EVtv Motor Verks

CALB CA180FI

Lithium Iron Phosphate
LiFePo4 Cell
3.2 volt nominal
180 ampere-hour capacity
576 Watt-hours

Power output: 540 amps continuous - 1800 amps for 30 seconds

Charging: CC/CV to 3.60v at up to 540 amps 32-113 F

CC/CV Termination: 9 amperes at 3.60 volts.

Discharge Temperature: 0-113 F

Fully charged open circuit voltage: 3.40v

Fully discharged cutoff voltage: 2.50v

Cycle life to 100% discharge: 2000 cycles

Cycle life to 80% discharge: > 3000 cycles

Termninal: M8 1.25 x 16 stainless
Torque to 20 NM or 14.75 ft-lbs

Includes 70 mm tinned copper braided strap,
two stainless terminal bolts, and two
zinc coated Nord-Lock washers

Alternate 76 mm braided straps allow
adjacent (edge-to-edge) configurations.

EVtv Motor Verks

CALB CA100FI

Lithium Iron Phosphate
LiFePo4 Cell
3.2 volt nominal
100 ampere-hour capacity
320 Watt-hours

Power output: 300 amps continuous - 1000 amps for 30 seconds

Charging: CC/CV to 3.60v at up to 300 amps 32-113 F

CC/CV Termination: 5 amperes at 3.60 volts.

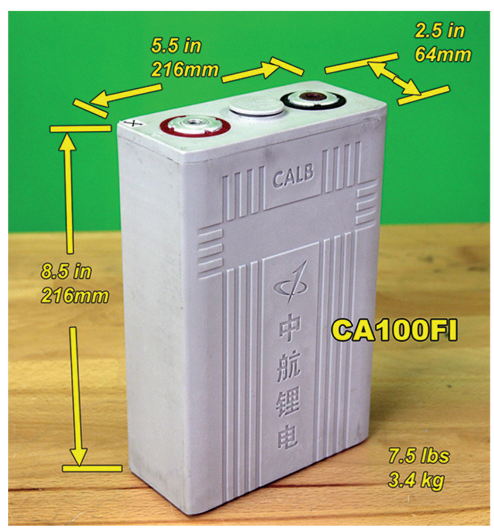
Discharge Temperature: 0-113 F

Fully charged open circuit voltage: 3.40v

Fully discharged cutoff voltage: 2.50v

Cycle life to 100% discharge: 2000 cycles

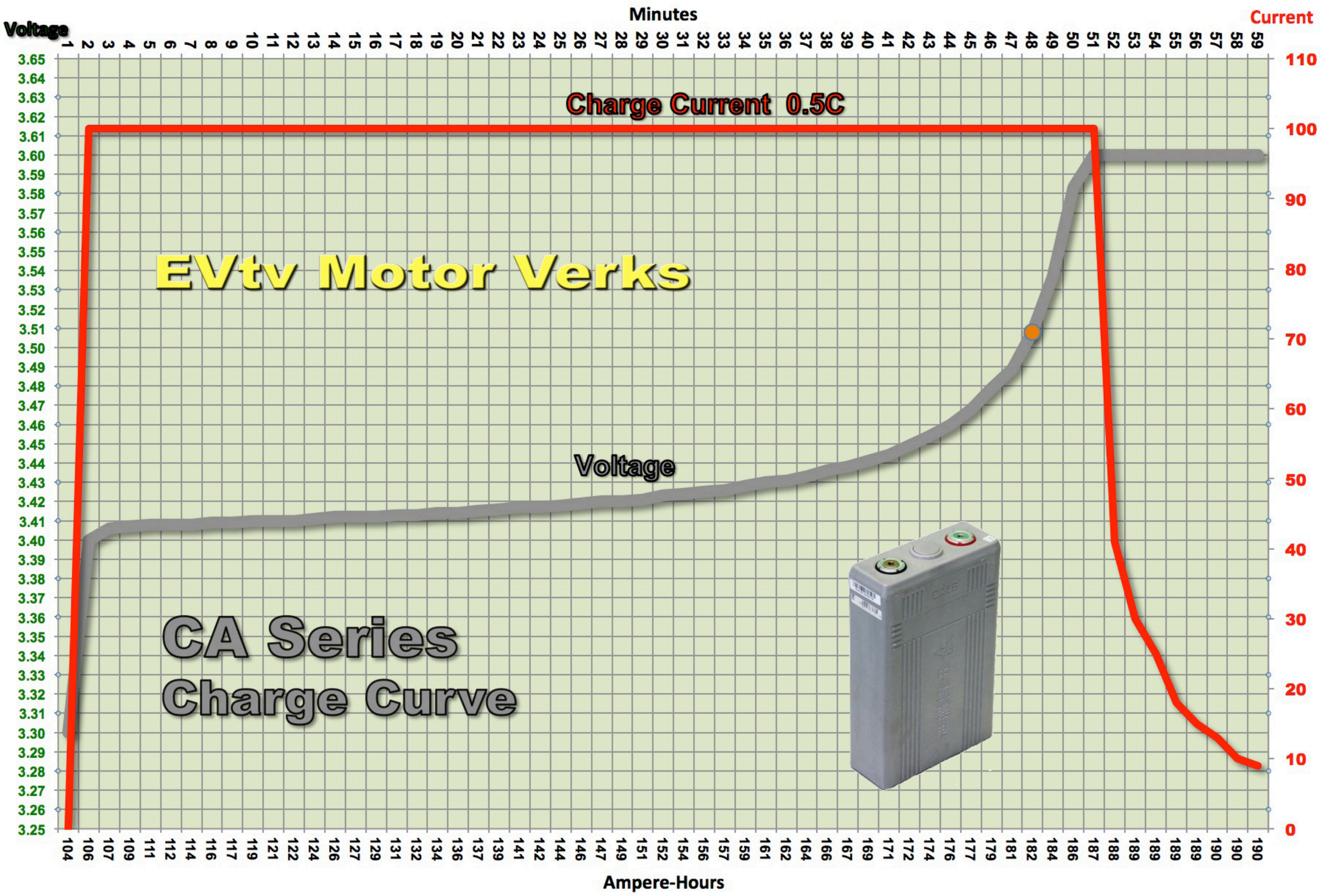
Cycle life to 80% discharge: > 3000 cycles

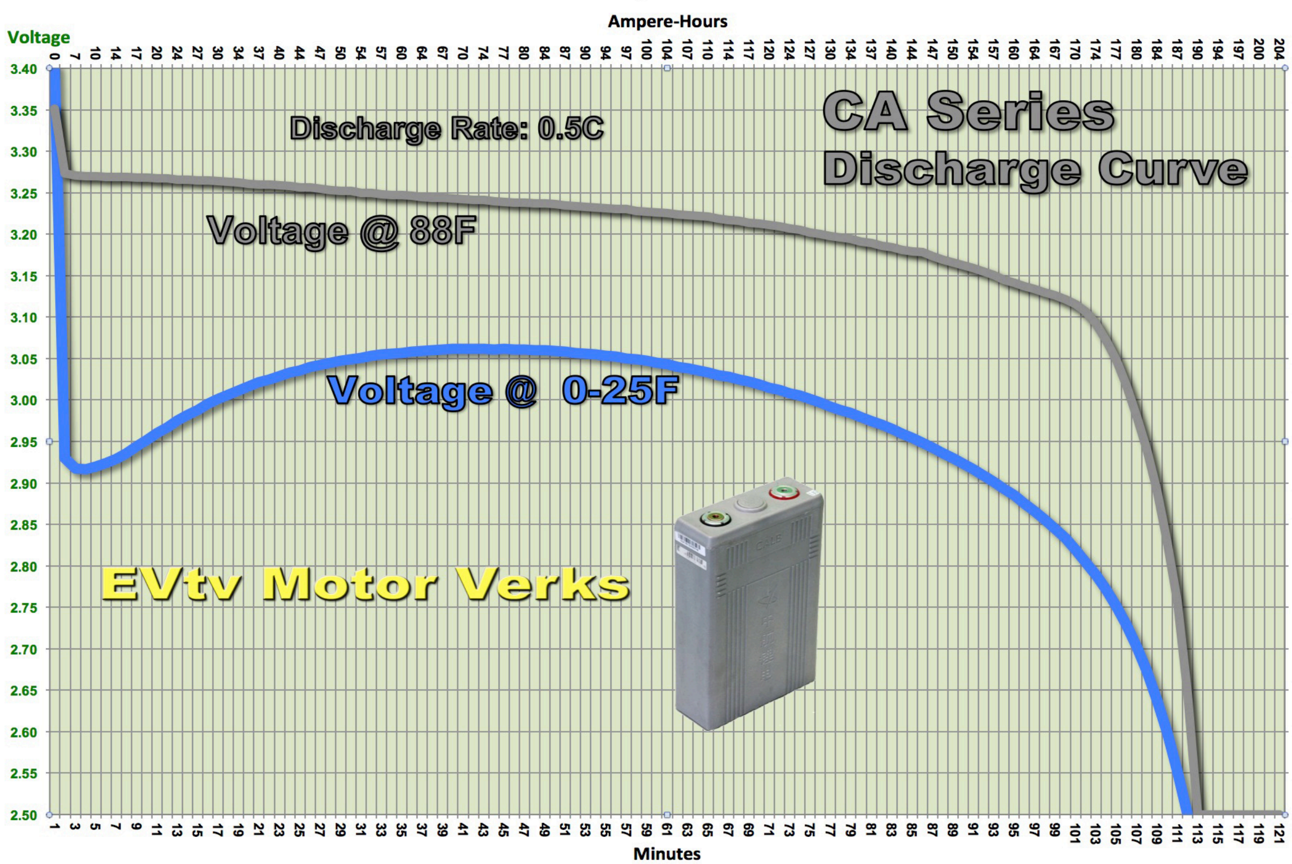


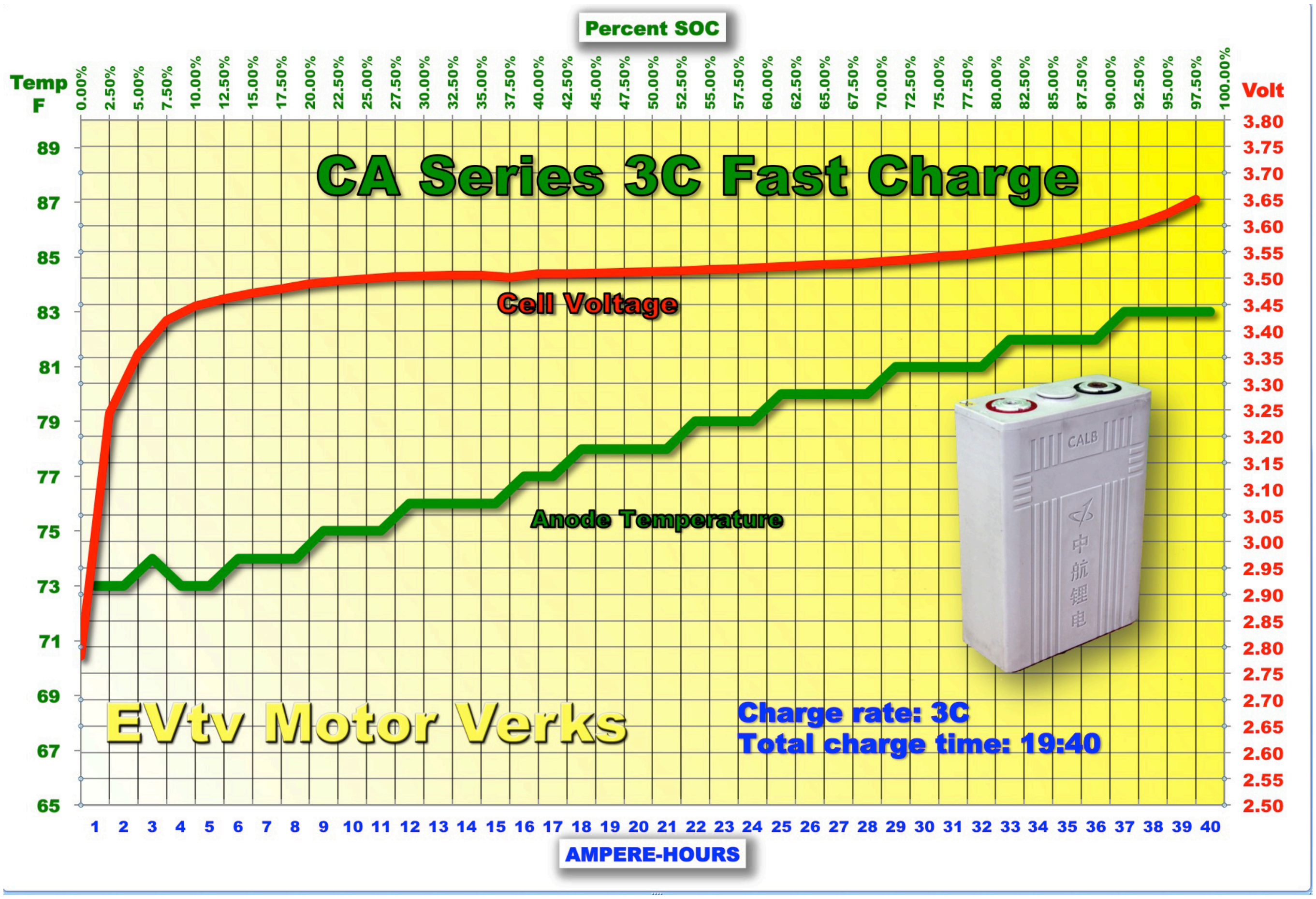
Termninal: M8 1.25 x 16 stainless
Torque to 20 NM or 14.75 ft-lbs

Includes 70 mm tinned copper braided strap, two stainless terminal bolts, and two zinc coated Nord-Lock washers

Alternate 60 mm braided straps allow adjacent (edge-to-edge) configurations.


Minutes
Voltage
Current
Charge Current 0.5C
EVtv Motor Verks
Voltage
CA Series
Charge Curve
Ampere-Hours


Ampere-Hours
Voltage
Discharge Rate: 0.5C
CA Series
Discharge Curve
Voltage @ 88F
Voltage @ 0-25F
EVtv Motor Verks
Minutes



The NEW China Aviation Lithium Battery Company CA series cells provide an advance in nanoparticle lithium iron phosphate cell technology featuring starkly improved cold weather performance, increased power output and greater cell to cell capacity consistency than ever achieved by any Chinese battery manufacturer. The increased power capability means less voltage sage for any given current output. The improved capacity consistency makes managing a series string much easier.

These cells are inherently safer with much higher thermal runaway temperatures than the Lithium Manganese and Lithium Cobalt metal oxide cells used by many automakers. We think these advantages make this cell the choice worldwide for electric vehicle applications. They are the only battery cell we carry at EVTV Motor Verks.

EVTV Motor Verks
601 Morgan Oak Street
Cape Girardeau MO, 63703
573-388-4580
sales@evtv.me
http://www.evtv.me

EVtv Motor Verks

CARE AND FEEDING OF YOUR CA SERIES CELL

The new CA/FI series cell incorporates some nanoscale improvements in cathode and anode materials along with some significant improvements in electrolyte chemistry that represent the absolute peak of performance in LiFePo4 ionic battery technology. With a recently completed modern manufacturing facility, the China Aviation Lithium Battery Company has achieved production consistencies heretofore unachievable. The result is the new “grey cell” the CA/FI series.

CA is an abbreviation of the **C**hina **A**viation Lithium Battery Company (CALB). **FI** is a series abbreviation for iron phosphate (**F**ePo) chemistry series **I**. This is their first series newly designed and manufactured subsequent to their acquisition of the **S**ky **E**nergy Battery Company – the previous **SE** series. The China Aviation Missile Academy purchased this company, and subsequently invested nearly a billion dollars in new plant and manufacturing to form the China Aviation Lithium Battery Company.

The new FI series offers some serious advantages over previous cells. They produce significantly more power than previous cells with a rating of 3C continuous output and brief outputs of up to 30 seconds at rates up to 10C. A CA100FI cell can produce 1000 amps with minimal voltage sag.

The cells feature improved cold weather performance. Longer cycle life. And due to better capacity consistency, they are easier to manage in serial strings.

Common wisdom regarding the care of lithium batteries requires a battery management system and a common myth advises you to balance the charge of those cells ensuring that each cell is charged to the same voltage. This has represented a huge opportunity to develop and sell inexpensive electronic devices to accomplish this at very high profit margins. A cottage industry has emerged to provide these. Unfortunately, most of these designs have been marginally effective and many are actually dangerous.

Over years of actually driving cars using LiFePo4 cells, we have developed a very different approach to caring for these cells and maintaining them for many years and miles. It has proven curiously effective WITHOUT spending huge sums on expensive, complicated battery management systems that turn your car into a spaghetti wire nightmare.

The basic rule is do NOT overcharge these cells and do NOT overdischarge them. Observing those two precepts will ensure many years of service. If you fail to observe this, even once, it will most likely result in cell destruction and loss, and it will absolutely lead to early capacity loss of your pack. But achieving this takes a bit of strategy.

BOTTOM BALANCING.

The cells do not actually drift apart from each other with regards to state of charge. And the top balancing process does not actually even balance anything. The charge process for LiFePo4 cells involves charging at a fixed current until a specific voltage is reached, and then holding that voltage until the current decreases to a certain minimum value. This is termed a Constant Current (CC) / Constant Voltage (CV) charge curve.

The CC/CV charge curve really has little to do with the actual battery voltage. The true open circuit voltage of the cell is nominally 3.38v and cannot be measured until some HOURS after the charge procedure.

The CC/CV charge process is a **PROCEDURE** – a recipe that if followed carefully, will RESULT in a fully charged cell. The basic recipe is:

1. Charge at a fixed current of 0.5C until the cell terminals measure 3.600v

2. Hold the voltage precisely at 3.600v decreasing current as necessary. As the cell adds energy, the voltage will naturally rise. The current will have to be decreased to hold the voltage down at 3.600v

3. When the current has reduced to 0.05C, **TERMINATE ALL CHARGING**.

Within a few hours, you should measure something in the range of 3.35- 3.38v on the cell terminals. THIS is the cell voltage. The 3.600 was a procedural measurement. NOT a cell voltage.

So for a 180Ah cell, you would charge at 90 amps to 3.600v and terminate when the current decreases to 9 amps.

For most of us, this procedure is not performable. Our chargers might manage 15 or 20 amps. But the procedure is reasonably flexible.

To account for this, and to intentionally UNDERCHARGE our cells a bit to maximize cycle life, we at EVtv NEVER charge to the full 3.60v. We normally use this procedure to a measured 3.50v and we've had very good success with this. At the low current levels we can accomplish, the charge curve is so steep that little additional energy is actually put into the cells between the 3.50v and 3.60v marks in any event. So little range is lost. But a lot of problems are avoided.

BOTTOM BALANCING PROCEDURE

Note that we do NOT top balance the cells when charging a string of cells in series. So how do we assure that the cells are all at the same state of charge – essentially balanced.

We do this **ONCE** when the cells are new and installed in the vehicle. And we do it at the **BOTTOM** of the charge curve.

1. Discharge each cell individually at a low current level of 30 amps until the cell measures 2.50v.

2. Allow the cell to rest overnight.

3. The cell voltage will "bounce" or recover to some value in the 2.75 to 2.85v range.

4. Discharge the cell for an indication of 2.65v.

5. Allow it to recover again for 30 minutes.

6. Continue this process until a stable reading of 2.75 volts has been achieved.

7. For cells lower than 2.75, you may need to add energy from a 5v or 12v power supply to bring them up to 2.75v.

8. Once all cells are stabilized at 2.75v, assemble your battery pack in a series string in your vehicle.

9. Charge the string using CC/CV to 3.5v X the number of cells in string. Ie, 10 cells in series would be charged to 35volts.

10. AFTER charging, this string should settle to about 33.4v – essentially 3.34 v per cell.

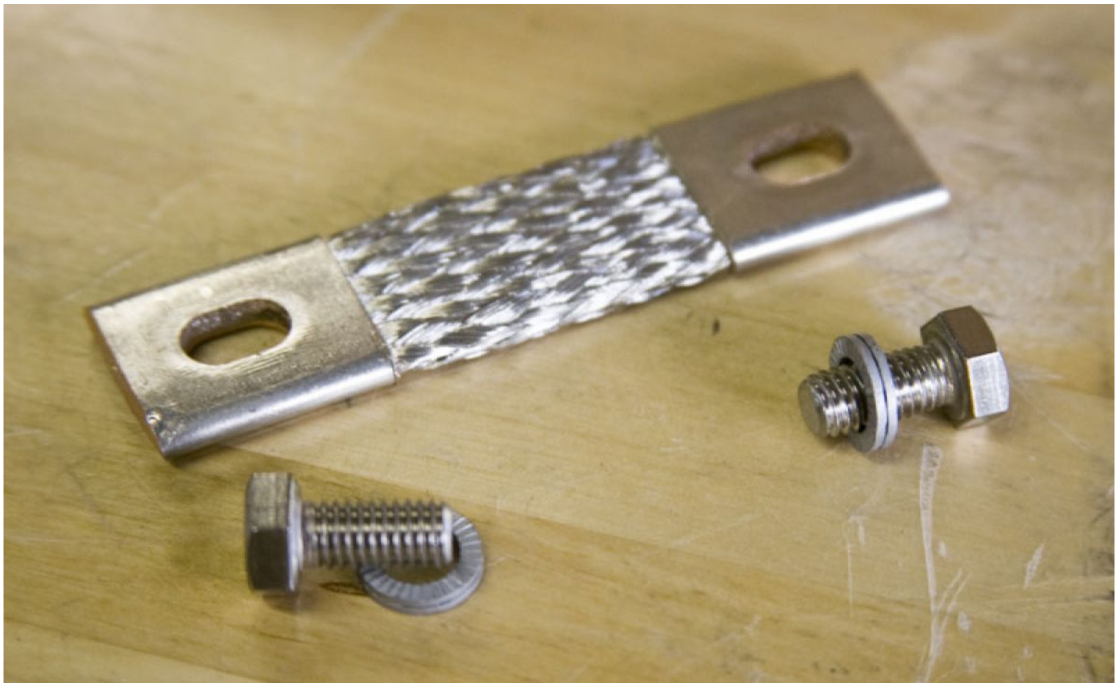
Your pack is at this point fully balanced and fully charged.

It is relatively easy to build an inexpensive device to help bleed cells using a 250 watt 0.1 ohm resistor with some terminal clamps. This will bleed individual cells at a rate of about 30 amps.

EVtv offers the Revolectrix Powerlab 8 Battery Workstation which is quite effective at automating the discharge process.

BATTERY STRAPPING

Your cells from EVtv came with some very high quality tinned copper braided straps, terminal bolts, and some unique cam-lock wedge washers from Nord-Lock. To connect your cells in series:



1. With a fine sanding block or garnet sand paper, lightly burnish the cell terminals. The positive terminal is the inner circle of aluminum while the negative terminal (anode) has a copper inner ring. Polish these to a high shine. This removes surface oxidation from the terminal significantly improving conductivity.

2. The tinned copper braided strap has two sides. The top side features rounded edges on the terminal bolt slot. The bottom side has a sharp edge on the terminal bolt slot. Use the sanding block to lightly burnish the bottom side in the terminal bolt area. Do NOT remove all the tinning there. Just lightly buff the surface, again to remove microscopic oxidation.

3. Position the strap bridging the positive terminal of one cell to the negative terminal of the next cell.

4. Insert a stainless steel terminal bolt with Nordlock washer into each terminal bolt hole. Do not tighten until both bolts are installed to avoid flopping the strap around to other terminals.

5. Once each bolt is carefully threaded, use a 14 mm or ½ SAE socket wrench to tighten terminals. On CA100FI and CA180FI cells this should be tightened to 20 newton meters or 14.5 inch lbs.

This strapping system is very effective but in some very subtle ways. Strapping batteries is actually a terribly important element of battery care because the cells are rarely installed in indoor static environments. The automotive environment is actually a bit of a challenge. And it is worthwhile to expand on this a bit.

Most metals have an interesting feature in that as they carry large current loads they heat. As they heat their resistance to current flow actually increases. Unfortunately this causes more heat. Which causes more resistance.

Terminal connections, because they use dissimilar metals, stainless steel, copper, tin, aluminum, are subject to galvanic corrosion. Corrosion increases the resistance of the connection. This increases the heat generated by current flow through it.

At some current/heat level, the junction of the terminal goes into thermal runaway where it gets hot, the resistance goes up, it gets hotter, increasing the resistance, and the result is a “blown” terminal. The terminal melts and sometimes blows explosively. The battery cell is still perfectly operational, but the terminal has blown off the cell and in some cases taking cell casing with it.

This entire process is exacerbated by two things in the automotive environment. Vibration and thermal cycling.

Vibration occurs in a car going down the road on a continuous basis and at a number of harmonic frequencies. Low frequency vibrations cause the cells to jostle vertically and this action causes the battery straps to pry up and down on the terminal bolts, stressing the connection.

Higher frequency vibrations simply tend to stress the bolt/thread interface, causing bolts to back out and loosen.

Thermal cycling is also a problem. Each time you press the accelerator, this increases the power draw and current from the batteries. This heats the connection. As soon as you take your foot off the accelerator, the current demand is decreased, causing an immediate cooling of the connection. This is repeated hundreds of times on even a short drive.

Seasonally ambient temperatures of course vary as well and there are temperature variations even from day to night in the same season.

All of this works to loosen the terminal connection. Using manufacturer supplied copper straps, bolts and lockwashers, we observed that after just a couple of months, EVERY SINGLE terminal in our battery pack had loosened by 1/8th to ¼ of a turn. And this leads to the admonition to check and tighten each battery terminal on your electric vehicle once per month.

This is almost unachievable on most electric vehicles. Batteries are installed all over the car many in difficult to reach areas. The normal driver of such a vehicle cannot be expected to locate, inspect and tighten each and every battery connection on a monthly basis no matter how excellent that practice might be.

We developed the EVtv battery strapping procedure to address this. And we are pleased to note that vehicles assembled six months or a year earlier have been inspected with ZERO terminal loosening or corrosion.

TINNED BRAIDED COPPER BATTERY STRAP. The role of this strap is quite important. The flexible braided copper in the middle of the strap allows each END of the strap to displace vertically WITHOUT prying on the terminal bolts. The tinned surface is an intermediary metal between copper and aluminum and decreases the galvanic potential, and thus corrosion, of dissimilar metal junction. These straps are capable of carrying high currents with minimal resistance. The individual braided copper wires actually decrease the resistance compared to a solid copper metal strap.

ZINC COATED WEDGELOCK WASHER. The zinc coated wedgelock washer serves two purposes. First, it “locks” the bolt in position. These washers are VERY hard material with serrations on the top and bottom half of the washer. These serrations are harder than the strap and harder indeed than the stainless steel bolt. They dig into the material and grip it very firmly.

The interface of the two washer halves features a reverse sliding cam. Any force tending to back the bolt off causes this cam to slide toward a wider interface, increasing the pressure of the bolt thread on the terminal hole thread. Load cell vibration testing has demonstrated that these nordlock washers are many many times more resistant to bolt loosening than lock washers, wave washers, or any other locking washer design.

The ZINC serves as a sacrificial anode to prevent galvanic corrosion. Any galvanic action causes loss of zinc, rather than erosion of the copper, tin or aluminum.

It is critically important to maintain clean, tight, corrosion free terminal connections in your battery pack. This EVtv strapping system assures that with a minimum of maintenance.

BATTERY STRAP SIZING

CELL SIZE	60Ah	100Ah	180 Ah
Face to Face	40 mm	70 mm	70 mm
Edge to Edge	50 mm	60 mm	76 mm

PARASITIC LOADS.

In order to prevent overcharging or overdischarging any particular cell in your battery pack, it is important that their state of charge relationship be maintained at all times – that they remain “in balance”. There are all sorts of theories as to why they will inevitably drift OUT of balance due to differences in location, temperature, and “internal resistance.”

In practice, we have observed NO measurable drift in cells over periods of several years in battery packs in daily service in vehicles. NONE measurable.

However, it is possible to induce imbalance by drawing energy from some cells, while NOT drawing energy from others. And even tiny 10 milliampere loads become cumulative over time.

For example, we used some very tiny voltage measurement devices to monitor 16 cells out of our pack. The devices were actually powered by the cells they measured and as it turns out, not even equally then. Over a period of three months, this moved those cells 15 Ampere hours away from the rest in the pack. When we drove the car to a low SOC, those cells were destroyed.

So be very careful NOT to power anything, even at tiny levels, from your pack UNLESS you are drawing from the ENTIRE pack. Instrumentation and well intentioned battery monitoring efforts are the usual source of parasitic loads.

STATE OF CHARGE MONITORING.

There are several reasonably effective ways to monitor state of charge.

ODOMETER. Least effective, and generally overlooked. But you will relatively quickly learn the range of your vehicle. By resetting your trip odometer after every charge, you have a reasonable rough estimate of how far you can go.

VOLTMETER. An accurate voltage reading of your entire pack voltage is very important. Fully charged, your pack should indicate about 3.34 volts per cell. So a 36 cell pack would read about 120 to 120.5 volts.

It is particularly important to check this voltage when starting your first drive after charging. This is to MAKE SURE you actually DID charge the battery overnight before starting your daily driving.

At 90% discharge, you will note a voltage of about 3.00v per cell. On a 36 cell pack, for example, this would read 108v. At that point, you need to be done and plugged in. You have little left in your pack.

The problem with voltage is that in this 36 cell pack, you will quickly drop to 117 volts or thereabouts, and then the voltage won't really move much. Very gradually decreasing to 114 volts. From there it will dive to 108 volts in a mile or so of driving. So the voltage indication, while good, is not at all linear.

COULOMB COUNTING. The best indication of state of charge is by counting the actual current flow out of your pack. This is done by ampere-hour or kilowatt hour metering.

An accurate AH or kWh meter is simply required to live with lithium ion batteries. The more accurate the better.

We offer the JLD404 meter at EVtv. It accurately counts ampere hours. If you have a pack of 180 Ah, at full charge you will have about 180 amp hours to "spend" driving. Reset or ZERO your amp hour meter after charging. It will then count the cumulative energy out of your pack as you drive and provide a digital display of amp hours. When you reach 180, you are 100% discharge.

Your batteries will last many times longer if you restrict usage to 80% depth of discharge (DOD). This would be 0.8 x 180 or 144 amp hours. Your cells are rated for 2000 cycles at 100% discharge and GREATER THAN 3000 cycles if you restrict usage to 80% discharge.

If your pack ever reaches 2.50v per cell (on a 36 cell pack – 90 volts), you have basically overdischarged your pack and caused significant capacity loss.

NORMAL CHARGING

Normal charging of your cells should be done in series, using a Constant Current to a voltage of 3.5v times the number of cells in the string. If you have a 48 cell series battery pack, this would be 3.5 x 48 or 168 volts.

On reaching this voltage, your charger should switch to a Constant Voltage procedure to hold that voltage fairly precisely. As the energy in the cell rises, the voltage will tend to rise as well. In order to hold it at the CV voltage, the current will have to be decreased. Almost all chargers do this automatically.

CV should be maintained until the current declines to 0.05C. This would be 5 amperes on a 100 Ah cell or 9 amperes on a 180 Ah cell.

At that point all charging should be terminated. No float or equalizing charge is required and indeed a float or equalizing charge would inevitably overcharge the cells and damage them.

Immediately after charge completion, the voltage of the pack will begin to fall. Within an hour or so, it will reach approximately 3.34 x number of cells. Again for a pack of 48 cells 3.34 x 48 = 160v.

After charging, before operating your vehicle, check the pack voltage to ensure that it is close to this value. Operation of DC-DC converters and other items in the car may have decreased it very slightly, but it should be very near this 160v. This is to make sure the car actually DID charge overnight, before embarking on a long trip. Lower voltages indicate some interruption in the charge process and a partially charged pack.

ALL charging should be done at a cell temperature ABOVE freezing – 32 F or 0C.

FAST CHARGING

One of the perceived drawbacks to electric vehicles is the time it takes to refuel them. Ironically and for many surprisingly, the batteries really aren't the restricting element here. The available power from the charger is.

The CA cells can be safely charged at currents of up to 3C with very little temperature rise (typically 10F) and essentially no damage to the cell at all.

This means that a 100Ah pack could be charged at a rate of up to 300 amperes, and a 180Ah pack at up to 540 amperes. At 3C, your pack would be fully charged in 20 minutes.

As a practical matter, we don't do it that way. First, there are no chargers or charge stations capable of delivering this level of power. And second, we do not want to fill the last 5-10% of the pack in this manner as that is where cell heating comes into play. We can extend the life of the cells by foregoing that final few percent.

There are several fast charging standards emerging, including ChaDEmo, and SAE J1772 Rev B Level I and II DC charging.

For CA cells, the fast charge procedure is very simple. Charge at up to 3C to 3.50v X number of cells. Terminate the charge at that point.

Note that we forego the constant voltage portion of the charge procedure entirely. Simply charge at a fast rate to the CC/CV voltage, and terminate.

DISCHARGING

CA series cells are rated at power outputs of 3C continuous and up to 10C for 30 seconds. A 100 Ah pack could provide 300 amperes of current continuously or 1000 amps for accelerations.

That does not imply that they should be operated to the maximum at all times. Indeed there is some evidence to suggest that cycle life is related to driving cycle load. And so you will always be better off with a larger capacity cell in relation to your power demands. 180Ah cells in the same vehicle on the same load will simply last longer than 100Ah cells in the same application.

The cells can be operated until cell voltage reaches 2.5v. Indeed, during 1000 amp accelerations, a full pack may experience this. Your cell is fully depleted 100% when it reaches 2.5v with NO LOAD.

You will observe when stopped at a stop light, for instance, that the pack voltage climbs or “recovers”. As long as it does this to a voltage greater than 2.5v x the number of cells, you still have charge left.

That said, the discharge curve is very non-linear. Quite flat in the middle and quite steep towards the end of charge. And so the difference between 3.0v and 2.5v may only be a mile or so. We would urge you to consider your pack “empty” at 3v x number of cells (144v for a 48 cell pack).

You can further extend the life of your pack by limiting discharge to 80% depth of discharge (DOD). This corresponds approximately to 3.10v x number of cells. (149 volts for 48 cell pack).

TEMPERATURE CONSIDERATIONS

CHARGING

One of the serious weaknesses of lithium ion cells is temperature. Actually all batteries suffer from temperature issues. But the lithium cells are quite different from other cells.

The most serious issue is cold weather charging. All charging should occur in the temperature range of 0 to 45 degrees centigrade. (32 – 113F). You simply should not charge your pack at any temperature outside of this range.

The most limiting part of this is the cold temperature charging. 32F or 0C is actually a relatively high temperature. But charging at temperatures below this, the lithium ions are simply unable to diffuse properly into the carbon anode of the cell. And so lithium plating of the anode occurs and it is IRREVERSIBLE. It causes capacity loss at best. And at worse, can lead to catastrophic failure of the cell during subsequent normal temperature charging and discharging.

The high temperature restriction is good practice, but somewhat more forgiving up to 50 or 55C. The ill effect is just higher aging losses of the cell.

You can alleviate the effects of low temperature on the cells by actively heating the cells while charging in cold weather.

DISCHARGING

Fortunately, charging and discharging are asymmetrical. You can safely DRIVE your car and discharge the batteries down to -20C or 0F. There are some issues you should be aware of however.

REDUCED VOLTAGE. Your voltage indications will all be off with lower readings of pack voltage initially and sometimes alarming deviations downwards while accelerating. This is normal operation in cold temperatures.

REDUCED CAPACITY. If you have a 180 Ah pack in normal temperatures, you assuredly do NOT have a 180Ah pack at 0 degrees Fahrenheit. Expect capacity loss of up to 20%. Keep an eye on your ampere hour meter and your voltmeter.

REDUCED PERFORMANCE. At low temperatures, the cells will not produce current and power as promptly as at normal temperatures. Because of the reduced voltage under load, the vehicle will likely feel sluggish and weak compared to operation during normal temperatures.

Again, you can alleviate the effects of low temperature on the cells by actively heating them in cold weather.

CELL POSITION

The manufacturer advises us that the ideal mounting of the cells is vertical with the vents pointing UP.

Mounting the cells upside down is absolutely forbidden as this causes electrolytes to pool in the pressure vent, disabling it.

Horizontal mounting is somewhat more controversial. The manufacturer advises this shortens cell life, with mounting on edge preferable to mounting flat side down horizontally.

We have yet to receive a cogent explanation of why horizontal mounting would cause any decrease in battery life or capacity. All such explanations we have found on the Internet are demonstrably nonsense.

But this remains the manufacturers recommendation and we pass it on.

CAUTIONS AND WARNINGS

Danger of intense fire and explosion. There have been repeated and numerous incidents of vehicles burning to the ground in intense fires that have melted the glass out of the windows, burned the tires off the wheels, and actually melted large steel components such as the transmission. There has also been significant collateral damage to garages, warehouses, and other areas where these vehicles were stored at the time.

In essentially every case, the fire was BMS related. The actual scenario is generally that the vehicle was wired to where the BMS controlled the charger. The BMS failed in some way, usually from electrostatic interference, lightning strike, etc. and failed to terminate the charge.

If these cells are significantly overcharged, the anode builds up ferric iron shunts, and a combination of the continuing incoming current and the breakdown of the SEI passivity layer on the cathode causes an exothermic reaction between the lithium ions in the anode and the electrolyte. At about 90C, the electrolytes begin converting to a gas, the cells swell and the pressure vent releases flammable electrolytes into the air. If those don't ignite, continued recombination of lithium ions and electrolyte reaches a temperature where the cathode begins to break down and release free oxygen. The cell goes into thermal runaway and the result is an intensely hot fire that is very difficult to extinguish.

There is a myth floating about the Internet that swelling in lithium cells is normal. In no case is it "normal". It is ALWAYS a sign of significant overcharge, or significant over discharge. If it occurs, the cell can go thermal and result in a fire DAYS OR WEEKS LATER. This can happen even with no further charging or discharging at all.

Indeed, in numerous instances, the fire has been PUT OUT by the fire department, only to RE-IGNITE several days later.

Operated within their normal range, these cells are virtually indestructible. Even with case puncture by nails or bullets, they do not go into ignition. High external temperatures can set them off, but they have to be in excess of 90C.

LiFePo4 cells are DRAMATICALLY safer than Lithium Cobalt or Lithium Manganese cells. But they can STILL suffer dramatic and intense thermal events – almost always caused by over charging.

It is critically important to use a quality charger that reliably terminates the charge process. Most failures are the result of well intentioned efforts to AUGMENT this and make it safer. Generally they result in anciliiary failures that make it LESS safe.

PRECAUTIONS DURING ALL MAINTENANCE

There are several things you should be aware of while working on these cells. Electrocution is of course a hazard on high voltage packs. Oddly, we've never heard of anyone being electrocuted working on a car with these cells or even receiving a serious shock requiring medical attention.

The danger is more about heat and burns. Do NOT wear rings, watches, Peace Symbol pendants, or other jewelrey when working on any electric vehicle. If you happen to get this across two points on the pack, you get your arm back after your hand burns off and falls to the ground. The current through the wristwatch or ring or whatever can go as high as 3000 amps. Imagine 10 arc welders connected in series.

By far the most common mishap is to drop a wrench or tool into the battery box – shorting two terminals in adjacent rows of the pack. This almost instantly results in blobs of molten metal shooting in all directions and if a drop of this hits you it makes a very painful burn.

Worse, in some instances we've actually had metal wrenches, eyeglasses and so forth not only melt, but gasify into a glowing plasma ball that can last for a number of seconds. Just the LIGHT from this can cause serious skin burns and the temperature at the center of these plasma balls can be as high as 5000F.

We insulate all tools and wrenches used to strap batteries with milspec heat shrink so that it simply cannot span two terminals of the pack. You WILL drop tools and eyeglasses into your battery pack. Have a plan.

We use a maintenance switch to disconnect the pack in the middle and keep a pair of cable cutters handy whenever working on the pack. We also install a Ferraz Shawmutt fuse in every pack we build. But neither of those precaustions will have any effect on dropping a tool across adjacent cells.

BATTERY PACK SIZING CALCULATIONS

One of the most interesting and difficult questions for those considering a vehicle conversion is how to size the battery pack. How many cells, what voltage, etc.

The first consideration for battery size calculations is the limits of the chosen drive train. Most motors and controllers have limits on power, and most importantly voltage.

If your controller is limited to 120vdc input, you don't really want to build a pack larger than the controller can take.

The second consideration is of course physical. How much room do you have for cells and how much cell weight can your vehicle safely carry.

At that point, pack sizing is mostly an exercise in determining how much range you desire. And range has penalties – larger up front costs for the cells, more weight in the car, and less performance because of the weight.

CALCULATING PACK SIZE. The battery pack is normally sized in kilowatt hours – kWh. A kilowatt is simply 1000 watts and a watt is a function of both current and voltage. A kWh would be consumption of 1000 watts for one hour. This increment of measurement is how your utility bill for your house is rated.

Calculating pack size in kWh is quite simple. The pack voltage times the amp hour capacity.

If you have a 160v pack that consists of 100Ah cells, it is 160x100 or 16,000 watt-hours. That is 16kWh.

Range is a function of power use, which will vary wildly and widely. But we have developed some rules of thumb that by and large work.

If you take the weight of the vehicle and divide by 10, this will give you a pretty good measure of your expected energy usage per mile. A 2400 lb vehicle will require about 240 watt-hours per mile of distance travelled and an 8000 lb vehicle will require, on average, 800 wH per mile.

Range then becomes packsize/power use. For a 2400 lb vehicle with 16kWh pack, 16000/240 or 66.66 miles. This represents the absolute maximum range of the vehicle. Again, we advise you limit discharge to 80% DOD to achieve maximum cell life. And so 66.66 x 0.8 = 53 miles. We term this SAFE RANGE.

And so you should size your pack for your desired "safe range" values.

Note that range suffers substantially at temperatures below 32F/0C. We estimate a 20% decrease in cold conditions.