitry, and processor. The sensor is used to translate measurable quantities such as current, voltage, temperature, speed, torque, and flux into electric signals through the interface circuitry. These signals are conditioned to the appropriate level before being fed into the processor. The processor output signals are usually amplified via the interface circuitry to drive power semiconductor devices of the power converter



Functional block diagram of a typical electric propulsion system

5. Drives

Classification of electric motor drives for EV and HEV applications is mentioned in chart below:



1. **DC Motor Drives** - DC motor drives have been widely used in applications requiring adjustable speed, good speed regulation, and frequent starting, braking and reversing. Various DC motor drives have been widely applied to different electric traction applications because of their technological maturity and control simplicity.
   The operation principle of a DC motor is straightforward. When a wire carrying electric current is placed in a magnetic field, a magnetic force acting on the wire is produced. The force is perpendicular to the wire and the magnetic field.

2. **Induction Motor Drives** - Commutator less motor drives offer a number of advantages over conventional DC commutator motor drives for the electric propulsion of EVs and HEVs. At present, induction motor drives are the mature technology among commutator less motor drives. Compared with DC motor drives, the AC induction motor drive has additional advantages such as lightweight nature, small volume, low cost, and high efficiency. These advantages are particularly important for EV and HEV applications. There are two types of induction motors, namely, wound-rotor and squirrel cage motors. Because of the high cost, need for maintenance, and lack of sturdiness, wound-rotor induction motors are less attractive than their squirrel-cage counterparts, especially for electric propulsion in EVs and HEVs.

3. **Permanent Magnetic Brush-Less DC Motor Drives** – By using high-energy permanent magnets as the field excitation mechanism, a permanent magnet motor drive can be potentially designed with high power density, high speed, and high operation efficiency. These prominent advantages are quite attractive to the application on electric and hybrid electric vehicles. Of the family of permanent magnetic motors, the brush-less DC (BLDC) motor drive is the most promising candidate for EV and HEV application

6. Power Devices

There are three major Power Electronic elements in the electric vehicle: Traction Inverter, DC-DC Converters, and Onboard Chargers. The inverter is an AC to DC converter that converts the Battery voltage to supply an alternating voltage to the traction motor.

There are three major Power Electronic elements in the electric vehicle: **Traction Inverter**, **DC-DC Converters**, and **Onboard Chargers**.

The **inverter** is an AC to DC converter that converts the Battery voltage to supply an alternating voltage to the traction motor. The typical power rating of the Inverter ranges from 120kW to

250kW for a passenger car. Inverter controls the rotational speed of the traction motor and provides the required torque to propel the motor. Another significant feature the inverter brings to the vehicle is its ability to provide precise “Electric Braking.” Electric braking helps reduce the usage of mechanical braking and hence improves the life of the mechanical brake system by reducing mechanical wear and tear. The electric braking feature also transfers the motor kinetic energy to the battery every time the vehicle is braked. This, in turn, improves the vehicle range.

The power conversion efficiency of Traction Inverter directly influences the vehicle range (miles/charge). The typical efficiency of the inverter is more than 98%, which is expected to improve in the coming years further. The typical power density of the inverters is 20kW/Lit. In the coming years’ power density is expected to improve to 40kW/Lit, which means double the power in the same size.

DC-DC Converter acts as a DC transformer that converts the high voltage from traction battery to low voltage to supply all low voltage electronics like power steering, power window, wiper control, dashboard multifunction display, and all other electronic control functions, including very critical “Vehicle Control Unit” (VCU). The typical efficiency of a DC-DC Converter is more than 96%. Typical power rating of a DC-DC Converter ranges from 1kW to 6kW for a passenger car.

An **onboard charger** (OBC) is a Battery Charger that is operational only when the vehicle is stationary. OBC converts the AC voltage of the utility power source to DC voltage to charge the battery. OBC has its in-built control function to charge the battery at constant current, constant power, and constant voltage. Onboard chargers for passenger car are typically rated for 3.3kW for operation from a single-phase power source and goes all the way to 22kW for operation from the 3-phase power source. The typical efficiency of Onboard Chargers is more than 95%, which is expected to reach better than 97% in coming years. Typical power density of Onboard Chargers is less than 1kW/Lit. In the coming years, the power density of onboard chargers is expected to improve to 3kW/Lit.

7. Advantages and disadvantages of EVs

Advantages of Electric Vehicle

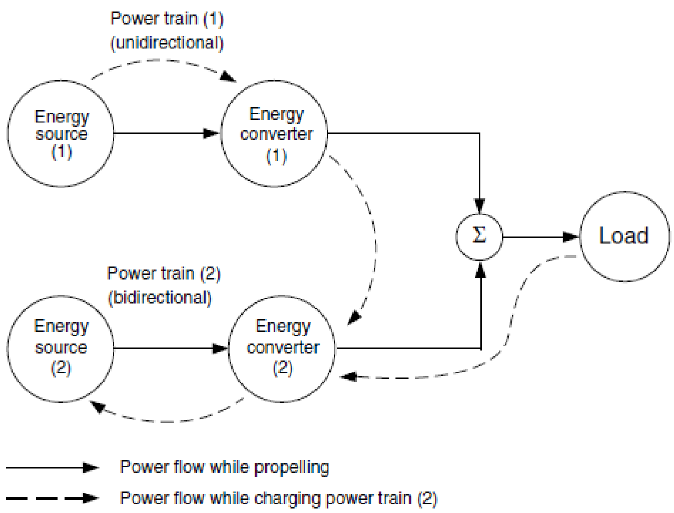
a. Environment-friendly: Electric vehicles do not use fuels for combustion and hence there is no emission or exhaust of gasses. Vehicles using fossil fuels are large contributors to harmful gas buildup in the environment so the use of an electric car can help contribute to a cleaner atmosphere.
b. Renewable energy source: Electric vehicles run on electricity that is renewable whereas conventional cars work on the burning of fossil fuels that exhaust the fossil-fuel reserves on earth.
c. Cost-effective: Electricity is much cheaper than fuels like petrol and diesel which suffer a frequent price hike. The recharging of batteries is cost-effective if solar power is used at home.
d. Low maintenance: Electric vehicles have fewer moving parts so wear and tear is less as compared to conventional auto parts. Repair work is also simple and less expensive relative to combustion engines.
e. Less noise and smoother motion: Electric vehicles give a much smoother driving experience. The absence of rapidly moving parts makes them much quiet with low sound generation.
f. Government support: Governments in various countries have offered tax credits as an incentive to encourage people to use electric vehicles as a go-green initiative.

Disadvantages of Electric Vehicle

a. High initial cost: Electric vehicles are still very expensive and many consumers consider them not as affordable as conventional vehicles.
b. Charging station limitations: People who need to drive long distances are worried about getting suitable charging stations midway which is not available everywhere.
c. Recharging takes time: Unlike conventional cars that require a few minutes for refilling fuel, recharging of the electric vehicle takes much more time which is generally a few hours.
d. Limited choices: Presently there aren't too many electric models of cars available to choose from when it comes to the looks, designs, or customized versions.
e. Less driving range: The driving range of the electric vehicles is found to be less as compared to conventional vehicles. Electric vehicles can be suitable for day-to-day travel but can be problematic for a long-distance journey.

8. Hybrid Vehicle and Hybrid Electric Drive Trains

Basically, any vehicle power train is required to (1) develop sufficient power to meet the demands of vehicle performance, (2) carry sufficient energy onboard to support vehicle driving in the given range, (3) demonstrate high efficiency, and (4) emit few environmental pollutants. Broadly, a vehicle may have more than one energy source and energy converter (power source), such as a gasoline (or diesel) heat engine system, hydrogen–fuel cell–electric motor system, chemical battery–electric motor system, etc. A vehicle that has two or more energy sources and energy converters is called a hybrid vehicle. A hybrid vehicle with an electrical power train (energy source energy converters) is called an HEV. A hybrid vehicle drive train usually consists of no more than two power trains. More than two power train configurations will complicate the system. For the purpose of recapturing part of the braking energy8 that is dissipated in the form of heat in conventional ICE vehicles, a hybrid drive train usually has a bidirectional energy source and converter. The other one is either bidirectional or unidirectional. Figure shows the concept of a hybrid drive train and the possible different power flow routes.



Conceptual illustration of a hybrid electric drive train

9. Advantages of HV

a. More environmentally-friendly
b. Automatic start/shutoff
c. Built From Light Materials
d. Dual power
e. Regenerate braking
f. Require less maintenance
g. Higher resale value
h. "Range anxiety" may not be a problem