"DO IT RIGHT THE FIRST TIME ! "

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Building an EV takes Time and Money. It requires 100-200 hours of labor and $5000 - $9000 in components. That is a major commitment, <u>so why not do it right the first time</u>?

That is exactly what Seth Murray did as a high school student. Electric Vehicles of America, Inc. (EVA) worked with him to ensure that his Electric Vehicle (EV) was right for him.

But first, we must define "what is right?". What is right for one individual and one application may not be right for another individual with a different application. So we must define the process, which consists of four major steps:

1. *Identifying your requirements.*
2. *Selecting the vehicle.*
3. *Selecting the EV systems.*
4. *Installing and testing the systems.*

Let's look at each one in detail.

1. IDENTIFYING YOUR REQUIREMENTS

This is the major decision. Ask yourself the following questions:

Why do you want an EV?
Where will you drive it?
Who else will drive it?
How many miles do you require on a daily basis?
How often will you drive the vehicle?
With or without passengers?
Will your employer allow you to charge at work?
How much do I want to spend?
How important is safety and reliability?
How much time do I have for the conversion?

These are important questions that must be answered.

Seth's criteria was to build an EV to compete in the 2002 American Tour de Sol (ATdS) Race sponsored by Northeast Sustainable Energy Association (NESEA). The race was from Washington, D.C. to New York City with some days requiring a range of 70 miles. This was a difficult challenge for many high schools, colleges and EV businesses. Seth was only a high school student, and his funding was from his part-time job cutting lawns and family donations and gifts.

In addition to the range, Seth was looking for an EV that could be used every day, so it had to be reliable, practical, and simple using proven technology. In the final analysis, the criteria became:

Range - Minimum 50 miles with the ability to go 70 miles if needed.
Acceleration - Reasonable; keep up with traffic.
No. of passengers - one
Safety - Maximum possible, at least as good as the original vehicle
Technology & Innovation - Use proven technology

Now the difficult step of translating those requirements into a specific vehicle and system.

2. SELECTING THE VEHICLE

Basically, there are three classes of vehicles: (1) Sports cars, (2) passenger cars and vans, and (3) trucks.

(1) Sports cars,
such as the Honda CRX, Pontiac Fiero, Toyota MR2, Porsche 914, Fiat X-19, Nissan Pulsar, MGs, Datsun 240Z. Sports cars have limited space and minimal payload capacity.

(2) Passenger cars and vans,
such as the Ford Escort, VW Rabbit, VW Beetle, Saturn, Honda Civic, Geo Metro, VW Vanagan, and Dodge Caravan. Vans are considered herein as a passenger car because they require the batteries inside the passenger compartment. The payload capacity within this class varies considerably from Geo Metros with a payload of 600 lbs to the VW Vanagan with a payload capacity of almost 2000 lbs.

(3) Trucks,
such as the Chevrolet S-10, GMC S-15, Ford Ranger, Dodge Ram and Rampage, and VW Rabbit Truck. Trucks have the advantage of locating batteries outside the passenger compartment and typically have a frame which permits a higher payload capacity.

Each of these classes have their own characteristics with respect to aerodynamic drag, curb weight, Gross Vehicle Weight Rating (GVWR), passenger compartment, and available space for batteries.

Before we select a vehicle, one must consider the battery system. Lead acid batteries typically cost $2000 or less. Many types of batteries and energy sources are being promoted, including Nickel Cadmium (NiCd) , Nickel Metal Hydride (NiMH), Lithium Ion, and even fuel cells. But the price for these batteries can be prohibitive, and many require special chargers. For a 20 kw-hr pack, the price can vary from $10,000 for NiCd, $30,000 forNiMH, and $100,000 or more for a fuel cell.

I prefer wet batteries vs sealed lead acid because (1) they typically provide more miles/ pound (2) they can take more abuse and (3) they cost less per mile (~10 cents/mile).

Most people use lead acid batteries, so there are two important considerations:

Weight of Fuel - Range is a function of lbs of fuel whether the fuel is gasoline or lead acid batteries. It takes 15-20 lbs of lead to achieve 1 mile in range. The lower number is for sportscars; the higher number is for trucks and vans. So if you want a range of 70 miles, then you will require a battery pack weighing 1050 - 1400 lbs.

Ratio of Battery Weight to Total Vehicle Weight - A Rule of Thumb is that about 30% of the EVs weight should be batteries; the other 70% represents dead weight (i.e. frame, suspension, body, motor, etc.). Naturally the greater the percentage of battery weight to total weight, the greater the range.

This clearly shows that the three most important considerations in selecting a vehicle are (1) curb weight, (2) Gross Vehicle Weight Rating (GVWR), and (3) available space.

(1) <u>Curb Weight</u>
Curb weight is the weight of the vehicle parked at the curb. No passengers and no payload. If you want to have 30-50% of the finished weight in fuel; then the initial curb weight of the vehicle should be less than 3000 lbs. The Geo Metro is one of the lighter vehicles with a curb weight of 1695 lbs. Consequently, an 800 lb battery pack seems ideal, except that GVWR and weight distribution become a major problem.

(2) <u>GVWR and Distribution</u>
This is the most important consideration in any vehicle, because this directly affects the safety of the vehicle (Refer to "Safety First" tech paper). As previously stated, converting an existing vehicle to an EV will add 800 - 1400 lbs in curb weight. Check the Gross Vehicle Weight Rating (GVWR) of the vehicle including the tires presently on the vehicle to see if it is designed for this increase. The GVWR and each axle rating are located on the drivers side door jamb. If the GVWR of the vehicle is exceeded, then the vehicle frame, suspension system, and braking system may be beyond their design value.

Although the Geo Metro can perform with an 800 lb battery pack, the payload capacity of the vehicle is 600 lbs. Payload equals GVWR minus curb weight. With two people in the Geo, the available payload decreases to 300 lbs. Consequently, an 800 lb battery pack can lead to braking and handling (See FWD vs RWD above) as well as a long term fatigue problem with the unibody. The lightest vehicle is not always the best vehicle.

(3) Available Space
You must also consider where the EV components will be located. Where will the batteries be located; they are the bulk of the additional weight. How will the weight distribution affect the vehicles handling?

Of course, there are other considerations, including:

Manual Vs. Automatic Transmission
Most EV conversions are manual transmissions because they are more efficient than automatic transmissions and provide greater range, require less motor torque, require no transmission cooler, and are easier to convert. The problem with an automatic transmission is that it shifts at about 2000 rpm; the electric motor is usually designed to operate efficiently between 4000-5000 rpm. Consequently, the automatic transmission is a poor choice which results in decreased range. If you buy a vehicle with an automatic transmission, you can replace it with a manual transmission. The additional cost is $150 and up depending on the transmission and used auto parts dealer. Consider trading the automatic transmission.

Front Wheel Drive(FWD) Vs Rear Wheel Drive (RWD)
A FWD vehicle has the advantage of being more efficient; which improves range. However, front wheel drive vehicles typically have smaller engine compartments which limit the location of batteries. Also, the front -wheel drive vehicle requires more weight (typically 60 percent) on the front axle. If you locate batteries in the trunk, the tail can wag the dog in rain or snow. This is a problem with many Geo Metros with batteries in the trunk.

In addition, the high voltage, high amperage EV controllers and motors can produce greater torque and horsepower than the original engine in the smaller FWD vehicles. This can produce a problem. There are two distinct limitations for FWD vehicle. During "launch"(initial take-off from a standing start) all cars tend to pitch up (front rotates up relative to back.) This is because the center of mass is above the force being exerted by the tires against the road. In a RWD, this pitch tends to plant the driven tires more firmly against the road, thus enhancing traction. In a FWD the effect is opposite. The force pressing the drive wheels against the road is reduced because of the pitch. If power is applied while the car is in a turn, RWD is much more stable. If the rear wheels spin, the car over-steers. If the front wheels spin, the car under-steers and may easily spin out.

Power Steering
Power steering is not recommended because of the continuous power required of the battery system. Even on many of the trucks that we converted, we eliminated the power steering. The cost to change from power steering to a manual steering box is under $100 and less than 1 hour of work. The equal weight distribution allowed reasonable manual steering.

Power Brakes

Power brakes are a definite advantage as you increase the weight of the vehicle approximately 800-1200 lbs with the EV components. In many cases, this represents an increase of 20   25 percent in the curb weight of the vehicle. Your goal should always be to have a safe vehicle. Power brakes unlike power steering are only an intermittent energy demand. A typical system requires a vacuum pump and a vacuum switch.

Availability of Spare Parts / Age of Vehicle

Spare parts should be available. This availability is related to the production of that specific vehicle and which part of the country in which you live. Also the availability of after market parts for suspension upgrades can be important.

It pays to do your research using old Consumer Report, Motor Trend, and other publications. Over the last 15 years, I have been surprised at some vehicles. For example, a high performance Mustang II (8 cyl) had a GVWR of 4000 lbs while having a curb weight of less than 3000 lbs. Not much different than a truck.

For Seth, his requirements defined the following type of vehicle:

- *A light-weight truck*
- *A manual transmission*
- *No power steering*
- *Power brakes*

Seth selected an S10 because it has more space between the frame rails and the drive shaft. This allows more space for battery boxes under the bed when a tilt bed is used.

3. SELECTING THE EV SYSTEMS

First, lets look at the major EV components and their relationship between each other. They are all related.

Vehicle Design => Battery Weight => Controller Voltage & Amperage =>
Controller Voltage & Amperage => Motor hp => Vehicle Performance

The selection of the motor and controller is a major decision when building any EV. These two components help establish the performance of the vehicle as well as the cost. The motor and the batteries establish the voltage, horsepower, vehicle weight.

These components or systems are the foundation for the EV. The decision on any one component prematurely can affect adversely the performance of the final product. For example, one customer had purchased a bargain motor which was to be used even though it was undersize. After he burned up the small motor, he bought the correct motor for his application.

To ensure that components are sized correctly for the application, Electric Vehicles of America Inc. (EVA) performs detailed calculations based on:

Vehicle Description System Design
- Initial Curb Weight -Motor
- Drag Coefficient - Battery
- Frontal Area - Voltage

But let's look at the output:

- The required horsepower
- The estimated amperage
- The horsepower under various terrain and speeds.
- The estimated range

For the S-10 truck which is one of our specialties, the results based on 50 mph are:

	RANGE		
HP REQUIRED	*MINIMUM*	*AVERAGE*	*MAXIMUM*
26	*45*	*61*	*92*

The calculation also identifies the hp, amperage, and range at various grades and speeds. The use of engineering calculations allow you to size components and compare the performance of different battery packs and voltages before you ever make a purchase.

We believe that this type of analysis is essential in selecting the right components. There are a number of other systems for an EV, including

Drive system
Battery system
Instrumentation
Power Brakes
Safety Systems

Let's look at the Safety System in a little more detail. The principal concern is personal safety and the prevention of damage to EV components; safety techniques include:

High Voltage components mounted on a non-conductive material
Multiple fuse within the battery pack
Use of a primary and a secondary contactor
Anderson Disconnects between batteries & controller
Battery covers over terminals
Batteries located in crush zones so they take the impact
First Inertia Switch to shutdown the systems on impact.

For more on safety, see EVA "Safety First" tech paper.

It is important that Safety personnel (i.e. Police, Fire, EMTs, etc.) know that your vehicle is an "Electric Vehicle" before they start cutting the body to extract occupants. This can be as simple as an "Electric Vehicle" emblem or decal. In addition, the Emergency Disconnect should be identified.

Seth incorporated many safety features into his S10 which he attributes to minimizing any injuries when his father and he were hit by a full size truck going substantially faster.

4. INSTALLING AND TESTING THE SYSTEMS

Installation and testing is the final step in doing it Right!

As we previously discussed, layout of the batteries is critical for weight distribution. Each component needs to be evaluated for its best location in relationship to the other components as well as how it will be tested and easily removed. Design for maintenance.

Layout of the high voltage components is critical for safety. If you use the control board concept, you can run the cable thru drilled holes in the board. You can also mount components on the bottom of the board.

We recommend that you use pieces of welding cable to see how the cable will be routed between components. Also how will the small wiring be routed. Will it look like a professional job? Or will it be haphazard? Appearance is the critical.

Testing the vehicle ensures that each system operates correctly and shows how to troubleshoot a component or system. Once the vehicle is road worthy, we encourage:

Testing to determine the maximum speed in each gear
Testing to establish a baseline as well as to compare to calculations.

Our EV Installation Manual identifies the test procedures in detail.

CONCLUSION

Your EV can meet your objectives - it can be Right For You! Take the time to understand the process.

Seth achieved success because the vehicle meet the following:

Affordability - Seth Murray, while in high school, converted an S-10 using his money with help of gifts from parents and grandparents.

Design Features - Seth's S-10 passed the technical testing at the ATdS the first time, receiving one of the highest scores.

Performance Criteria - The S-10 did 80 miles on his longest run before being rear-ended by a larger truck. More range was available.

Safety Features - The S10 was in a major accident with a full size truck, but Seth and his father received minimal injuries because the S-10 took the impact.

Maintainability - Components are easily replaced. Most components can be replaced in less than 30 minutes!

Success was achieved because it was done Right The First Time!

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See Seth's Truck at Seth Murray's '85 Chevrolet S-10

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"Meeting the Needs of Electric Transportation"

"Do It Right The First Time"
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