# *A Motor and Battery Primer*

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**How much Motor HP will you need?**

Selecting and calculating the right motor/battery system for your vehicle depends a lot on the weight of the vehicle, where you live and the surrounding terrain. If you live in a hilly or mountainous locale you will need more horsepower than if you live in an area where the grade is flat. It is also dictated by the vehicles aerodynamic profile before and after the conversion and its intended end use. A simple commuter vehicle driven in normal city traffic will require a much cheaper motor than someone who wants to win a race or have fast acceleration. There are many other variables.
This motor primer is something that is intended to help you understand how much motor HP you will require.
Here are some helpful hints on things that you should consider when selecting a motor and a controller that will match the motor.

## Speed

Your speed will be mainly be determined by the voltage in your battery pack. In a DC or AC motor 144 volts will usually get you freeway speeds of 70 + miles per hour.

## Range

The available power stored in the batteries will determine the distance that your car can go before you need to recharge. Power is a calculation of the voltage in the battery times the amperage in the battery times the useful power available in the battery without damage to the cells. Battery chemistry determines this figure. This does not mean that you cannot discharge the battery lower than these figures. To get the maximum life out of a battery cell then these figures should not be exceeded.
Lead Acid Batteries ------ Voltage x Amperage x .55% = Usable Available Power.
Lithium (LiFePO4) Batteries ------ Voltage x Amperage x .80% = Usable Available Power.

## The Horsepower Rule

It will take between 6 and 8 HP for every 1000 pounds of finished converted vehicle that is on the road. This is assuming the terrain is fairly flat with occasional grade changes of no more that 2%. You can usually find the gross vehicle weight printed on the sticker inside the door jamb of each vehicle.

## Regen

There is a great deal of misinformation floating around about the ability to recover power when the vehicle is slowing to a stop or going down a hill. This has been perpetuated by uninformed car sales people who are trying to capitalize on regeneration in order to sell more hybrid cars. Here is my take on this matter. It is very difficult to get regeneration from a DC motor. With an AC motor you will probably never get even 10% of your power recovered through regeneration. We consider 15% tops. If you want to install an AC system with regeneration, your system will cost more than a basic and straightforward DC conversion.

## HP Required Formula

Rolling Resistance (HP) + Aerodynamic Drag (HP) + Hill Climbing (HP) + Acceleration (HP)
Rolling Resistance is typically 1% for every 1000 pounds of vehicle weight on level ground traveling at a speed of 25 MPH, or 1.5 HP for each 1000 pounds of vehicle on level ground.
Thus a 4000 pound vehicle would require a minimum of 6 HP. 4000 x 1.5 HP = 6 HP.

## Aerodynamic Drag

Is a function of the speed squared and the frontal area. Your drag goes up exponentially. Meaning that if you drive a very aerodynamic shaped vehicle the drag may be about .7 HP at 25 MPH. If you drive the vehicle at 50 MPH the drag is increased to a little less than 3 HP. Most older cars have a drag coefficient less that the more aerodynamic cars of today so it would generally mean that you can figure a drag of 1 HP at 25 MPH and something over 4 HP at speeds over 50 MPH.

## Hill Climbing

Hills naturally require more HP. A 1% grad means that the elevation will increase 1 foot for each 100 foot traveled. You can use 1 HP for each percentage of grade. This calculation is the same as your rolling resistance. A 6% grade will require you to take 6 times the car weight rolling resistance to calculate the HP required. (Remember that it takes 6 to 8 HP for every 1000 pounds of car) Thus a 4000 pound car would require 4x6HP x 2 or 48 HP to push it 50 MPH up a 2% grade.

## Acceleration

Electric motors have a great deal more torque at slow speeds than an internal combustion engine. The Automobile manufactures try to impress people with the Horsepower that their motor puts out. They rarely mention the fact that the engine is turning over 6000 RPM in order to get that HP. Generally speaking it will only take about 13 HP to maintain a 4000 pound vehicle at 50 MPH.

## Watts per Mile

My experience is that it is a function of all of the above calculations. For normal driving you can usually count on drawing less than 400 watts per mile with a 4000 Lb. car using lead acid batteries. The deciding factor is how much your batteries weigh. With lithium batteries your car will weigh much less so you can usually get something below 300 Watts per mile. (often below 250 watts)

## Lead Acid Batteries

Figuring a generally assigned number of 65 pounds for a standard flooded lead acid battery, it will take you 24 each 6.2 volt lead acid batteries for a 144 volt powered car. Because of their robust design a 6 volt lead acid battery will last more than a 12 volt battery of the same chemistry. You can figure between 300 and 700 charge cycles dependent on the quality of the battery and voltage of a lead acid battery pack. A typical Trojan T-105, 6 volt battery will weigh 63 pounds. It will take 144 volts to get an average 4000 Lb. car to go freeway speeds.
That is 24 each batteries.
24 x 63 pounds= 1,512 pounds.
A Trojan T-105 battery has a 20 Hour capacity rating of 225 Amps. 225A x 6.4V x 55% = 792 Usable Watts/Hr.
1,584 watts x 24 batteries = 19,008 watts or 19.Kilowatts.
Giving the cautious driver, under somewhat ideal conditions, a range of 19000/400 = 47 miles

## Lithium (LiFePO4) Batteries

The energy density of lithium is much greater than a lead acid battery. As a result they weigh much less than a lead acid battery. A 200 Ampere Hour ‘AH’ lithium prismatic battery will only weigh 16 pounds. A 100 AH prismatic lithium battery will weigh almost exactly half or about 8 pounds. However , you must remember that a typically lithium cell only produces 3.2 volts so you will need 1 of them at 16 pounds to give you the same 6.4 volts. A 200 AH prismatic lithium in a pack packs will occupy about 45% the space of a lead acid battery and at 200 AH will carry nearly the same energy as the equivalent lead acid battery. Keep in mind that lithium has a capacity of 80% of their full state of charge. Thus 48 each time 3.2 volts times 200 AH batteries times 80% will have a usable stored wattage of 24,576 watts or 24.56 KW, 48 x 8 pounds = 768 pounds. 50.7% the weight of the lead acid batteries. Because of this weight difference you can usually get about 50 miles range out of a 100 AH pack and about 100 miles in a 200 AH lithium battery pack.

**Battery Economics:** Lead Acid verses Lithium

| | Lead Acid (Trojan T-105) | 2 Lithium HiPower 100Ah-200Ah Cells |
|---|---|---|
| Voltage | 6.4 Volts | 6.4 Volts |
| Amperage 'AH' | 225AH @ 20hrs | 100AH-200AH |
| Usable Watts (Volts*Amps*discharge level) | 55% = 792 | 80% = 512-1024 |
| Price | $105+25 shipping | $230+$10 shipping-$420+$20 shipping |
| Weight In Pounds (kg) | 65 with connectors etc. | 15-29 with connectors etc. |
| | | |
| Batteries Required In A 144v Installation | 24 Each | 48 Each |
| Weight In Pounds (kg) | 1560 (707) | 350-696 (158-315) |
| 100 AH Battery Pack Cost | Na | $5,760 |
| 225/200 AH Battery Pack Cost | $3,120 | $10,560 |
| Battery Life In Charge Cycles to 80% | 750 | 2000 |
| Cost Per Stored Kilowatt Over Batteries Life | $.00678 | $.00426 |

**Polymer and Cylindrical Batteries Verses Prismatic Batteries. The 'C' Ratings of Lithium's**

For average driving the best value in Lithium batteries is the square shaped prismatic battery. However, if you want to have the ultimate in performance you probably should consider a different lithium battery construction. Most prismatic batteries on the market will be capable of discharging at a peak discharge current for up to three times their continuously operating current for time duration of less than 30 seconds. This number is referred to as the C rating. So a Peak Discharge rating three times over the continuous drain on a battery would be defined as 3C. Frequently operating any battery in excess of its continuous operating rating of 1C will shorten the life of the battery.

**Cylindrical Cells**

Typically a Cylindrical (Round) battery can operate for a brief period of time at a much higher C rating than a Prismatic battery. Often in excess of 8C's. Cylindrical batteries will usually cost you about 30% - 60% more than a prismatic battery and the total pack will weigh more and take up more space than a prismatic battery for an equivalent pack voltage. Cylindrical lithium cells can be found in great abundance in smaller sizes from .5 to 3 AH. Cylindrical cells over 5 AH are not common. Interconnecting a large quantity of Cylindrical cells in a serial, for voltage, and parallel, for amperage, combination is a daunting task that the manufacture will often supply at no charge but usually is left to the consumer to figure out.

**Polymer Batteries (aka "Pouch" Cells)**

Polymer lithium cells are usually supplied in a flat square aluminum foil shaped packages with positive and negative tabs. Often the tab thickness is utilized to carry away excess heat. Thus the price on a single cell size will often vary on the tab length, width and thickness. They come in various sizes from small in amperages all the way up to 30 AH. They have C ratings from 3C's to 30C's. This means that they can deliver a tremendous amount of current for short durations of time. Typically a polymer pack will weigh about 30% less that and equivalent Prismatic cell. A Polymer cell will usually cost between 60% and 150% more than an equivalent prismatic cell in a pack. Some manufacturers have even higher price.