How To Build An EV Car!

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Planning Your Conversion

The first step in the conversion process is determining what kind of car to convert. You also have to determine if an electric car will fit your needs. Below is a list of items to consider before embarking on the project. All the assumptions are based on using deep-cycle or sealed lead-acid batteries which are available today.

Is an EV appropriate for your needs?

The average conversion EV has a realistic range of 30 to 70 miles in everyday driving conditions depending on the type of batteries you have and the weight of the vehicle. If your commute is more then 35 miles one way in very hilly terrain an EV may not be a good idea. However, if your commute is on average terrain and is about 20 miles each way an EV is perfect. If you are a two car family and one car is usually used for short trips you may want to consider an EV.

Do you have easy access to charge your car?

Town homes, apartments and parking garages may impose a challenge and will probably require permission from the management or homeowner's association.

Do you have the facilities to build your conversion?

If you don't have a driveway, carport, or garage all is not lost. Ask a friend, family member, or rent garage space. The project should take anywhere from 2 months to a year.

Do you have the proper tools to build an EV?

With conversion kits available today most people with basic hand and power tools can do the work themselves. Some tasks can be contracted out such as welding. The only special tools you will need are a torque wrench, cable crimpers, and an engine crane; all of which can be rented.

What is your budget for the conversion?

For a complete kit consider spending $4000 - $6000. Batteries can cost another $700 to $1200. Kits are highly recommended because they include all the parts necessary for the conversion as well as instructions. It is highly recommended that the first time EVer buy the book "***Convert It***" if it isn't available with the kit. This book has detailed step-by-step instructions on converting a car from scratch.

Choosing a car

Now that you have a basic idea of what you will need to do a conversion, the next step is choosing a body style and chassis. You may already have a car picked out for this purpose.

Do you want your EV to be a family commuter, utility vehicle, a high performance watt rod?, or a combination of uses?

- For a family commuter with a range of 40 miles or more consider a light compact sedan that has enough room to accommodate 16 to 20 6-volt batteries. Escorts, Hondas, late model Novas, GEOs, Saturns, Rabbits, Neons, etc. are popular choices. 6-volt batteries are preferred over 12-volt batteries in this application because they have more energy density which is necessary for range. To add pep but sacrificing some range you may consider 8-volt batteries from Trojan or US Battery.
- Pickup trucks are great for utility purposes and are popular for a high school rally project. They have the extra payload capacity to carry the batteries and you can fit them under the bed. 20 6-volt batteries are common configurations. For extra range add 4 more 6-volt batteries for a total of 144 volts.
- High performance EVs are a blast to drive and fun to race at NEDRA events. You want as light a car as possible with the structural integrity to handle the weight of the batteries. Typical configurations are 2+2s or two-seaters such as Toyota MR2s, Honda del Sols, Porsche 911s and 914s, and Mazda RX-7s. 144 volt systems or more using 12-volt deep-cycle batteries are very popular today. These include the Optima Yellow Tops and the Genesis Hawker batteries. You can expect a range of anywhere from 20 to 40 miles. You can increase your range and amp hour capacity by running two or more parallel strings of batteries.
- Be creative and mix and match your own configuration.

Hints on choosing the right chassis

Manual 4 or 5 Speed Transmission

Use a manual transmission instead of an automatic. Automatics are avoided because they are not as efficient. Driving an EV with a gear shift is easier then with a gas car because EVs don't idle so there isn't a problem with stalling. Electric motors are also 98% efficient so you will not need to shift as much. Many city EVers just leave the car in second gear.

Power Brakes

Power brakes are recommended because of the extra weight of the batteries. Vacuum can be restored with an electric vacuum pump available through kit suppliers.

Power Steering

Power steering can be use but for a simple conversion it's not necessary because an extra motor would be needed to drive the power steering pump. If your vehicle has power steering just cap off the hoses. If power steering is necessary there are ways to rig up a motor to drive the pump.

Air Conditioning

Most conversion don't use AC systems because they add space and place a greater load on the batteries. However, you can still retain the AC by adding a 1 horsepower permanent magnet DC motor to drive the compressor.

Choose a car without rust

Even if a car has light surface rust this could be an indication of something worse under the car. EVs require a sound undercarriage to carry the extra weight of the batteries.

Weight

Typically an EV will add 200 to 500 pounds to the weight of the car. Check the weight rating of your car to make sure the weight of your conversion will be within reason.

For the purpose of this conversion we'll be using a 1986 Ford Escort. The car will be used as a commuter vehicle and family car. It will have a 96 volt system using 16 US Battery brand 6-volt batteries. This conversion was done in the early 90's when 96-volts was a popular conversion at the time.

Costs

Now that we've decided on our body style and voltage system it's time to discuss the budget for the project. There are several options here. Kits are the easiest way to build an EV. They include all the parts you need except for the batteries. There are several kit suppliers in the U.S. The kit for this conversion was purchased from KTA Services in California. Highlighted parts are included in the conversion kit.

For those on a shoestring budget, used parts can be found within the EV community or from surplus catalogs. Parts can also be ordered as you need them from the suppliers as well. Every so often used Advanced DC motors and controllers can be found for a good price.

Advanced DC 8" motor	$1320.00
Adaptor plate and hub	650.00
Motor mount	137.50
Curtis-PMC1221B motor controller	750.00
Throttle controller	60.00
Main contactor	130.00
Main circuit breaker	110.00
DC/DC Converter	420.00
Voltmeter	48.00
Ammeter	48.00
Onboard battery charger	550.00
Charger interlock relay	15.00
50 ft 2/0 welding cable	180.00
Cable lugs	144.00
Shrink tubing	19.00
120 volt battery box fan	20.00
Wiring diagrams	20.00
Vacuum brake system	205.00
Heating system	395.00
Electric wire and connectors	170.00
16 6-volt batteries, US Battery @ $42.00 each	672.00

4 Goodyear Invicta low rolling resistance tires @ $60.00 each	240.00
New wheels	250.00
New clutch	63.00
Air shocks	65.00
"Convert It" Manual	25.00
Hardware	300.00
Battery box plywood	30.00
Tools and supplies	200.00
Paint and supplies	120.00
Angle iron	40.00
Welding services	350.00
Flywheel resurfacing	55.00
Total	**$7926.00**

Components

Here is a list of the main components that will be installed in the car:

Advanced DC Motor

The motor is an 8" Advanced DC series-wound motor. It weighs 107 pounds and is rated at 68 peak horsepower. These motors are available in several sizes.

Adaptor plate

The adaptor plate mates the motor to the transmission. It is constructed of 1/2 inch aluminum and is pre-drilled with bolt hole patterns for both the motor and transmission. An aluminum spacer is also used for proper spacing between the shafts of the transmission and motor. Adaptor plates are available for many cars.

DC Motor Controller

The controller regulates current going to the motor. It is a solid-state device that uses a pulse width modulator (PWM) that sends short bursts of current to the motor at a rate of 15 kHz. Controllers are available from both Curtis and DCP.

Potbox (Potentiometer)

The potbox is a 5K ohm throttle between the controller and the accelerator, similar to the way a sewing machine pedal works. The potbox's lever arm is attached to the existing accelerator cable.

Main Contactor

An electric relay that serves the same purpose as the ignition switch in a gas car. When the key is turned to the start position, the contactor closes the circuit to allow current to flow to the controller.

Circuit Breaker

A safety device that shuts down power for servicing or during an emergency. The circuit breaker is installed under the hood and can be switched both off and on from the drivers seat with an extension or cable.

Main Fuse

The main fuse protect the system from high voltage spikes. A fuse should be installed at each battery box or group of batteries.

Shunt

A shunt is placed in series within the wiring as a means to connect meters. Shunts are available in different sizes for both high and low power configurations.

Charger interlock

A relay that keeps the circuit open so nobody will inadvertently drive off with the charge cord plugged into the car.

DC/DC Converter

The DC/DC converter is similar in function to a gas car's alternator. It charges the 12 volt accessory battery by chopping voltage from the main battery pack down to 13.5 volts.

Batteries

The most common batteries used in conversions today are deep-cycle lead-acid batteries. Although Nickel Metal Hydride (NiMH) batteries are being used by the auto manufacturers for their EVs they are not available to the average EVer building their own EV.

The deep-cycle lead acids are divided into two groups: flooded batteries, also known at wet cells and sealed batteries also known as valve-regulated lead-acid (VRLA) batteries.

Flooded batteries are available in 6 and 8-volt versions from Trojan battery and US Battery. Flooded batteries are inexpensive, can take some abuse, and have a high energy density which makes them a good choice for range. They can last anywhere from three to five years. On the down side they are heavy, up to 70 pounds each, and have high internal resistance which doesn't appeal to the racing set. For distance and cost they are a good bet.

The most popular 12-volt sealed batteries used in EVs today are the Optima Yellow Tops and Genisis Hawker batteries from GNB. Sealed batteries are lighter then wet cells, have low internal resistance and can be installed in various positions. On the downside they are expensive, have a shorter lifespan and limited range. To increase range the batteries can be run in parallel strings which increases the amp/hour capacity of the pack.

Tools and Supplies

Most do-it yourselfers already have the tools required to convert an EV. Equipment such as engine hoists can be rented and welding can be contracted out.

It is a good idea to keep a notebook with you as you work on your conversion. There will be times when you need to write down measurements, create drawings and list hardware and supplies for different aspects of the project. Keeping these notes all in one place will make referencing information easier. You also may need to refer to them years after you have completed your project.

Tools

- Jack stands
- Floor jack
- Wheel chocks
- Engine hoist
- Saw horses
- Workbench or Workmate
- C-clamps
- Drop light
- Soldering iron
- Combination wire stripper and crimping tool
- Cable shears for 2/0 welding cable
- Lug crimpers for 2/0 welding cable
- Heat gun for heat shrink tubing
- Hammer
- Punches
- Chisels
- Hack saw
- Screwdrivers
- Socket wrenches
- Torque wrench
- Wrenches
- Pliers
- Aviation snips
- Drill and/or drill press
- Circular saw
- Saber saw
- Grinder
- Measuring tape
- Square
- Level
- Volt meter

Supplies

- 1" x 1" x 3/16" angle iron, 12' length for battery rack
- 1" x 1" x 3/16" angle iron, 5' length for battery rack

- 1 1/2" x 1 1/2" x 3/16" angle iron, 20' length for battery rack
- 3/4" x 3/4" x 1/8" angle iron, 20' length for battery hold down
- 1" x 1" x 1/8" metal, 10' length for various brackets
- 4' x 8' x 3/4" plywood for battery box
- 4' x 8' x 1/2" polyurethane foam insulation for battery box
- 1 1/2" x 20' PVC pipe for conduit
- 5" x 10' vent hose for battery box ventilation
- 1/4" Fomecore for models and templates
- Elmers wood glue
- 4 cans Black Rustoleum spray paint for engine compartment and brackets
- 2 quart Rustoleum primer for battery box
- 2 quarts White Rustoleum Waterproof paint for battery box
- Noalux: compound applied to battery lugs to prevent corrosion
- Stainless steel bolts, nuts, washers and lockwashers for brackets and hardware
- Grade 8 automotive bolts, nuts, washers and lockwashers for motor mounts and battery racks

Safety

Like any project involving automobiles and tools there are inherent risks. However EVs have hazards that you should be aware of. Being aware of these possible hazards will prevent damage to the vehicle and serious injury to yourself. Below are a few basic guidelines to follow.

1. Always shut off the power when servicing the car.
2. Dissipate the capacitors from the controller before servicing the controller or propulsion system. Even though the controller is off the capacitors may still be live. A light bulb works well as a dissipation device.
3. When servicing the drive train always keep the drive wheels off the ground with proper jack stands.
4. Keep loose hair, jewelry or clothing away from spinning motor shafts.
5. Always wear proper eye protection when working with power tools and handling batteries. Deep-cycle batteries contain caustic acid which may splash or spill when they are moved or handled.
6. Wear protective clothing when carrying or moving batteries. Acid could spill and burn a hole through any clothing it contacts.
7. Wear steel toed boots when carrying or moving batteries. Batteries can weigh up to 80 pounds and can cause serious injury if they fall.
8. Wear heavy gloves when moving or carrying batteries. Use protective rubber or latex gloves when checking or watering batteries.
9. Always provide proper ventilation when charging batteries. A small spark can cause a fire if hydrogen gas accumulates in an enclosed area.
10. Never inhale the fumes when watering the batteries.
11. Tape the ends of wrenches when tightening battery terminals. A loose wrench can come in contact with battery terminals and cause a short.
12. Never ground the propulsion batteries.
13. Never work on the car when you are tired or in a hurry.

Getting Started

This is where we get our hands dirty - removing all the greasy gas parts. This includes the engine, radiator, gas tank, fuel lines, exhaust system, and emission wires and hoses. The transmission, clutch, and flywheel are retained for use in the conversion. Many parts that are removed can be sold. It's best to purchase a Haynes manual, car specific, for this project.

Yuk!! View of engine before removal
Important wires are located and labeled.

Before starting it is important to take down measurements of the car's original ride height so when the conversion is done you will know if the suspension will need additional work. Measure the ride height at the top of each fenderwell.

Label all wires leading to the engine before removing it. Ignition wires will need to be located and labeled because the existing ignition switch will be used to turn the electric car on. The accelerator cable will also be retained. Measurements also need to be taken from the transmission to ensure proper alignment when the electric motor is installed.

All gas components removed. It just needs a little clean-up and painting.

With all the old gas stuff removed it's time to get down to business and install the electric components. But first, the engine compartment will be degreased and painted.

This is the point where the actual conversion begins. The empty engine compartment provides a better perspective of how the components and batteries will be layed out.

Installing the Motor

Before putting the motor assembly together take the flywheel to the machine shop and have the flywheel balanced. This may be a good time to replace the pressure plate and clutch disk and start with new ones. Also inspect the throwout bearing on the transmission shaft.

The motor is mounted to the transmission with an aluminum adaptor plate and spacer ring. The adaptor plate is made of 1/2 inch thick adonized aluminum. Adaptor plates are available for a whole range of cars. The spacer ring ensures correct clearance between the motor shaft and the transmission shaft. The hub, which is attached to the motor shaft, is used to mate the flywheel to the electric motor. And the clutch assembly bolts to the flywheel as it did on the gas engine.

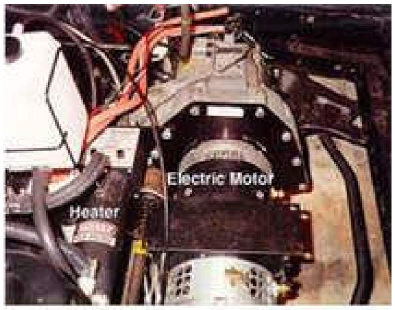
Motor, adaptor plate and flywheel clutch assembly

The first step of the motor assembly is attaching the hub to the motor. The hub in the kit is machined with a key way, two threaded holes for the set screws and a matching bolt pattern for the flywheel. Once the hub is on the shaft drill into the shaft through the set screws holes so the screws will seat properly. Blow out any metal shavings and screw the set screws in place. Two set screws are used for each hole, one on top of the other.

Position the motor so the terminals are easily accessible once the motor is mounted in the car. Next, position the spacer plate and adaptor plate to the face of the motor and bolt them into place. Bolt the flywheel to hub. Then bolt the clutch assembly to the flywheel. Make sure all the bolts are tightened to the correct specifications.

Lowering the completed motor assembly

Once the motor assembly is complete, it is lowered into the engine bay and bolted to the transmission. It may take a few tries to align the shafts of both the motor and the transmission so an engine lift and an extra set of hands is real helpful. After the unit is bolted into place, with the drive wheels off the ground, put the car in gear and rotate the tire to make sure the motor shaft is also rotating. After this test hook up the motor to a 12-volt battery and briefly run through the gears to make sure everything is working and well balanced.



Motor assembly bolted to transmission

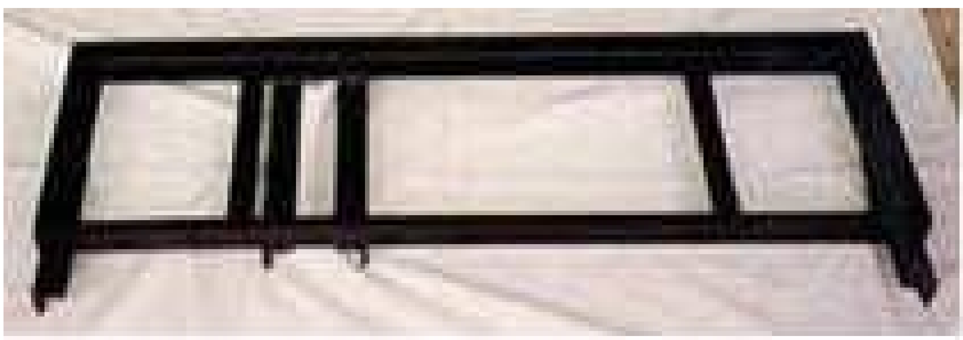
At this time the car's new heating system is also installed. The new heater pumps hot Prestone solution through the existing heater core. The unit uses the existing heater controls and operates when the heater lever is moved to the hot position on the dash. The tank above the heater supplies Prestone to the heater. The heating element is powered by the propulsion batteries and the unit's pump is powered by the 12 volt system.

There are other options for heaters as well. A popular heater being used today is a resistive heater that resides where the heater core is inside the heater plenum in the dash area. This heater requires no plumbing like the other heater described above. In some cars such as the Ford Escort the heater core can easily be removed from the heater plenum behind the glove box. The ceramic element of the heater is powered by the main battery pack. This unit also can use the same heater controls on the dash.

Getting back to the motor we need to securely bolt the motor to the frame of the car. One end of the motor is already anchored to the frame with the transmission so we need to secure the other end. The kit comes with a motor support that wraps around the motor and has a base to provide an area to mount a bracket to the car. You have several options here. Attaching a brace from the upper motor mount attachment points on the car to the motor support is a common option. For rear wheel drive cars the motor support can be attached to a brace that attaches to both frame rails. In rear wheel drive cars it may be also necessary to add a torque bar from the frame of the car to the motor to prevent the motor from twisting in the motor support when the motor is started.

For this conversion a rack system was designed to span the width of the engine compartment to support not only the motor but the controller, three batteries, and the battery charger as well. The rack is made of 3/16 inch thick angle iron. The rack rests on top of frame rails integrated into the unibody construction of the car. A smaller rack is located where the radiator used to be. This rack will support three batteries. It helps to build fomecore models of the racks for positioning purposes. You can also give the finished model to the welder. To accomplish this fist measure your compartment, frame to frame. Then design your rack to best accommodate the space you have. Below is a photo of the finished rack.

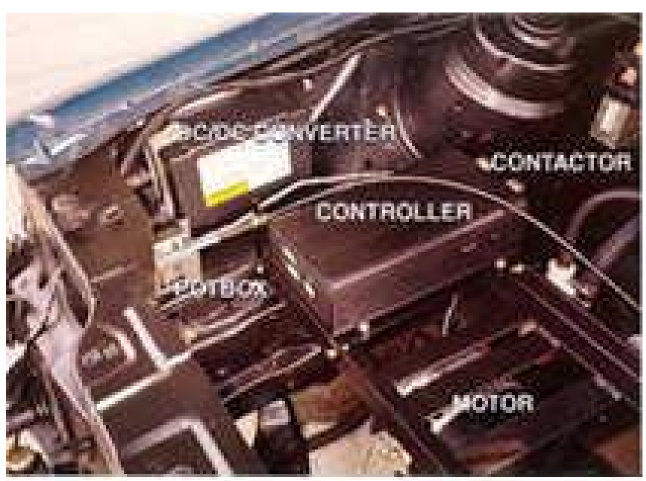
Battery rack models



Front rack which will support three batteries, the motor and controller

Installing the Components

EVs require very few parts so installing the components is relatively simple. Below is a photo showing the major components installed in the car. As you can tell they don't take up as much room as the engine. The rest of the space will be filled with batteries. Not



Electric components installed

shown in the photo is the compact battery charger which is mounted at the opposite side of the new motor compartment.

Ideally, the components should be placed close together to keep wire lengths short. The controller requires sufficient cooling to work properly so it should be placed in the airstream or mounted on a heatsink with a thermal joint compound for heat conduction. The potbox should be mounted on a sturdy surface and the accelerator cable should be routed in such a way so as to prevent kinks or pinching. Since there is a slight spark when the contactor closes it should be placed below the top level of the batteries. Each component should be kept away from water splash. Some EV converters mount all their components on a board that is hinged to allow easy access to batteries and the motor.

Underside showing conduit, battery box vent and air bags installed.

PVC pipe is mounted under the car as a conduit for the wiring that runs to the rear battery pack. The wiring harness that runs inside the conduit includes heavy cables that connect the battery packs, a charging wire for the positive lead of the top most battery, wires for the battery box fan, and extra wires for future expansion.

Air bags are installed in the coil springs to support the weight of the rear batteries. The vent in the rear spare tire well is ventilation for the battery box. The spare tire will be stored on top of the battery box.

Installing the Battery Box

Rear battery box

Since 10 of the batteries will be located in the rear section of the passenger compartment the batteries will need to be stored in a protective box. This is to prevent fumes from entering the passenger compartment when the batteries are charging and to protect occupants of the car in an accident. The box also keeps the batteries warm in cold weather. Because of the limited space in the front of the car, battery boxes were not installed.

Mounted on the side is an explosion proof brushless fan that ventilates the box when the batteries are charging. The fan is wired in series with the fan in the battery charger so when the charger is on the battery box fan is on. A marine grade ventilation bilge hose is attached to the fan and routed to the vent on the underside of the car.

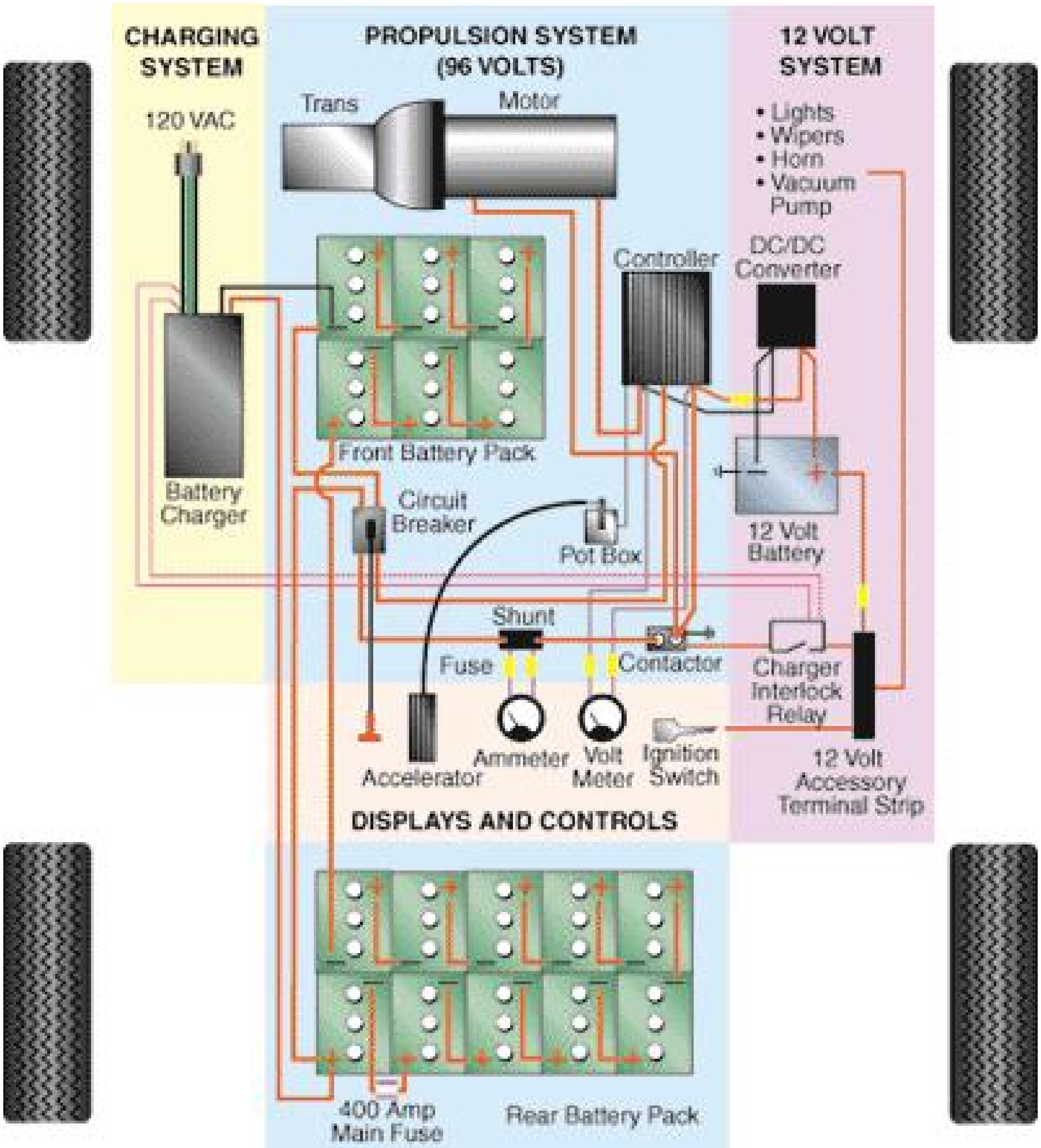
The box is constructed of marine grade plywood and painted with water repellant paint. Metal banding is secured around the box so the weight of the batteries will not break the box apart in an accident.

Rear battery box installed

The box is securely mounted with bolts to the frame of the car. For ease of installation the box in this conversion fits in the trunk. However, with careful planning, some cutting, and a little welding, the battery box can be sunk into the floor of the trunk to regain storage space. Before the batteries are installed, a layer of baking soda is spread on the floor of the box and the air bags in the coil springs are filled with air.

Wiring

As shown in the wiring diagram, there are four basic systems in an electric car: the propulsion system, 12 volt system, charging system and the driver's displays and controls. The propulsion system uses high voltage to power the electric motor, in this case 96 volts. The 12 volt system powers the accessories such as the radio and lights. The onboard charging system uses 120 VAC household current rectified to DC power to charge the batteries.



The driver's display and controls are pretty much the same as in a gas car. Although not shown in the illustration, the clutch pedal and mechanism are the same and the power brake system is the same except an electric vacuum pump supplies vacuum for the power brakes. The accelerator linkage is now linked to the potbox. Instead of a fuel gauge there is a voltmeter and there is an ammeter that measures the propulsion system amperage.

The propulsion system's battery pack is split between the front and rear of the car. Since high current, up to 300 amps, will be used in this conversion heavy duty 2/0 welding cable capped with heavy duty lugs is used for connections. In addition, a 400 amp fuse is placed in the circuit. To prevent corrosion a thin layer of Noalux is applied on each battery terminal.

Low and high voltage wiring of the components

On the 12 volt side, 16 gauge wiring is used throughout the vehicle, except the wiring for the 12 volt battery which is heavier. The existing ignition wire, 12 volt accessories, and components including the vacuum pump, and contactor are wired to a terminal strip. When the ignition key is turned to start the car, the contactor closes the circuit in the propulsion system. Although the circuit is closed, current will not flow to the motor until the driver accelerates.

Also wired into the car is a charger interlock which is a safety relay that opens the contactor while the car is charging. This prevents the car from being driven off while the car is still plugged into the charger.

The charger is an onboard transformerless unit with built in GFI (ground fault interruption). Input wiring includes 10 gauge household wire that is wired from the charger to a 110 VAC outlet under the front bumper of the car. Output wiring includes a positive lead from the charger to the top of the battery pack and a negative lead from the charger to the bottom of the battery pack. The charger has a built in ammeter so amperage can be adjusted according to the available current at the charging location. This means the car can be charged anywhere where there is available electricity.

Testing the Car

We've finally got the car together, or almost together, and it's time for a road test. Before heading out, the battery charger is tested and the batteries are charged. The 12 volt system, propulsion wiring, fuses, and battery terminal connections are inspected one last time and the air shocks are filled.

Now for the time we've all been waiting for. Turn the key to the start position. Instead of the usual "er-er-er-vrooom" you'll hear the contactor click then silence. Put the car in gear, release the brake, press the accelerator and off you go.

The first thing you'll notice is how quiet the car is. This will make it easy to spot any unusual noises or vibrations. The car should brake and accelerate smoothly. The vacuum pump should occasionally turn on to provide the proper level of vacuum for the brakes. If all checks out take a few laps around the neighborhood and enjoy your efforts. Don't be surprised if your car's range is shorter on the first run then expected. The batteries usually need about 40 charges before they meet optimum range.

The new EV is ready for its first road test