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HOW TO BUILD A BATTERY PACK

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BACKGROUND

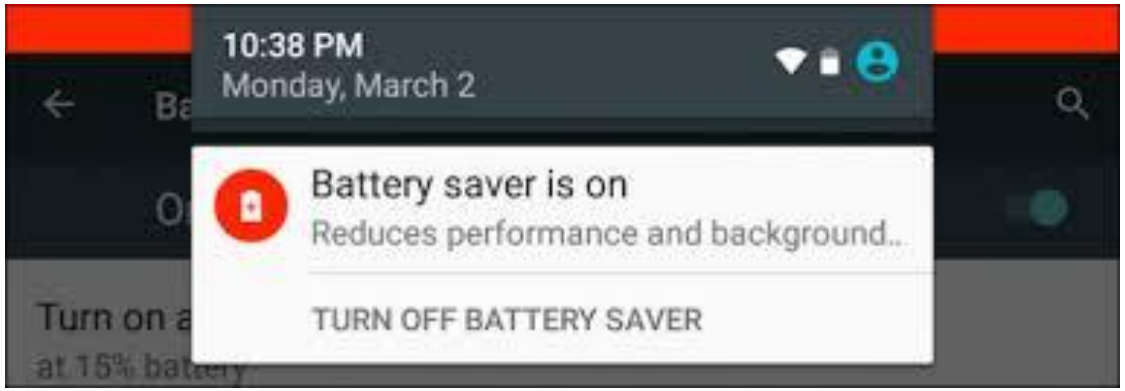
Typically, Solar Race Vehicles must be very efficient to be competitive and cannot spare energy to waste.

Balancing either during charge or discharge consumes energy that could be used for raycing

Therefore; creating a balanced pack from the start is preferred to any form of balancing after pack assembly.

Since Rayce events are typically 10 or so days, the battery sees 10 or so cycles.

It is from this perspective
that this presentation is prepared.



HOW TO BUILD A PACK

Functions of importance:

- Cells from common manufacturing lot
- Cells from the center of performance distribution – not the tails (No hi or low capacity cells in your pack)
- Cells with equivalent Capacity and Impedance
- Cells with equivalent performance within a module
- Modules with equivalent performance within a pack
- Battery Protection system with properly located sense points.

HOW TO BUILD A PACK STARTING OUT

First and foremost, UNDERSTAND all you can about the battery technology you choose, MSDS , product design, testing and performance.

Different variants of 18650 cells have different limitations/failure modes as an example.

Acquire “manufacturer’s” data sheets for any cells you expect to use.

Submit it to ASC prior to order for preliminary review, consultation.

URL & MSDS are required for final pre-approval prior to vehicle inspections at Scrutineering.

The Battery Guru of your team should live, sleep and breath battery if your team wishes to be competitive and successful.

HOW TO BUILD A PACK
THE BASICS (EXAMPLE)

Supposedly, we are considering a battery pack of say 400 cells to make the required weight.

We want a current to drive the vehicle of 60 amps and each cell's **Discharge Current** is limited to 6 amps per the battery cell manufacturer.

We will need a minimum of 10 cells in parallel to acquire the needed discharge current.

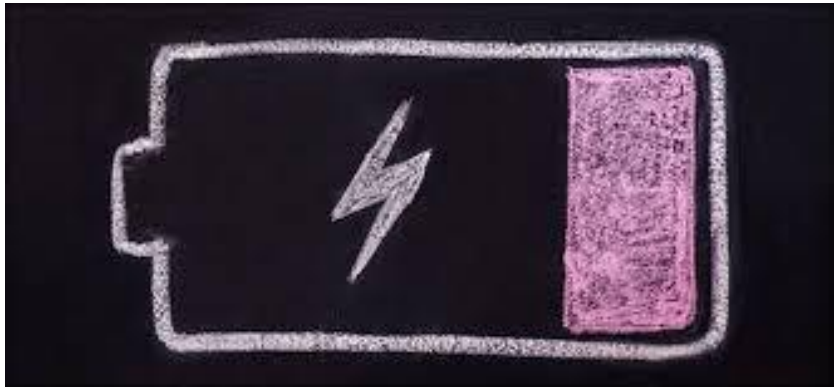
Likewise this means the pack will consist of 40 modules and this number @ Nom Voltage = Nominal Pack Voltage

Similarly, suppose **Charge current** is limited to 3 amp/cell based on the cell manufacturer, thus with 10 cell modules, 30 amps will be pack charge current limitation.

Cells grouped in parallel are considered to be Modules

This pack results in a nomenclature of 10P40S
= 10 cells in parallel, 40 modules in series

Modules placed in Series to provide voltage are considered to be a Pack. No other configurations should be considered in your design: paralleled cells for modules strung into a string for the pack is required for pack safety.



HOW TO BUILD A PACK
WHAT TO MEASURE

Before you even purchase a bunch of cells, a sample of 5 can tell you many things:

- Cell Impedance (think of this as: What potential in/out efficiency the battery pack will have). **The lower the number, the better!**
- The Less Variation the better. Lithium based cells have the lowest cell impedances of major commercial batteries

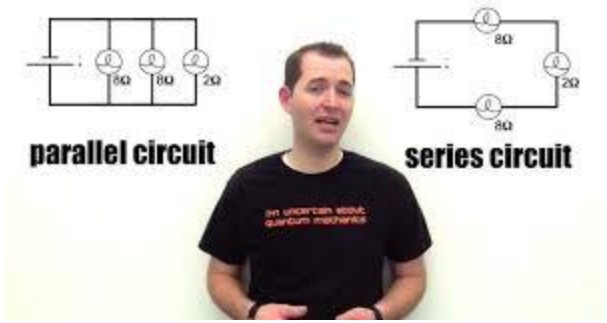
Capacity is the other metric of importance!

- Although important, Capacity is difficult to accurately measure as many cycles are needed to get a reasonable estimate.

Those cells with similar impedance will provide the pack with the most usable energy as long
as they are assembled at equivalent

SOC.

When measuring cells, Hysteresis must be considered(on charge curve or discharge curve)



HOW TO BUILD A PACK VARIATION

So now we now know which cell we want and we have preliminary understandingfrom ASC.

We discuss with supplier the quantity we want and that they need to be from the same “Manufacturing Lot”

Why, one might ask from the same Lot?

Those cells from common lot will have less variation than with cells from various lots.

Why do we care about variation?

Battery Packs **HATE** variation. If many Cells vary in impedance/capacity, they operate differently and result in an inherently imbalanced pack, resulting in a shorter rayce day.

HOW TO BUILD A PACK TESTING

How might a team go about testing cells?

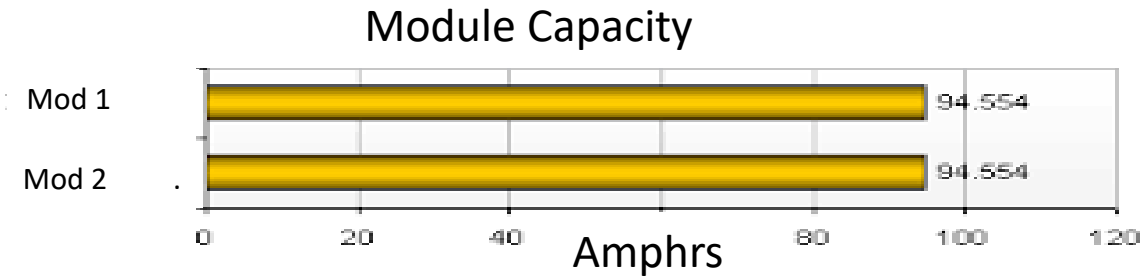
You may consider a tester with as many banks as can be afforded. Impedance being the reasonable measure, Capacity as well. If it can store large amounts of data easily read by a computer, this is best.

1. Measure all cells for your metrics and match them as close as possible for each module.

   (A mismatched Module is very dangerous, one cell within the module, will not operate as the rest even though electrically they are paralleled)

2. The battery protection system (BPS) can not detect it either. It can only detect the result on a module.

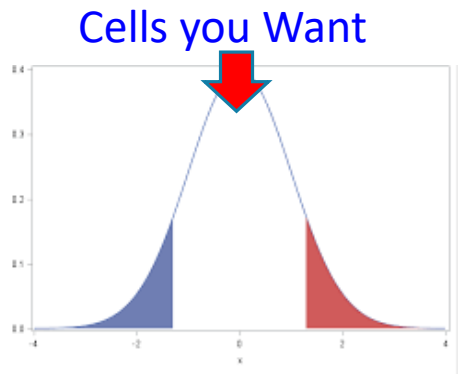
So make sure cells within a module are matched as closely as possible.



HOW TO BUILD A PACK TESTING CONT.

Once many cell are considered, Take those cell with the most equivalent metric to assemble into a module.

"It is very likely, during testing that outliers or tails of the distribution will be found. These are the reason you test. Even if the Supplier claims to have already sorted for you, I would still measure each and every cell".



Your measurement equipment should have 10 times the resolution of what it is you are trying to measure.

Impedances of 100 to 200 m-ohms, you'll need 10 m-ohms or better testing capability, likewise, Voltage differences or Millivolts meaning you'll need tenths of millivolts capability with your measurements.

Don't skimp on testing cells or the equipment that will be doing it, it'll cost you with **higher variation.**

HOW TO BUILD A PACK TESTING CONT.

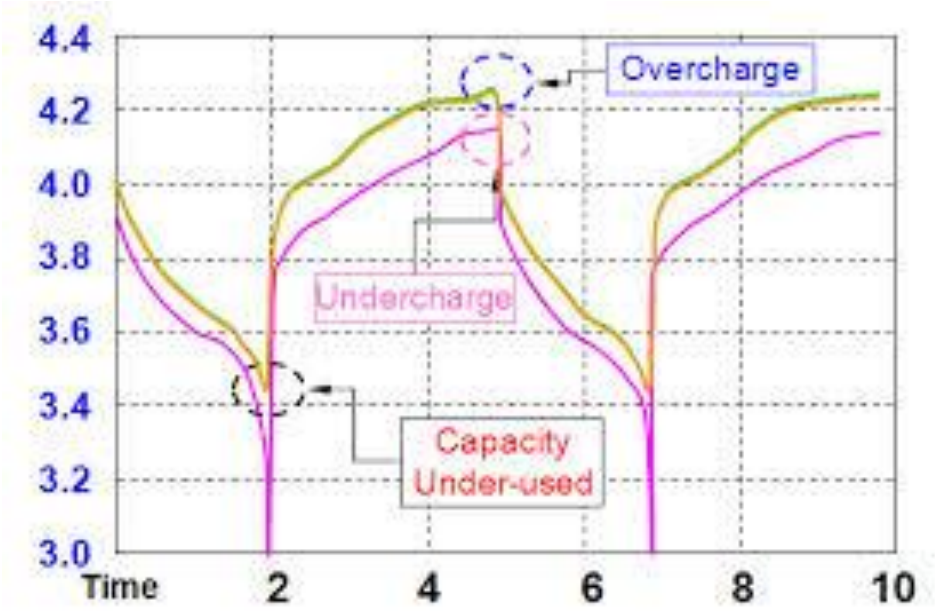
If you have a situation with a mismatched cell in the module, obviously, the paralleled cells will force the voltage and current to share.

Chemically, the cell will not support the differences that result and the cell will either charge or discharge in the attempt to meet voltages.

Basically, the slope of voltage curve will force a weaker cell to go to a different SOC to meet common module voltage.

So understanding the Slope(AC impedance) of the cells leads one to understanding the balance aspects.

This is very Important



Four Modules, Yellow, Green and White and Pink.
Pink has less capacity/higher impedance all others on top of one and other
Note! Capacity continues to degrade in Pink as it is not recharged completely
Assumes BPS Protects Pink, and not all others

HOW TO BUILD A PACK
MODULE TESTING

So, now you have modules built, hopefully without damaging the cells in the process (overheating the terminal connections or something bad like that)

Make sure that the connections can carry your pack current, as it will be flowing through them

No undue stress on the terminals, or package.

Now we test modules. Impedance and capacity.

This will certainly require a different test stand. This may even use a resistive load such as a power light bar

Anyhow, capture equivalent testing results for each module and use it to match modules best you can.

By no means should the pack be as small as possible, unless you don't want to rayce it in the summer, it will likely overheat.

How you mount the cells in the battery pack is important:

- 1) for service should you need to replace one
- 2) to measure it compared to the others
- 3) for vibration & restraint

HOW TO BUILD A PACK -PACK ASSEMBLY

Now that all modules are Characterized, assemble the most equally matched modules into a pack by stringing them together serially.

Do not parallel modules! This introduces other balancing issues that are not easily protected with the BPS. If the BPS can not detect an issue, then it is dangerous, so do not parallel modules or strings of modules.

Notice, more cells/modules will be needed to develop a Good rayce pack than just one.

The amount needed depends on the amount of variation in the cells you buy. So if you buy cells from a supplier who doesn't keep manufacturing lots together, this may require 3 packs worth to get a good pack of tested rayce cells.

Not a pretty picture, but that's the cost of putting together a good pack.

Cells/Modules Charge and Discharge at slightly different voltages for a common SOC (hysteresis).

Also when connecting modules in series, make sure the relative SOC is consistent between Modules not just the voltage.

Not having a Consistent SOC between modules will cause Pack Imbalance right from the start or may result in high inrush current at the connection.

HOW TO BUILD A PACK
HOW LONG WILL IT TAKE?

Next Question is how much time will a pack build take?

I wish I could provide an answer to that, but lets say it takes a good team 2 years of study and work to get a good pack.

Yes, some have had successful packs with less work than I have listed, but those that have completed this level of work ended up raycing the same pack for three and sometimes more events.

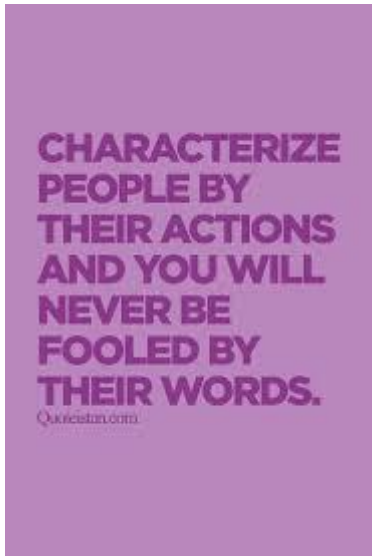
HOW TO BUILD A PACK BEFORE YOU RAYCE

When you finally get a pack built, everyone thinks its ready to put in the solar car and rayce it. **Not quite!**

Next, you need to **CHARACTERIZE** the pack, so the team can predict some performance standing during rayce days.

To do this, it may take a resistive based load and a controllable voltage power supply.

You also now need to consider placement of sensors to detect worst case situations you are aware of (Temperature and Voltage) within your pack. The benefit of monitoring what are the worst cells is that your pack will last vs degrade or worse.



HOW TO BUILD A PACK
BATTERY COOLING

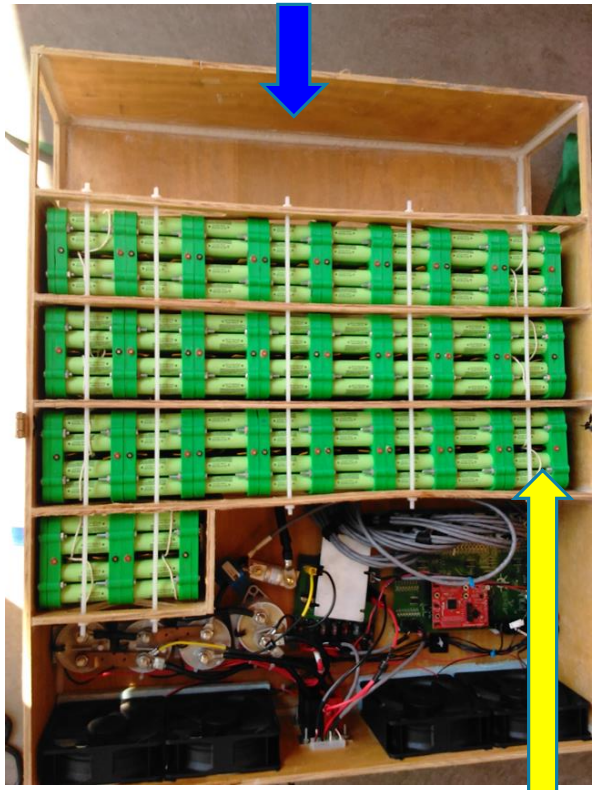
After placing the Pack of cells in the Battery Pack Box and drawing a load on them, they will likely display a thermal imbalance.

This should be understood by the team and compensated for by the battery ventilation, as it is typically too late to change spacing.

It should be the goal of the team to keep the cells at the same temperature throughout the pack. This can only be done with **adequate spacing, and distributed airflow (modeling may be important here).**

Variation in temperature results in **variation of cell performance**. Those cells that are hotter chemically react faster and wear out faster.

Notice! Air Distribution Cavity



Adequate Spacing

Hot Cells within a Pack Don't last as long and cause imbalance!!!

HOW TO BUILD A PACK
WHAT IS IMPORTANT

"A Balanced Pack is better than High Capacity Pack"

A thermally spaced cool pack is better than saving energy on lower air flow or a compact (dense) pack.

It only takes **ONE** cell to take down a pack.

Be considerate of those weaker cell(s) and monitor them ahead of the event so you can change them out before rayce time, should they need it

HOW TO BUILD A PACK

Ok! We spent seventeen slides telling you how to build a pack.

What you do with this information is up to you.

How your vehicle performs will be predicated on how well you build a pack for the solar car.