Powering the Solar Car

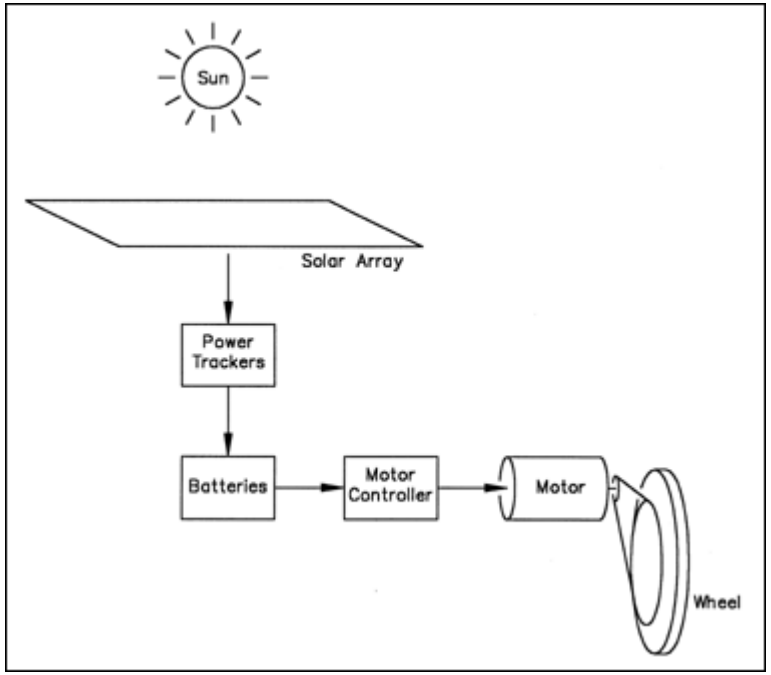
Liam Hubbard, Lead Electrical Judge

Powering the solar car

- How do you get the car moving?
  - Photovoltaic array choices
  - Power trackers
  - Electric motors and controllers

Powering the solar car

- **Solar Arrays**
- **Maximum Point Power Trackers (MPPT)**
- **Batteries**
- **Electric Motors**
- **Gearing**
- **The Electrical System**
- **Everything Else Electrical**

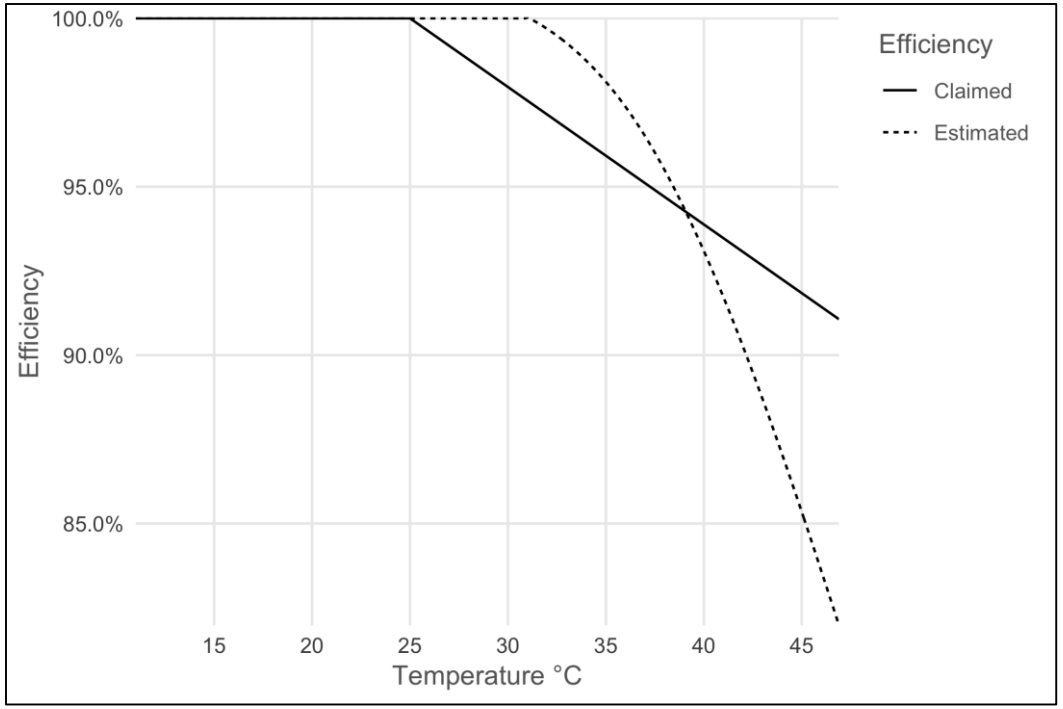


Substrate and Support Frame

- Varies Depending on the Type of Array
- Main Considerations
  - Rigidity
  - Cooling
  - Weight
  - Conductivity

Panel Temperature

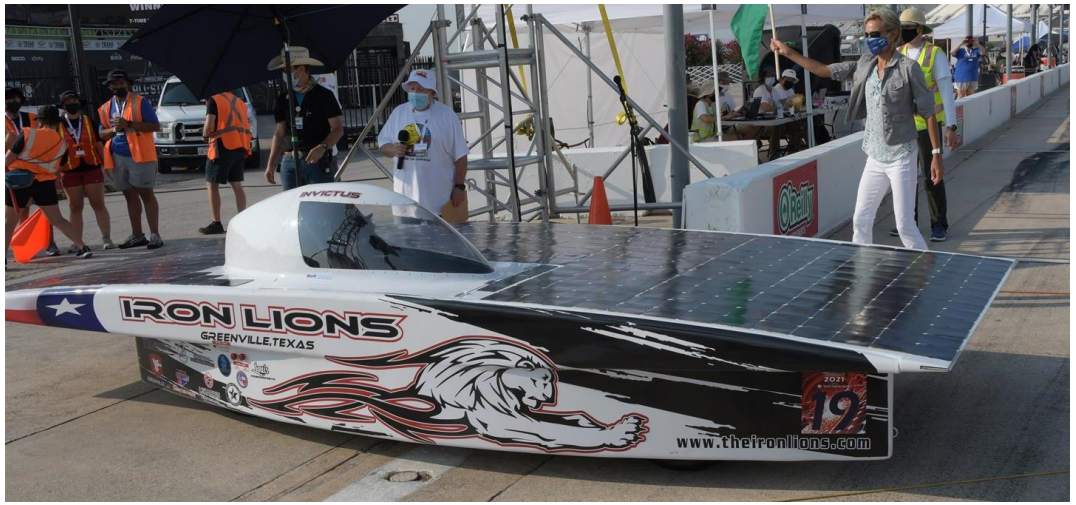
- **Solar Cells change efficiency as their temperature changes**



https://www.jeroenboeye.com/blog/solar-panel-analysis-pt-2-temperature-and-efficiency/

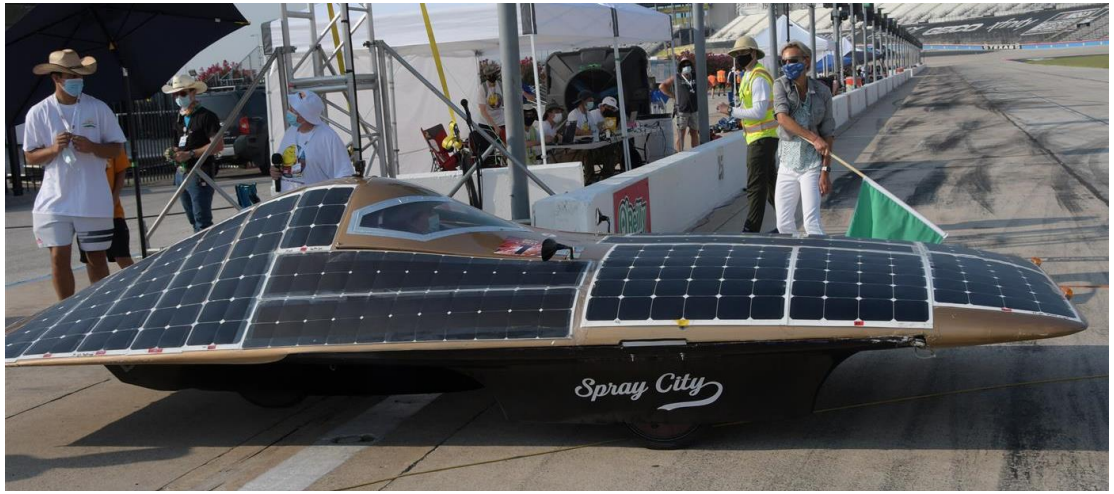
Shape of Array

- **Flat Solar Arrays**
  - **Easier to execute**
  - **Angle to sun *l*ess of a concern**
  - **Wing over body vs Canopy Above Array**



Shape of Array

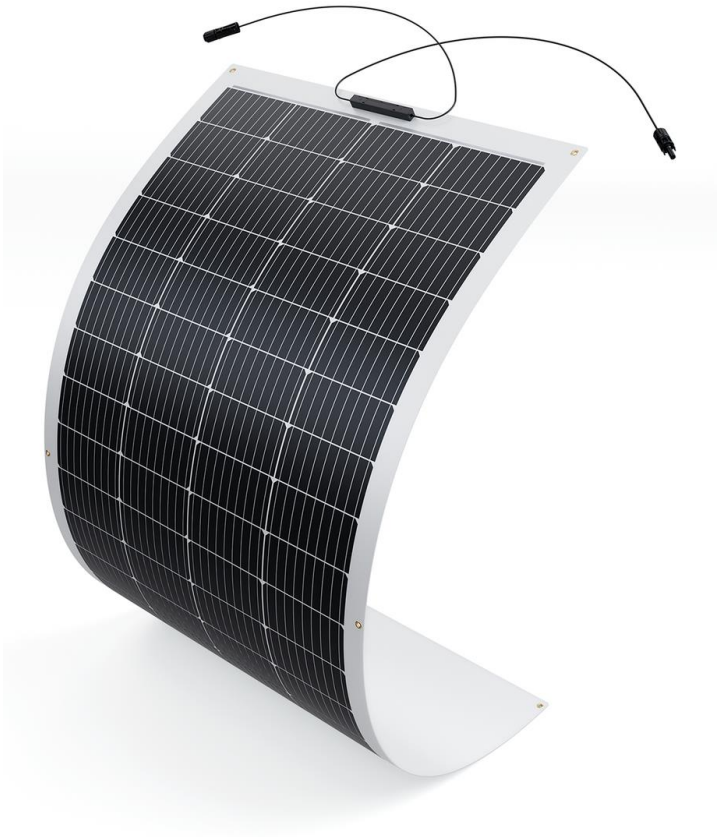
- **Curved Solar Arrays**
  - **Higher the angle the greater chance for breaks without ideal support.**
  - **Angle to sun *more* of a concern**



The Solar Array

- **Pre-made Commercial panels**
  - **Reliable**
  - **More Easily purchased**
  - **Typically HEAVY (glass top adds weight)**

The Solar Array



- **Pre-made Semi-Flexible panels**
  - **Lightweight (but requires own framing)**
  - **Typically less efficient (junction boxes)**
  - **Readily available**

The Solar Array

- **Pre-made or Custom panels**

SBM Solar

SUNPOWER | FROM MAXEON SOLAR TECHNOLOGIES

- **Many more on our website and online…**

The Solar Array

- Raw cells and lamination
  - Planning has to start FAR in advance (you are probably too late already!)
  - Process is expensive
  - Panels are very light and can be built to fit your car
  - Easy to maximize power and reduce aerodynamic drag
- SunCat Solar – encapsulation services

Laminated Cells

The Solar Array

- Do-it-yourself solar array
  - Amazing learning experience
  - Learning curve is steep
  - Hard to find raw cells
  - Takes a lot of man power
  - Hard to watch when cells are continually breaking
  - Can fit exactly to your car

Do-it-yourself

Do-it-yourself

SunPower Wishbone Tabs

Tabbing makes it easier to solder

Cells are still fragile

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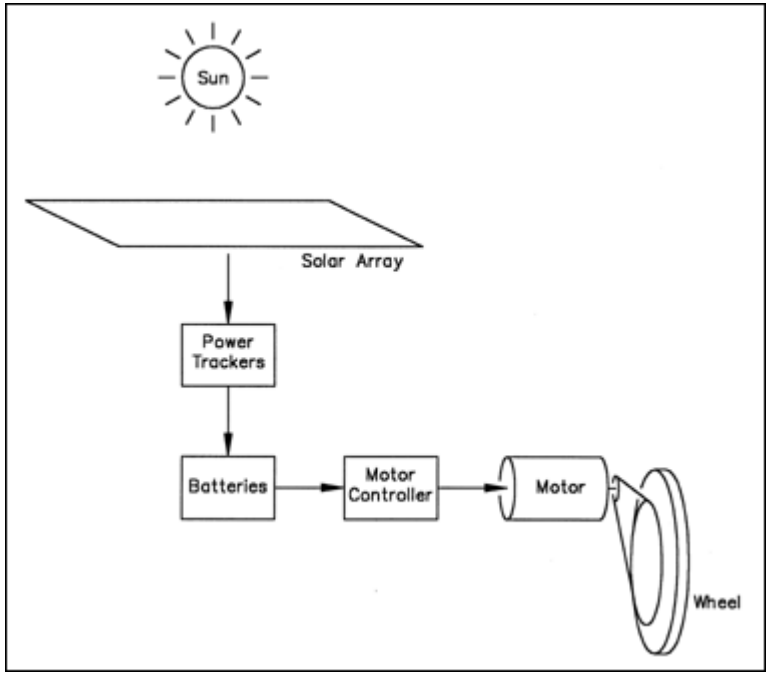
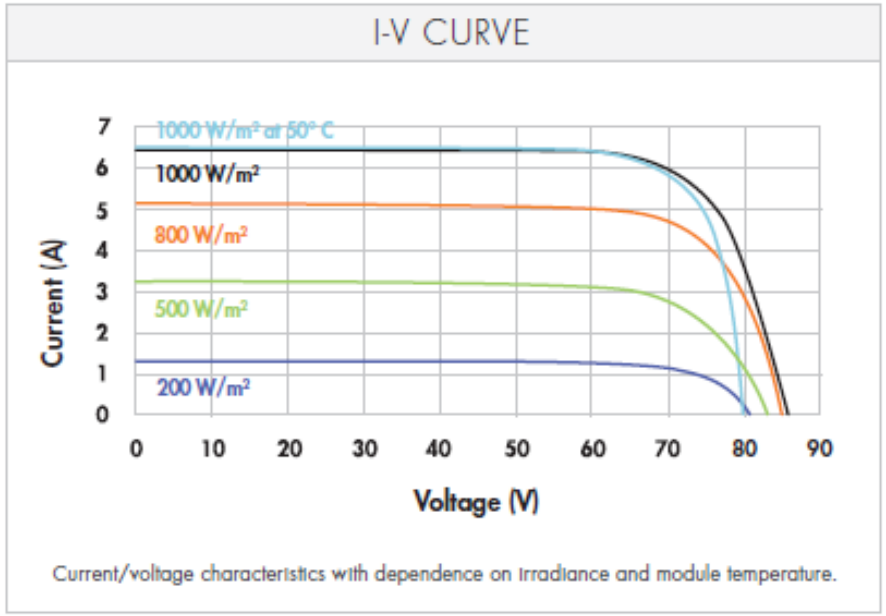


Maximum Point Power Trackers (MPPTs)

- Moving power from the solar array to the batteries is not as easy as hooking up a couple of wires!
  - Voltage from your solar array needs to match the voltage of the battery pack.
  - More often than not the group of solar panels will not match your system / pack voltage
  - Even if you do match the pack voltage it will not be efficient for charging your battery pack
  - Without protection you can have reverse current flow into the panels when they are shaded

What MPPTs Do

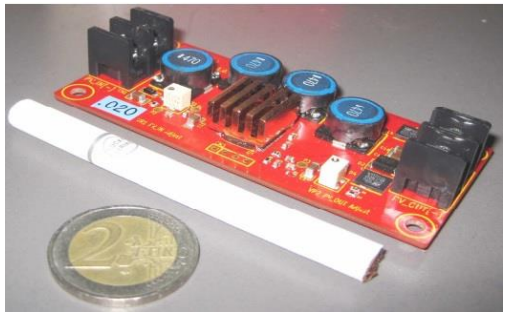
- **Maximum Power Point Trackers (MPPTs) adjust voltage and current from your array to give you the most efficient transfer of power to your vehicle**
  - **They adjust the output voltage of your array to always be at the right voltage for ideal charging of your battery**
  - **They can either "boost" voltage (40V to 72V) to a higher value or "buck" voltage (140V to 80V) to a lower value**
- **MPPTs are also a main source of telemetry for your array**



Current/voltage characteristics with dependence on irradiance and module temperature.

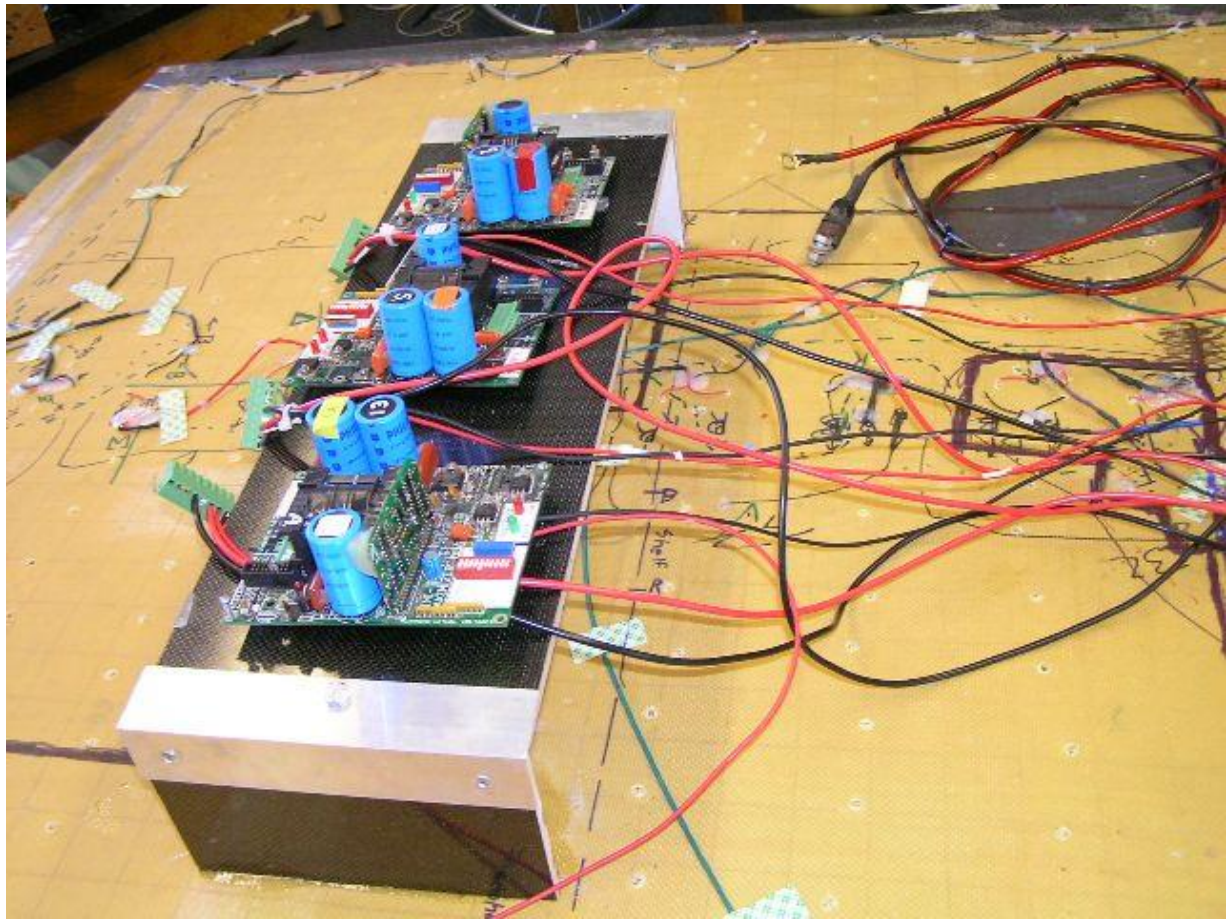
MPPT Choices

- AERL (Australian Energy Research Laboratories) RaceMax 600B
  - Needed for V_{out} > 72V
- Nomura MPPT
  - Small/light, V_{out} = 34.5V
- MidNight Solar / Outback Power (and other grid type MPPTs)
- Genasun
- DC-DC Converters → Don't do this!



https://www.facebook.com/NomuraCo/photos/a.2709579579286363/2709579905952997/

AERL MPPTs



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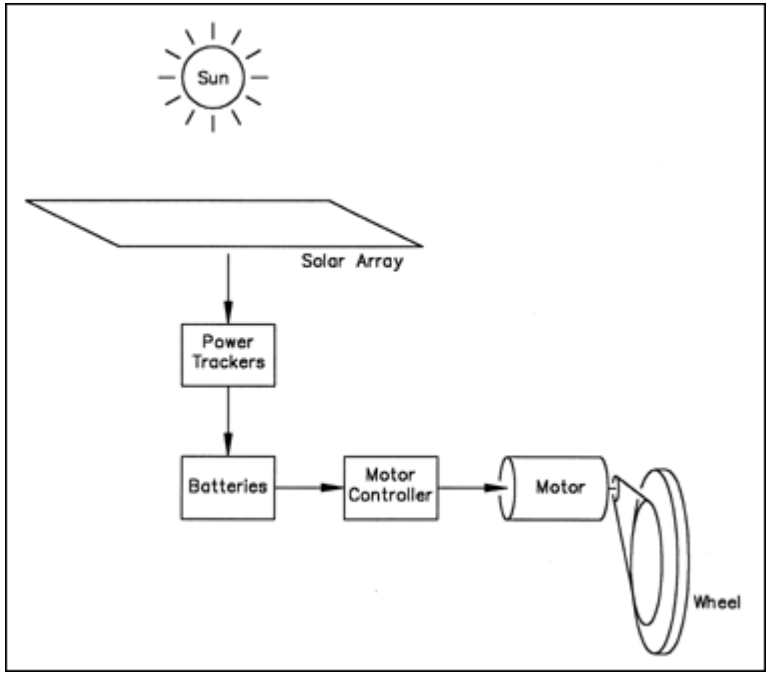


Batteries

- Choose carefully!
- Batteries are one of the areas where you get what you pay for.

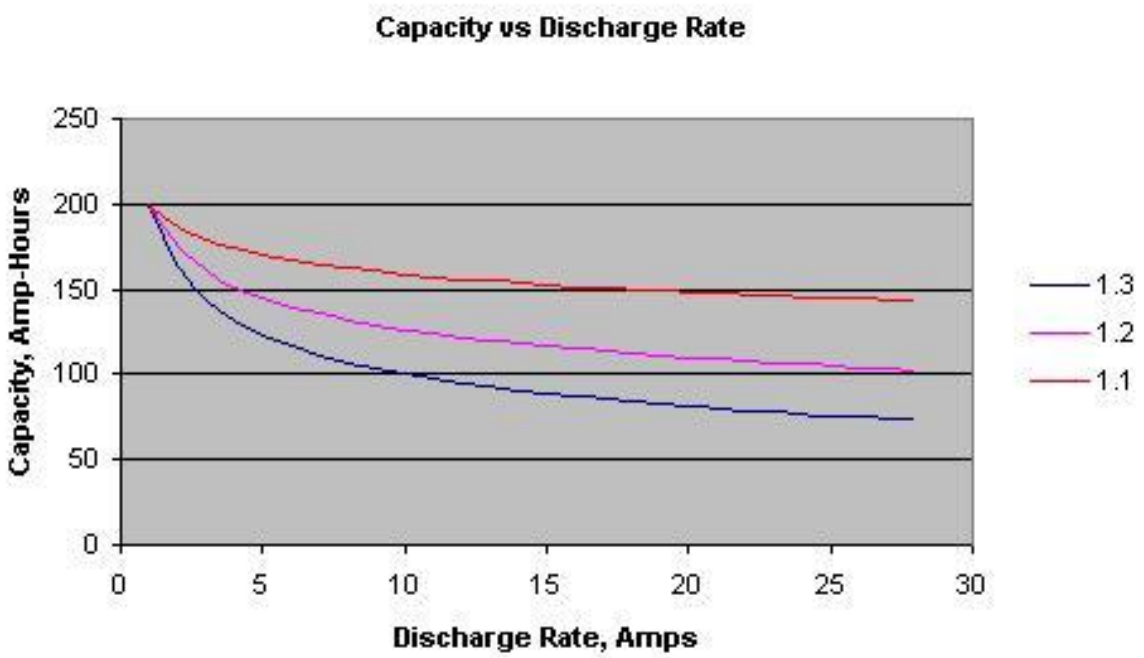
- Decisions to make:
  - What voltage does your car run at?
    - Higher voltage means lower current
  - How much weight can you carry?
  - How much energy can you get at that weight?
  - Can your solar panels recharge the battery pack?
  - Is it a road race or a track race?

Batteries

- The 5.25 kilowatt-hour rule
  - kW-h = Amp-hours x Voltage
    (at the 20 hour discharge rate for PbAcid)
- Example:
  - Four, 12 volt, 84 amp-hour batteries in series
  - 84ah x 48 v = 4032 watt-hours or 4.032 kilowatt-hours
  - (this battery pack would weigh around 230 pounds)

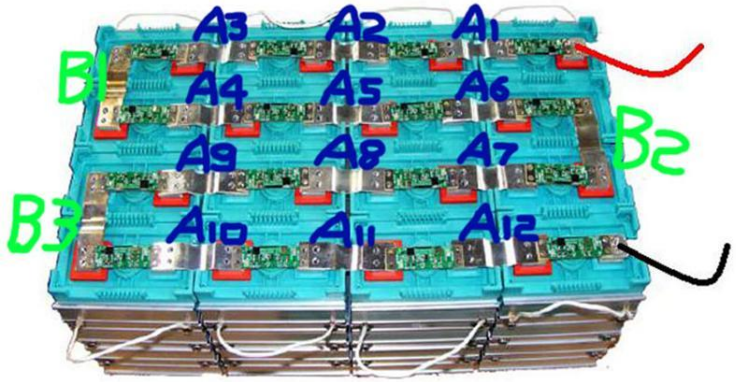
Peukert's Number

- **Choosing batteries based on the Peukert number:**
  - **A typical sealed lead acid battery has a Peukert number between 1.1 and 1.3. (The closer to 1.0 the better!)**



LiFePO4 Now Allowed!

- Same power for less weight
  - Lead Acid: 35-40 Wh/kg
  - Lithium Iron Phosphate: 90-160 Wh/kg
- Must have BMS monitoring batteries at a cell level
  - Lithium cells are typically ~3V
  - Monitor each series string (e.g. 4S2P = 4 taps)
  - Need to verify manufacturer's documentation for adequacy
- Usually a drop-in replacement for lead-acid
- Very stable chemistry (does not require Class D fire extinguisher)



Testing Batteries

- Understanding how your batteries perform is one of the most important things you can know BEFORE the race starts.
- Carefully recording voltage, current, and amp-hours will help your team make good decisions during the race

Some of the Team Favorites

- Concorde Sun Xtender series
  - 84 Ah $245/battery

- EnerSys Odyssey Marine series
  - 68 Ah $250/battery

- No specific recommendations for LiFePO4 (yet)

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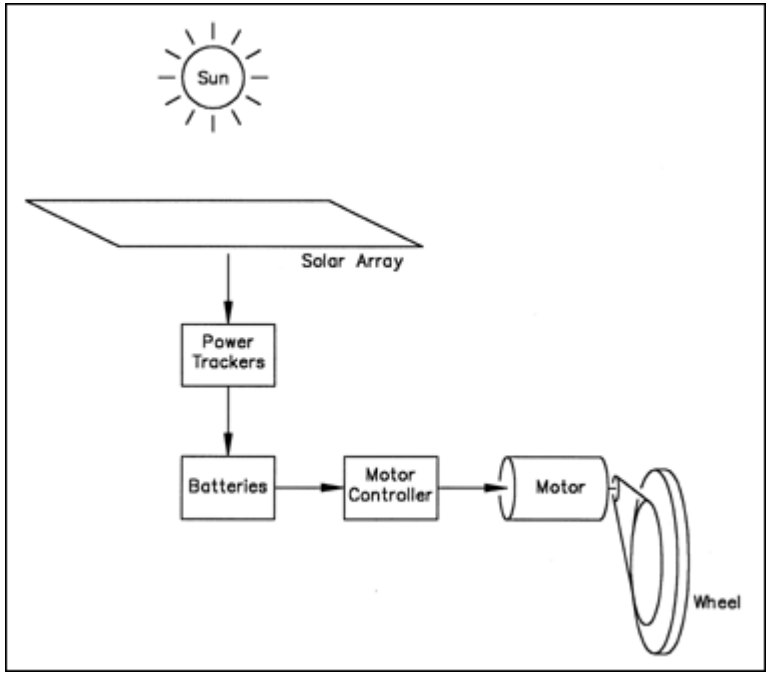
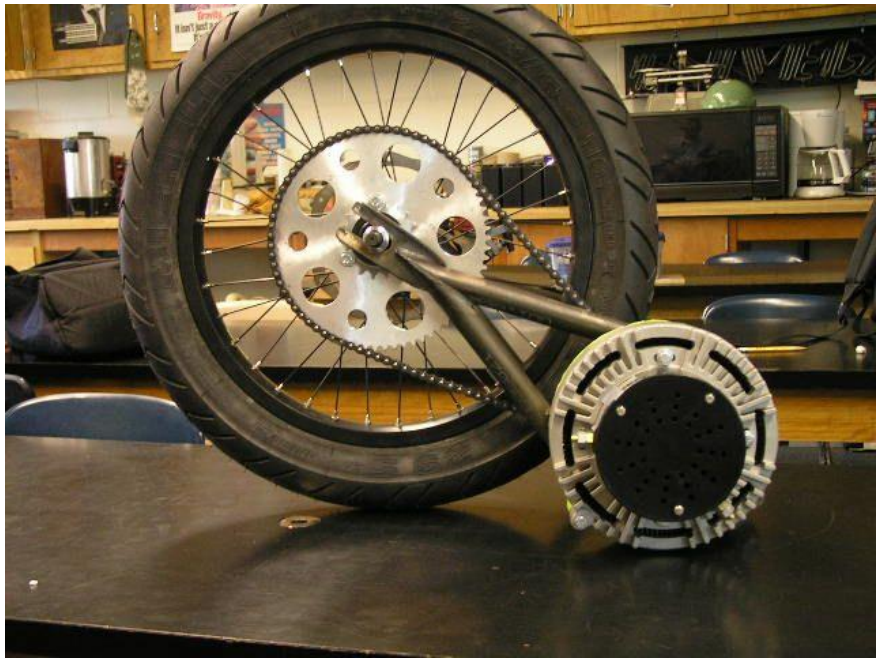


Electric Motors

- **Brushed Electric Motors**
  - Inexpensive
  - Lower overall efficiency
  - Controller is inexpensive and easy to wire
- **Brushless Electric Motors**
  - Very efficient
  - More expensive
  - Controller is more difficult to wire (typically 3 phase)



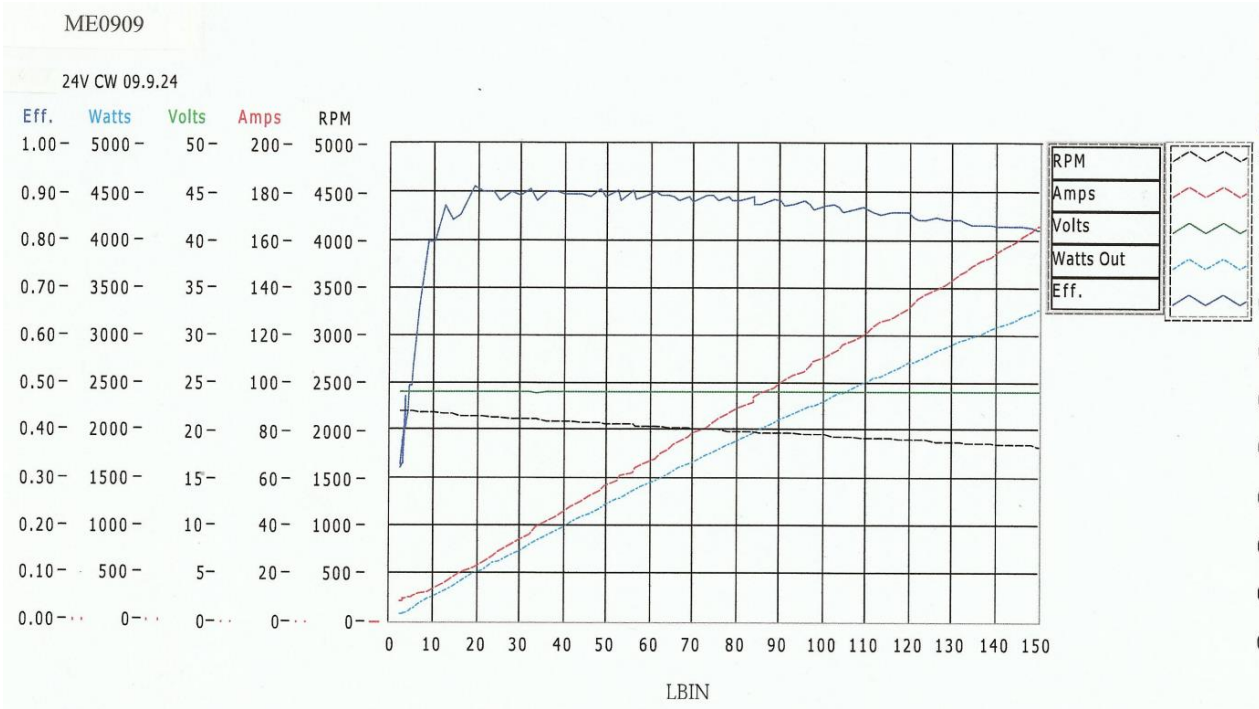
Brushed Motor Examples

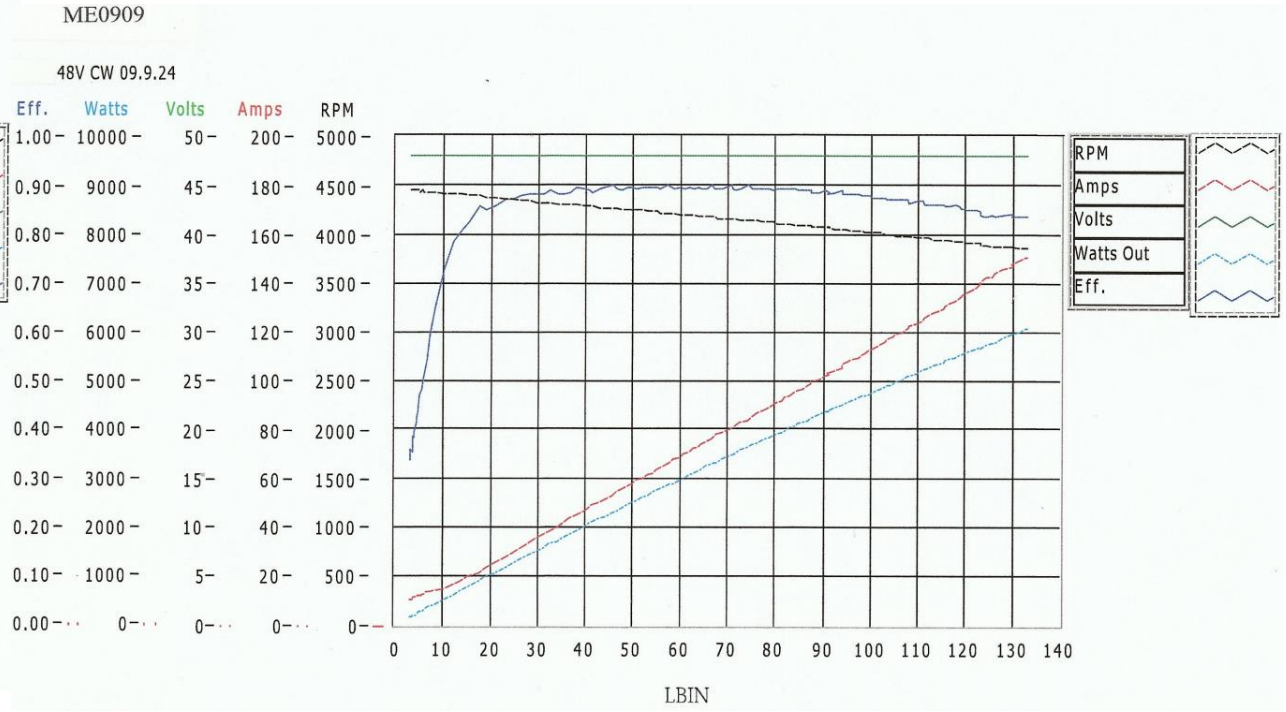
- Briggs and Stratton ETEK
- Lynch LM200
- Perm-Motor PMG-132 12-72 VDC
  - 90% efficient
  - Wide voltage range (12-72 volts)
  - Light weight (24 pounds)
  - $1400

Brushed Motor Examples

- **Motenergy ME0909 Permanent Magnet DC**
  - **Best replacement for original Briggs and Stratton E-tek**
  - **12-48 volt**
  - **Light weight (24 pounds)**
  - **Inexpensive ($450)**

Motor Efficiency Data (ME0909)





Brushed Motor Examples

- **Advanced DC K91-4003 motor, 48-96VDC**
  - **Higher voltage motor (48-96 volts)**
  - **Strong motor for heavier cars**
  - **Low cost ($800)**

Brushless Motor Example

- **Motenergy ME0907 Brushless PMSM/BLDC**
  - **No brushes=no maintenance**
  - **24-72 volts**
  - **Very efficient (over 90%)**
  - **High current (up to 100 amps continuous)**
  - **Motor is inexpensive ($460)**
  - **Special controller needed**

Hub Motor

- NGM ‘Direct Drive’ high efficiency in-hub motor with variable air gap adjustment.
  - Super efficient over a broad range of speeds
  - No need for gears or chain
  - Very expensive (Motor + controller > $25,000)
- Mitsuba / Nomura hub motors replacing NGM as favored motor for solar car teams
  - Still ~$25,000

Brushed PWM Controller

- Alltrax AXE
- Easy to wire
- 0-5k Pot control
- Programmable
- Durable

Sevcon controller (Brushless)

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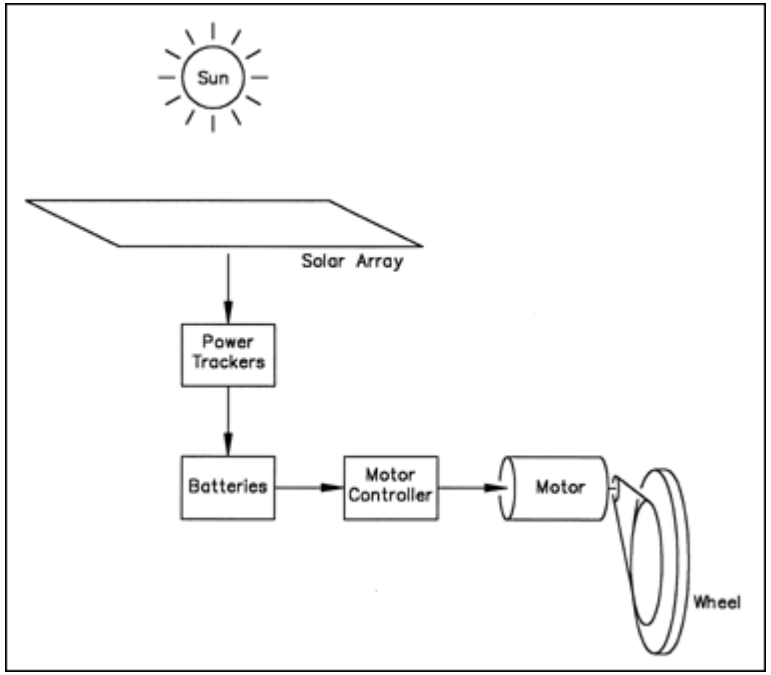


Choose the Correct Gears

- Don’t gear a car for 50 mph if you are going to drive it at 25 mph. Be realistic about your cars speed!
- Chain drive systems can be very efficient if gears are aligned and lubricated.
- Pictured: 48V system, 15 tooth front, 70 tooth rear. Max speed = 36 mph

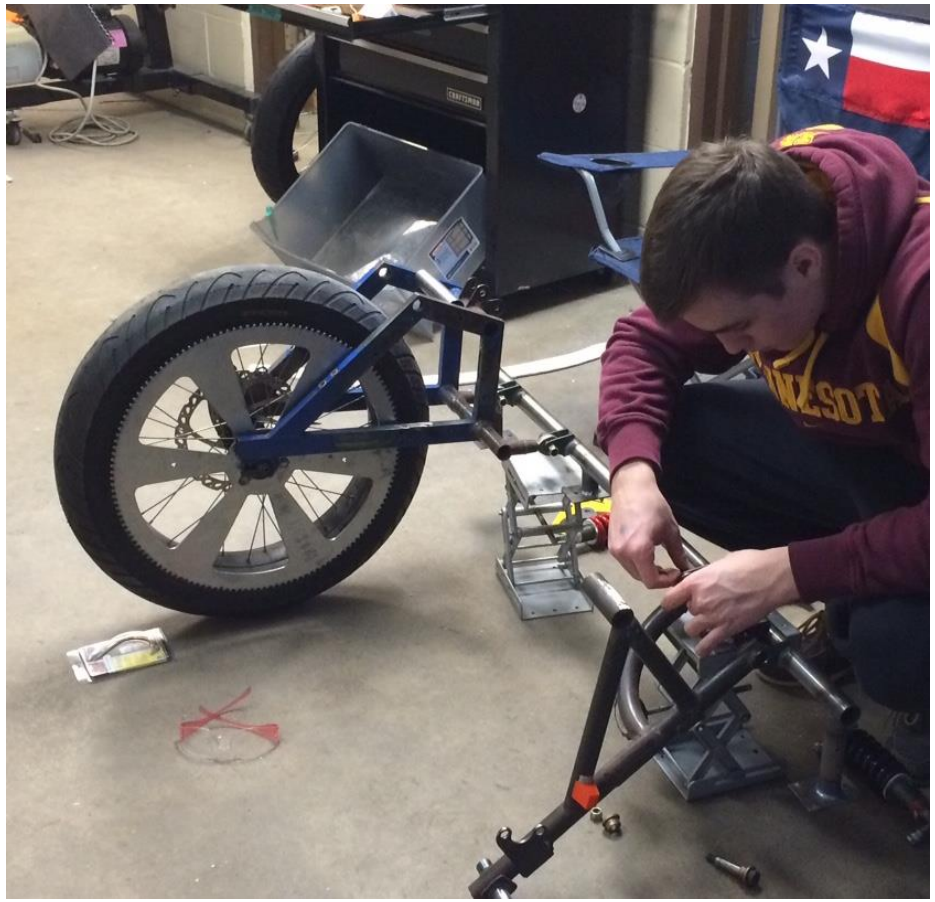
Gearing to match your motor

- How fast will I go with…

- $S_{MPH} == \frac{60 * M_{RPM} * T_{SS} * \pi * D_{Wheel}}{T_{BS} * 5280 * 12}$

Variable	Defined As
S_{MPH}	Speed in Miles/Hour
M_{RPM}	Target Motor RPM
T_{SS}	# Teeth Small Sprocket
D_{Wheel}	Diameter Wheel in Inches
T_{BS}	# Teeth Big Sprocket

Choose the Correct Gears



Custom Sprockets:

Rocket Sprockets
www.rocketsprocket.net

PMP Sprockets
www.pmpsprocket.com

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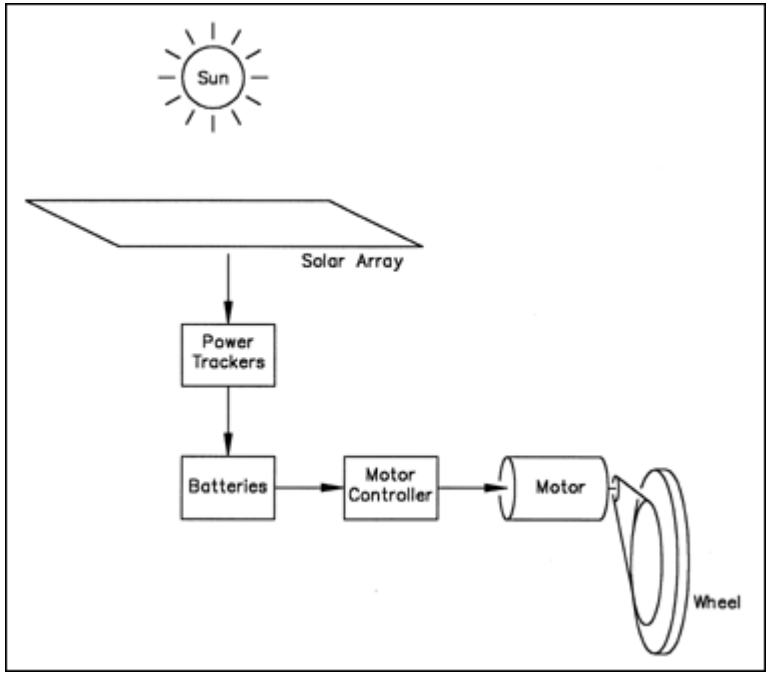
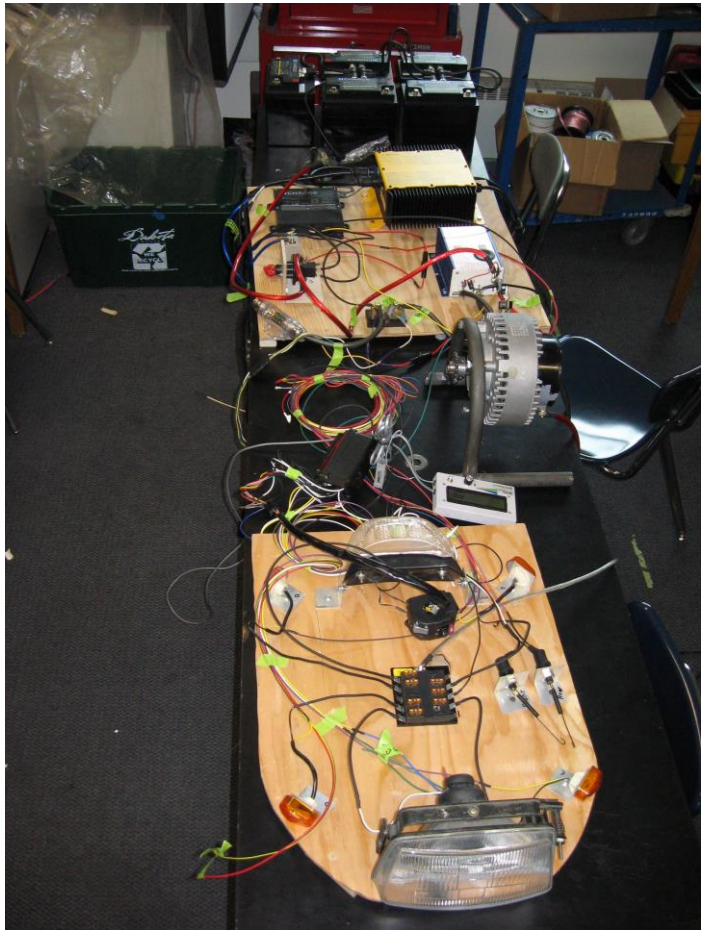
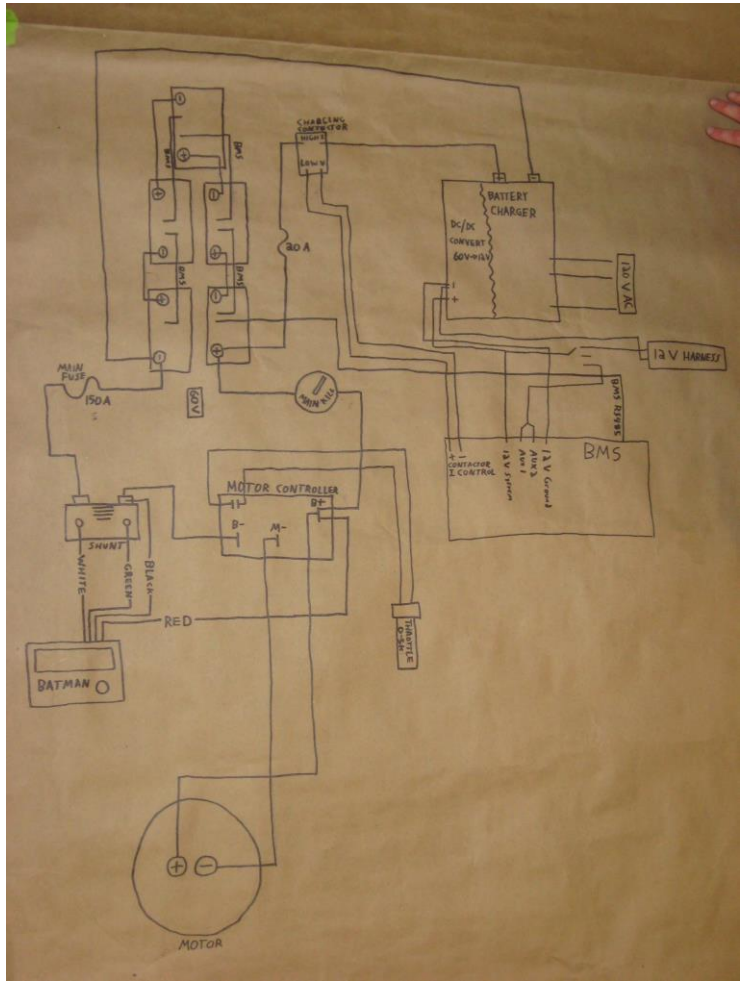


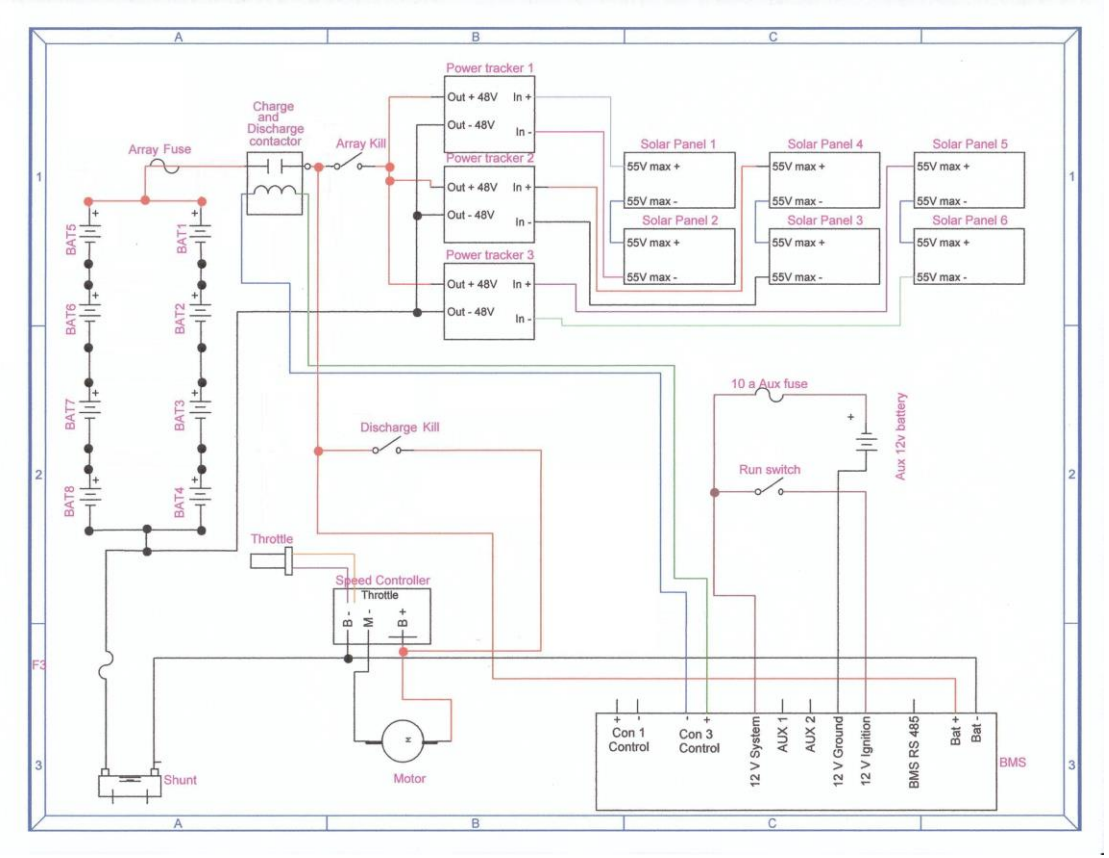
Electrical System

- Propulsion System
  - Use the correct gauge wire for the job
  - Disconnect switches should be designed for DC
  - Fuses
- Auxiliary electrical system (everything else on your car)
  - Lights
  - Fans
  - Horn



Electrical Schematics





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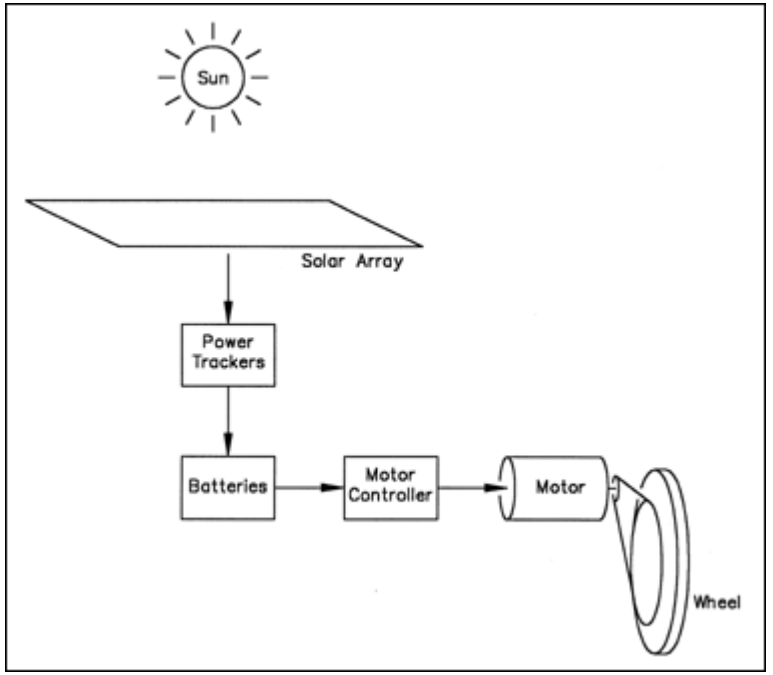


Switches/Fuses

There are a lot of resources for switches and fuses. Be sure they meet the race requirements before ordering! Be sure they are rated for your DC system. (AC rating will not qualify!)

(Bussmann FWH Fuses are rated at 500V DC)

Relays are required!

Electric Motorsport
www.electricmotorsport.com

Tecknowledgey
http://www.tecknowledgey.com

No longer need "Big Red Button"

Single Pole On/Off
Rated load: 400 A
Break Current: 1200 A @ 48 V DC
(600 A @ 96 V DC)

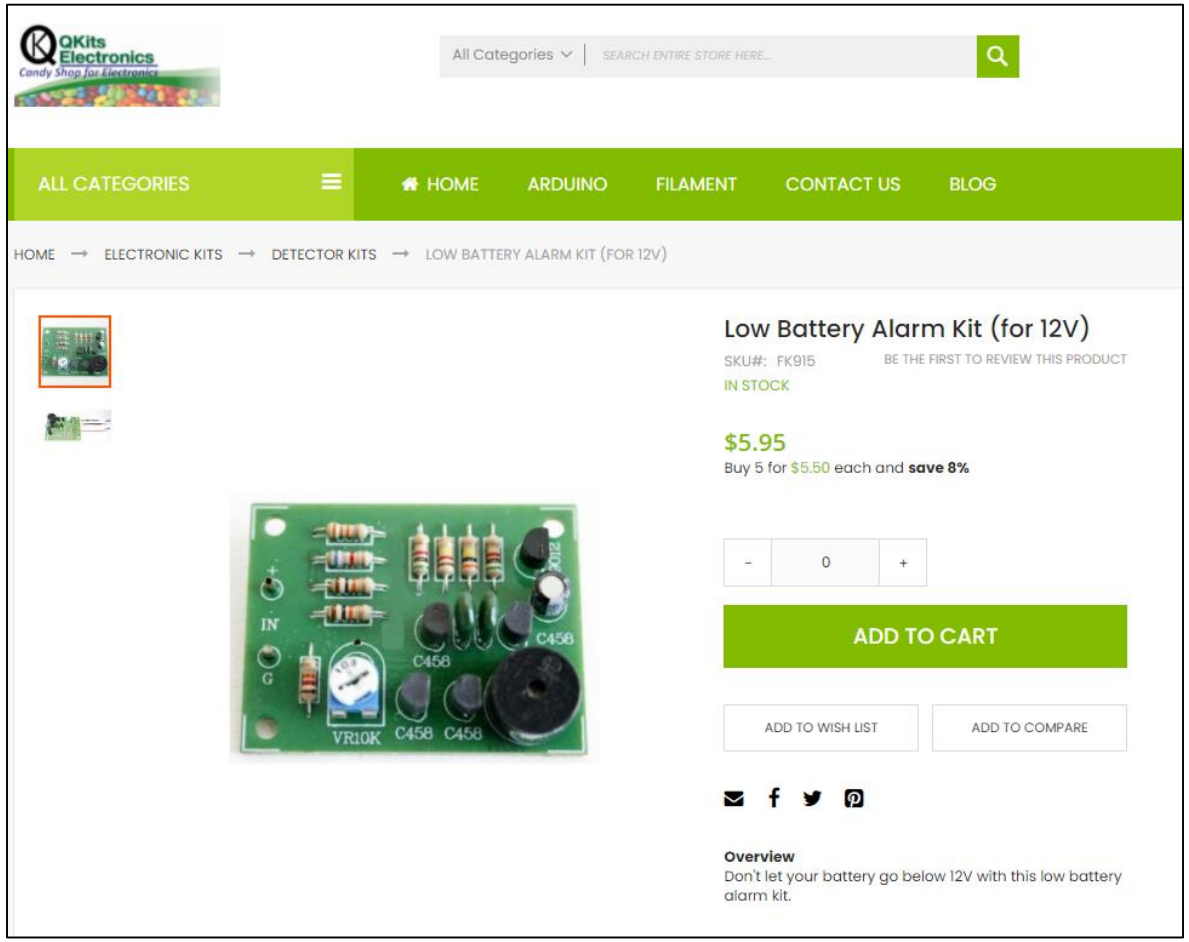
500V DC @90 amp fuse
is about $50

Low Voltage Indicator

- **Cots Solution**

Do-It-Yourself kit available at: http://store.qkits.com/

Look for “Low Voltage Alarm”

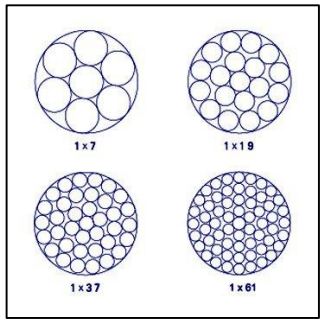


Wire

- **Propulsion System Wire**
  - **Use welding cable**
    - **Should be very flexibly**
  - **Use proper crimping tools and lugs**
    - **Don’t attempt to solder**
    - **Don’t attempt to splice**
  - **Be aware of counterfeit cables**
  - **Be sure to size to your system**

http://www.flex-innovations.com/counterfeit.htm

- **Auxiliary System Wire**
  - **Have a variety**
  - **Get higher quality wire with more strands**



Different Strand Configurations
For the same wire gauge

Heat Shrink

- Heat shrink
  - Should always be used
  - It's worth it to spring for the 3M heat shrink
  - You will need a heat gun

Wagner Spraytech 0503008 HT1000 Heat Gun, 2 Temp Settings 750°F & 1000°F, Great for Soften paint, Caulking, Adhesive, Putty Removal, Shrink Wrap, Bend Plastic Pipes, Loosen Rusted Nuts or Bolts

Visit the Wagner Spraytech Store

4.4 out of 5 stars 17,306 ratings

Price: $24.99 prime & FREE Returns

Get a **$10 bonus** when you reload **$100 or more** to your gift card balance (Restrictions apply).

May be available at a lower price from other sellers, potentially without free Prime shipping.

Size Name: **HT1000**

HT400	Furno 500	Furno 700
$29.26 prime	$44.59 prime	7 options from $70.09

Soldering Tools

- Wire strippers
  - My preference is nothing fancy
- Solder
  - Lead free can be used but 60/40 Tin Lead Rosin Core is typical
  - There are many diameters
    - Very small diameter (0.6mm) solder is not meant for 16 ga / 18 ga wire
    - Larger diameter (1.5mm+) solder is not appropriate for fine soldering (like making connections on a printed circuit board)

- Irons vs Guns
  - Irons
    - Slow to heat up / slow to cool
    - Precision temperature control and application with different tips
    - Recommended for fine work (PCBs, solar Cells, ect.)

  - Gun
    - Fast to heat up / Fast to cool down
    - One or two temperature settings
    - Good for working on general solar car wiring

Most reliable wiring:

- Crimp connectors that have been crimped and soldered with a heat shrink sleeve
- Tin wires before putting them in the heat shrink

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