BUILDING YOUR OWN EV USING A MODERN DONOR.

Introduction.

The lack of available manufactured EVs, the price of those that are available, and the urge to tinker mean that there will remain a place for home conversions for some time to come.

At first, the task looks insuperable, but, if you take it in stages, it is not really that difficult. The trick is to get the stages right. So, here goes…

Choosing a donor vehicle.

This is the critical decision, and be prepared to take some time over it. I will break it down into some DOs and DON'Ts:

Dos

- Decide how many people are to travel in it. Be realistic. Two is the common number, but maybe four will need to travel often enough to justify the extra work and expense.
- Decide where you will be driving it. In hills? In the city? On country hauls? How far? Again, be realistic. Build for around 90% of your demand. (Unless, of course, you have an unlimited budget, in which case, think Tesla).
- Consider the speed limits of the roads you will use. If your EV will only do 70kph on a !00kph road, you will be a menace to everyone including yourself.
- Choose a vehicle which will present the least problems for conversion. Think about computers, power steering, and availability of parts.
- Check that the motor will fit in the space it must go in.
- Having ascertained your power requirements, check that the vehicle can carry the necessary batteries, both for space and weight.
- Consider that you will probably need the car to run for 10 years to amortise your work and investment, so choose a vehicle that is not so old that it will collapse before that time. Ie. You should choose a reasonably modern donor.
- Check for things like power steering and brakes. How will these be retained? Electric power steering is a lot simpler than hydraulic.
- Consider a vehicle model which is suitable and has been converted previously. As you read on, you will see what this entails. You can gain by past experience.

Don'ts

- Don't just choose a vehicle because it is available or cheap. Make sure it meets your criteria above.
- Don't select complex vehicles. Replacement parts can be a nightmare, and getting information about computers can be difficult.
- Don't rush your choice. When you think you have found a model, consider how everything will fit.

- Don’t buy a battered version of your selected model because it is cheap. Getting it up to scratch to pass inspection can set you back more than a good one. The donor vehicle’s cost will pale beside the cost of conversion, so be careful.

Choosing the motor.

Once you have chosen the donor vehicle, you will need to choose a motor. This breaks into two parts:

- AC or DC
- Size/power.

The AC vs DC argument is tricky. Most (if not all) manufactured EVs use AC.

The advantages of AC are:

- Regen is included.
- They are more efficient.
- They are the “modern” choice.
- They tend to be slightly lighter.
- No brushes to wear.

The disadvantages are:

- Cost. Both motors and controllers tend to be more expensive.
- They will need a gearbox in most cases, as they need revs to develop torque. There are exceptions, but they are expensive (consider a Tesla).
- AC is a little more complicated for beginners.

If you are intending to use your EV on flat country or in the city, you might find that the amount of regen energy available will never recoup the extra cost of AC over DC.

I suppose this really boils down to personal choice and whether you feel the need to be “cutting edge”.

Note that permanent magnet DC motors are very efficient, but are hard to find with enough power.

Separately excited DC motors can provide regen, but are usually only available for smaller vehicles. Their controllers are more expensive as a rule, and they can be fiddly to set up for smooth regen.

The power rating of electric motors can be quite confusing. We are accustomed to cars having 80-150kW in petrol guise, so a 20kW electric motor looks pretty feeble. Don’t be fooled! A 20kW electric motor can put out much more, and its torque can be massive.

Typically, a “30kW” electric motor might deliver up to 60 or more kW and its torque might exceed that of its of 100kW petrol counterpart.

Confusing? Yes! Look at what others are using, and how they work.

Note that the cheaper Chinese motors tend to be heavy in relation to their power. This might cause an issue with weight.

The battery.

To date, the choice of batteries is limited to Lithium Iron Phosphate (LiPO) and Lead Acid (PbA). The latter being the older (and much heavier) option.

LiPO batteries have dropped markedly in price since their early appearance to the point where they are probably cheaper than PbA on a whole-of-life basis. Typically, 10+ years for LiPO and 4 for PbA.

Strictly speaking, the battery is the total pack made up of individual cells. LiPO come in individual 3.3Volt cells, while PbA comes in batteries made up of individual cells of 2Volts each.

Pb comes in 6,8 and 12Volt batteries, but most builders opt for the 12Volt version.

Considering the cost of a good conversion, the obvious choice for all but the most cash-strapped will be LiPO.

It doesn't end there. Batteries can be made up of any number of cells, and these cells come in a dazzling array of shapes and capacities (Amphours).

There are even second hand cells from crashed Nissan Leafs and the like, trickling onto the market.

The Voltage in Volts multiplied by the capacity in Amphours (Ah) will give the total power of the battery in Watthours (Wh). If you divide this by 1000, and then reduce the number by 20% (multiply by 0.8), you will have the available energy from your battery in kWh. This is the term that you will come across in EV circles.

The number of kWh that your car will need, will depend on the mass of your vehicle, where you drive it (terrain), how you drive it (fast or slow), and the general efficiency of your drive system.

Everyone will have a different figure, but around 180Wh/km of travel is a reasonable starting point. Add a bit for a big EV, and take off a bit for a Sherpa or Matiz.

You will see that the more cells you have, the higher the voltage, so you will use less Amps to get a given performance. More and bigger cells will increase your kWh.

So, how much is enough?

For very small cars, which will be used only around town, you can get around with as little as 72 Volts at 80-100Ah. This will give around 5.5kWh of available power, which equates to around 30km. This might be enough for local running, and the cost of such a conversion can be comparatively low.

Most builders will set their sights higher, and go after a range of 100-150km, which will require around 30kWh. This is a big pack, and many will moderate their expectations accordingly.

This is the time to examine how the cells will fit into the car. Hopefully, you still haven't bought your chosen vehicle, so you must find one that you can measure and crawl around.

The cells can be divided into more than one pack, and can be distributed in the vehicle for good weight distribution. A lot of packs will become a nightmare to connect, so be careful in how you choose.

You **must not** need to cut or modify any structural member of the car. If you do, you will cause yourself massive headaches when it comes to inspection and approval.

DO NOT MIX TYPES AND SIZES OF CELLS!!! Every chosen site for a pack will have to accommodate the same sized cells.

Small packs of cells are more easily restrained, but each box will need to have its strength and anchorage approved. Try to standardise your designs.

Remember that the various packs of cells will need to be interconnected, and long interconnections will cause losses through resistance.

All of these factors tend to limit the voltage to about 120-144 Volts. For DC motors, this seems to be the maximum recommended on most cases. The higher the voltage the faster the motor will turn.

If you are sure that you can get all your required cells into your chosen vehicle, you need also to think about the space for the controller and charger, plus any other equipment needed. It not only has to fit, but the cable lengths between parts must be as short as possible.

The controller.

The controller must be big enough to deliver the current required by the motor. Otherwise, you will be very disappointed.

Big motors in big cars will draw heavy currents under acceleration. However, the higher the voltage, the less current will be needed for a given performance.

If you are buying from a reputable retailer, he will probably recommend a good matching pair of motor and controller. Otherwise, ask around, and see what others have done successfully. It is not hard to do.

The controller must be kept cool and dry. This means away from the bonnet and other sources of heat. It also means keeping it away from open grilles. A fan might help in very hot weather, if necessary.

The other stuff.

The rules state that whatever features the original donor car had must be retained. That is, vacuum boosters, power steering, windscreen demister must all continue to work.

Warning lights for the brakes must still come on when the ignition is turned on, and must go out soon after.

Fortunately, none of these are particularly difficult, but some cost more than others, and some use valuable battery power.

The brakes must remain boosted after the ignition is switched off, but this can normally be achieved by a non-return valve in the vacuum line. Failing that, a small reservoir will do the trick (but it needs space).

Hydraulic steering assist is available after market, but need space and uses power.

Electric power steering is becoming more popular, as it uses power only when turning.

Heaters for the windscreen are available to hook up to the existing pipes. While they are a little more expensive than some home-made systems, they are easy to install and take up little room. The old radiator reservoir can be used. All this saves pulling the dash to bits, which can be tricky and time-consuming. It is also quick to get at if things need work.

Other stuff includes fuses, inertia switches and so on. I have found that it is handy to provide junction boxes for 12V continuously live, 12V actuated by the ignition switch, and another for HT voltage. This saves searching for wires to splice into, and with appropriate fuses, you know that every appliance is properly protected.

If you number the terminals, and keep records, these junction boxes become an invaluable point for running diagnostics.

Final decisions.

Up until now, you are better off without the donor car in your garage. It will just gather dust and make you feel that nothing is happening. It will also cost you money.

Now you are ready to search for the perfect donor. You have learnt whether your first choice earlier is still the right one. You can reassess everything in the light of what you have learnt as you go through all the above steps.

You might well decide to rethink you original choice. If you have already bought, you are locked in.

Getting the official word.

Now you know what you are going to build; which car, motor and battery, etc., you can fill in your application to convert a motor vehicle.

This form changes from time to time, but is your notification to the Motor Vehicles Department of your intention to alter a particular model, and what you intend to do.

You will receive a Statement of Requirements in return, and this will remain in force for a year or so. The important thing here, is that these requirements are all that you will be held to, and if you think that you will need extension of time, you should get that extension before the expiry date, or new conditions might be imposed.

The Statement of Requirements will require that the vehicle meets the Design Rules that applied to your original vehicle plus others relating to Vehicles Fact Sheet MR648 as current.

These requirements will almost certainly require certification by an accredited engineer. This is the time to find one, and make arrangements for his/her involvement.

You are now on your way!

Starting work/clearing things out.

You will need a covered area (shed) with sufficient room to get at all sides of the vehicle. A standard garage should be enough, and a pit is a worthwhile bonus.

It will be a great help if the donor vehicle is registered, as your first act should be to weigh it front and rear and in total, and get an official weigh note. You will need this later.

It will also enable you to test your conversion and get to and from the final inspection without hassles.

Disconnect the wires from the motor and label them. Identify those cables that feed a computer, and measure voltage outputs where possible. Some of these cables might need a feed signal to allow the computer to continue working.

Do not cut any cables at this stage. Cables that run fore and aft can be useful for new purposes.

Remove the motor leaving the gearbox if you wish to retain it. Pay particular attention to the location of mounts for mid-half-shaft supports in front-wheel-drive vehicles. These will need to be remade in most cases.

Remove the radiator and fuel tank plus exhaust system, and any other redundant bits relating to fossil fuels.

If you can, weigh the components removed. This is not essential, but helps you to know where the weight is coming from.

Make up templates for the motor and battery to see exactly if and where things will fit before making them. Cardboard cartons and the like are useful here.

Remember to allow about 10mm more width, as the cells might swell or be slightly curved. Any excess “rattle room” can be packed with a piece of hardboard.

Draw up the design of the box/s the way you think they will be. Look for suitable anchorage points for the motor and battery box/s. Usually, it is possible to mount the motor off the existing engine mounts, but they don’t have to do this. Battery boxes will need to be attached to strong points to prevent them ripping out.

Bolts through box sections will need crush tubes to prevent distortion. You will need access to install these. Basically, you will need to have mountings/attachment points that can withstand twenty times the weight of the box plus battery in it.

Send your draft designs to the Engineer for his/her comment and instruction.

While everything is out of the engine bay, give it a good clean, and even a paint, as it will never be easier to get everything clean and tidy. Mask off wires and remaining components to achieve a workmanlike appearance.

Remember that your work will be inspected, and a tidy job will go a long way in convincing the inspector that you know what you are doing.

Tools.

Obviously, more and better tools will make life easier. However, quite basic tools will get you a long way.

Essential tools are:

- Pliers

- Hammer
- Vice
- Crimper/wire stripper
- Portable drill (preferably cordless)
- Screwdrivers
- Spanners
- Hacksaw
- Tin snips
- Multimeter
- Soldering iron (electric)

Desirable tools are:

- Drill press
- Welder
- Trolley jack
- Ramps or pit
- Double-end (bench) grinder
- Angle grinder

The build.

At last, you can start to the actual build. There are three major things to do at the start:

- The conversion plate to join the motor to the gear box. This includes the coupler to connect the shafts.
- The motor mounts. This will include the outrigger bearing on the front-wheel-drive axle if there is one.
- The battery box/s

These tasks can be done by others if you are not able to do them yourself. Do what you can, but don't compromise the job.

Once these parts are made, it is tempting to put them straight in, but it is well worth getting them Zinc passivated or painted with epoxy paint. It will take a few days, but it can be very dispiriting to have you project rusting before it is even finished.

It can be worth doing a trial assembly before the above, just to make sure that everything fits.

Don't forget to fit crush tubes where necessary, and it is a good idea to photograph them as they are fitted. This will be evidence that they are there if asked.

Backing plates for bolts through thinner sheeting should be well rounded at the corners to prevent tearing under impact. Better still, use round backing plates where possible.

Next, install the controller. Remember to keep it dry and cool.

As you build, resist the temptation to "bury" anything under another component. Inevitably, the part most deeply buried will be the one that fails and needs replacement.

The various other components can now go in. Keep wires short to reduce resistance.

Use as many coloured wires as you can, and try to follow some pattern to help you trace things. For example, use orange for high tension (HT), brown for any 12V cable actuated by the ignition, red for permanently live 12V, green for the reversing circuits, yellow for enabling, and so on.

A Dymo label maker is a very handy tool. Labelling wires really helps both during the build and later.

It is still wise to record your circuits. Don't necessarily try to do one complete diagram like the ones in car manuals. Individual circuit diagrams for each separate circuit can be easier to follow, particularly if you have colour-coded.

Check each circuit as you complete it. This is simpler in the long run, as when you are finished, and if something doesn't work, it can be daunting.

The charging circuit.

This is fairly straightforward. You will need a charger of the correct voltage, usually bought at the same time as the batteries.

There will be a 240Volt input from the external "filler" point to the charger. This must comply with wiring regulations. The shorter the cable the better.

The charger output will go to the battery (+ to + and – to -). However, the battery cells will probably be distributed at both front and rear of the vehicle, so one of the cables will need to be carried to the front. This is an HT cable, and should be suitably protected and identified.

If there is to be a meter to record power usage, it is important that the charger cable is connected on the correct side of the sender unit.

The charging cables will carry a reasonable current, and should be suitably heavy. ($16mm^2$ is usually fine).

The charger will usually be connected to the battery management system (BMS) so that the charger shuts down if a BMS module directs.

The BMS will also be wired into the enabling circuit as part of the "daisy chain" which includes the fuel filler.

The auxiliary (12V) battery will also need charging. This battery must be able to supply power for as long or longer than the HT drive battery.

The simplest way to achieve this is to fit a DC/DC converter, which continuously charges the 12V battery from the HT battery.

The above enables you to use a smaller (lighter) auxiliary battery, and does away the need for a separate 12V charger.

If you use a small $LiFePO_4$ auxiliary battery, you will also run that circuit at 13.3V, which is close to the real voltage in a running petrol car.

The 20Ah battery and DC/DC charger should fit in the original battery cradle, which is very neat.

Don't forget to fit fuses.

Joining new to existing.

This can be tricky if you don't have the wiring diagram of the original donor.

If you kept all the old wiring (as I recommended), you can find an ignition wire (there might be more than one. This wire will have a fuse of the right value foe everything on it including the engine.

The ignition wire will certainly have the capacity to drive a simple 12/12V relay which can switch on a line directly from the auxiliary battery (don't forget the fuse!).

The relay can then feed a junction box (mentioned earlier), from which wires can be run to the various new components through a fuse box with appropriate fuses for each. This is simple, easy to follow, and contains no nasty surprises. Number the fuses, and record what they supply for later.

If your car has a computer or several, they might not allow things to happen without an "OK" signal from the now non-existent motor. This is where your earlier precaution of measuring signals in the various wires pays off. You will need to replicate those signals to make things behave. A friendly mechanic will be invaluable if you get in strife.

Sometimes the computer will be specific to the original engine management, and you can bypass it altogether. My advice is to leave everything in place, and cut nothing unless you are absolutely sure.

Any leftover original wires can be masked, rolled up, and stored in neat junction boxes against future need.

Rev counters frequently run through a computer. They usually count pulses, so it might be possible to rig up a Hall Effect sensor on the motor. Sometimes it is much harder, and you will have to decide whether you really need it, or whether to install an aftermarket version.

If you have removed the gearbox, and have an old mechanical drive speedometer, you will need to find another system. Grafting an aftermarket speedo into your dash is possible, but fiddly work. An aftermarket speedo running off the tailshaft/diff works well, but getting it to look good is hard. Every vehicle will be different.

The Fact Sheet states that you must have a system to disable the car while charging. A simple proximity switch on the filler lid, and connected into the enabling circuit will do the job well.

Most builders try to use the original filler cap, as this looks tidy, and everything seems to fit in most cases.

The old fuel gauge wire can sometimes be utilised in the above circuit, but it can sometimes be easier to buy a length of trailer loom containing 7 coloured wires, and run this under the car. It is neat and easy, and leaves plenty of wires for all manner of tasks.

Wiring.

A fair bit has been written about wiring, so I will set out some guides:

- Record what you do.
- Label wires and components.
- Keep like with like.
- Colour code your different types of wire.
- Make sure that everything is on a fuse

- Crimp all terminals well.
- Use wire of sufficient gauge.
- Keep it tidy.
- Try to avoid taping wires in long looms so that you can't trace them. Split conduits make access easier.
- Avoid flapping wires.
- Check as you go.
- Install junction boxes and fuse boxes to keep things together.
- Don't hide bits like fuses and relays.
- Protect relays and other delicate bits from the elements.
- HT cables should be orange, in solid ducts, and tucked up well out of harm's way.

Finishing off.

When you think that you are finished, check against the Fact Sheet MR 648.

Drive the vehicle around the block (if you have kept it registered).

Check the temperatures of the HT terminals. They should not get hot. Use an infrared thermometer, not your hand.

Remember that controllers are full of **capacitors which remain charged for some time after the HT power is switched off.**

Get the vehicle weighed fore and aft and in total, and get a certified weigh note. You will need it.

Check that you have not exceeded the allowable loads, and that fore and aft weight distribution does not vary too much from the original in percentage terms.

Have your Engineer inspect and sign off on the items in the Statement of Requirements.

Get a mechanic to give the car the once-over for roadworthiness. Things like bushes, brakes and hoses, steering, tyres, rust, lights, etc. This is why it is so important to start with a good donor.

When everything looks right, book your inspection.

Present your vehicle clean and tidy, with all your work looking professional. First impressions will influence the way that the inspection is carried out.

Conclusion.

Even at about ten pages, this document must be superficial. It is intended to show the steps needed in the right order.

I make no recommendation here about brands or sources. These are readily available on enquiry at any meeting of AEVA or on the net.

I assume that the builder can read, has some access to the internet, and has at least rudimentary mechanical skill and tools or access to them.

The builder should learn two formulae:

- **V=IR ,** V is the voltage in Volts, I is the current in Amps, and R is the resistance in Ohms. As with all equations, the terms can be manipulated so that you can determine any one if you have the other two.
- **P=IV,** where P is the power in Watts, I is the current in Amps, and V is the voltage in Volts.

Finally, the builder has do decide how much time and money they have to spend. If you haven't enough of either, your project will join the list of broken dreams. You won't get your money back.

None of this is meant to scare you; rather it is intended to show that it is possible, but only with thought and planning.

GOOD LUCK

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