FAMU-FSU College of Engineering
Sustainable Engineered Solutions

Solar Car Design:

System Level Design Review

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Executive Summary

The FAMU-FSU College of Engineering has tasked this team of engineers with the challenge of building the FAMU-FSU Solar Car. The overall goal of this year's team is to design and develop a 2 year plan to achieve a Solar Car ready for the Shell Eco-Marathon America (SEMA) in spring of 2014. The new design is a very light weight, three wheeled, one man automobile that is capable of utilizing renewable energy to produce an energy efficient vehicle. The vehicle will be designed under the guidelines of the Solar-Battery Electric Prototype division.

During this year, it is not possible to design, test and build the solar car to meet all the specifications of the Shell competition. This year's electrical engineers will focus on the simulation and design of the energy system consisting of solar panels, solar panel protection, DC-DC converter, MPPT controller, batteries, battery management system, battery protection and selection of efficient motor. This year's mechanical engineers will focus on the design, testing and building of the body/chassis, plus the necessary safety requirements, such as Exit Strategy, roll bar and bulkheads, along with the suspension and wheels.

A current and future objective of this project is to work closely with Sustainable Engineered Solutions (SES) to bring in future sponsors for the Solar Car Club. The SES website will be a cornerstone for the procurement of funds as it will act as a medium that the public can both get involved in the project and view the cars progress throughout future years. The website will also help give credit to contributors of the project by displaying their information with links to their website.

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1 Introduction

1.1 Acknowledgements

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1.2 Problem Statement

The FAMU-FSU Solar Car Team of 2011-2012 provided the first fully functional Solar Car. After showcasing the design and model, the car was procured by a FSU student organization called Sustainable Engineered Solutions (SES). The Solar Car Design this year relies upon three main focuses: a redesigned body and chassis, develop braking and steering systems, a solar panel-battery energy system, and a microprocessor controller. Selection of the focuses was made based on the SEMA design requirements and limitations.

The solar car this year will not be fully functional, yet a redesigned body with necessary safety requirements will be built and a newly designed energy system using solar panels and will be simulated and prototyped, along with the chassis, suspension, and wheels will also be determined. Due to limited time, this year's group won't be able to complete the entire car; however the design and all the purchased parts will be in line with the SEMA rules and requirements. The following year's plan, 2013 is included in this document, located under year 2. The overall goal for these two years is to take the final designed car to competition in Houston, TX. The new design team in 2013 with focus on energy system integration with motor and chassis, install brakes and regenerative braking as outlined in 2012, and finish all necessary safety requirements and communications related to the SEMA in 2014.

The proposed solution approach for all mechanical aspects includes developing models using Pro-Engineer CAD. A few mechanical components will require the use of simulations to easily change the design parameters and determine the best design (for example, simulating air flow over the chassis the best aerodynamic design).A materials selection process will be used to properly choose the best materials possible for each component and will lead to purchasing, fabricating, and installing each component. After a component is installed, testing will occur to determine if the component is working properly and if there needs to be additional redesigns or recalculations performed.

The proposed solution approach for all electrical aspects includes development of simulation models for the solar panels, batteries, DC-DC converter and motor. The simulations will determine power efficiencies and voltage/current characteristics during different driving conditions. In order to necessitate simulations, predetermined components and their real-world parameters will be used to complete each simulation scenario.

The deliverables, in March 2013, will ideally replicate a working and integrated energy system along with a fabricated chassis with suspension, wheels and the ability to conform to the predetermined exit strategy.

The final design, in March 2014, will ideally include all working components and integrations for a functioning solar vehicle ready for SEMA 2014.

1.3 Operating Environment

The FAMU-FSU Solar Car shall be able to operate in standard North American climates. The car needs to be able to withstand normal wear with seasonal changes that a commercial automobile would encounter. The car will be resistant to rain, dust, debris, etc. The car's electronics will be protected electrically and physically and be able to operate in humid conditions as well as dry hot environments. The car will not be built to operate in extreme conditions such as mountainous terrain or heavy snowfall. The car will be able to handle up to a 12 percent grade which can be found on residential roads and have the ability to remain still at a 20 percent graded hill using brakes.

1.4 Intended Use(s) and Intended User(s)

With SES at the FAMU-FSU College of Engineering, the car will be used for future senior design projects and the Solar Car Club. The car will be taken to various events and shows such as the FSU homecoming parade in order to get publicity for current and potential sponsors. This in turn will hopefully generate donations to help the progression of SES and its related projects, and also to generate money for more research in sustainable energy solutions.

This year the intended users will be solely project team members for design and testing. This will change for next year's senior design team; the solar car will be in the home stretch for competition at the SEMA. The solar car club hopes to inspire other engineering students to pursue an increased knowledge of sustainable energy and its immense applications. For either case, the 2 year goal is to design a car fitting all requirements for entering and competing in the SEMA in 2014.

1.5 Assumptions and Limitations

1.5.1 Assumptions

- Vehicle will operate safely and efficiently.
- Batteries will be able to charge from solar panels.
- Mechanical energy will be recycled through regenerative breaking.
- Vehicle will be made to street driving legal regulations.
- Vehicle's completion will be focused toward the SEMA.
- The vehicle will consume no more power than the batteries and solar panels can provide.
- The vehicle will be able to maintain an average speed around 15 mph.
- The motor will be able to run for extended periods of time.
- The vehicle will be able to travel greater than 6 miles.
- The vehicle must me all specifications, rules and regulations set out by the SEMA.

1.5.2 Limitations

- The solar array must be fit into 0.17 square meters.
- The batteries, if Li-ion based, must utilize a Battery Management System (BMS).
- The vehicle must not exceed 3.5 x 1.3 x 1 meters in dimensions.
- The maximum vehicle weight without a driver must not exceed 140kg.

Note: More specific constraints and limitations see Need Analysis and Requirements Document

1.6 Expected End Product and Other Deliverables

1.6.1 Year 1

The end product for year 1 will be a designed, tested and built chassis with suspension, under necessary SEMA regulations. Included with the chassis will be a simulated and verified energy system. Although the energy system and chassis/suspension will not be integrated this year, necessary testing and development of prototypes will be accomplished. The overall assume energy system will be simulated and verified with MATLAB software, and each piece of the physical system will be tested using Dr. Edrington's DC load bank test set up at CAPS. The energy system including the solar panels, batteries, BMS, MPPT, converter will be integrated and tested a hardware-in-the-loop (HIL) case at CAPS. This HIL case will provide derisking for the connection of the motor, so not to cause any damage to all components.

2 System Design

2.1 Overview

The goal of the project this year is to improve upon the solar car that has been built by teams over the past few years. The car will have a carbon fiber body with a single-wheel powered by a motor in the rear, while the two wheels in the front allow for steering and braking. Aerodynamic testing will be done to provide the team with the chassis shape with least drag.

The energy system consists of a packaged battery system including BMS, an array of solar panels, a converter, a motor controller with regenerative braking, and a 48V, 800W motor.

2.2 Major Components of the System

2.2.1 Chassis

The chassis will be a monocoque structure meaning it will be a one piece shell capable of supporting all of the stresses that will be exerted on it. This will include the stresses from the driver, roll bar, electrical equipment, and mounts for the wheels. The chasses will be rigid and not deform to these stresses while parked or when it is in movement. It also must be a size that is able to hold the necessary components, as shown in Figure 2.1.

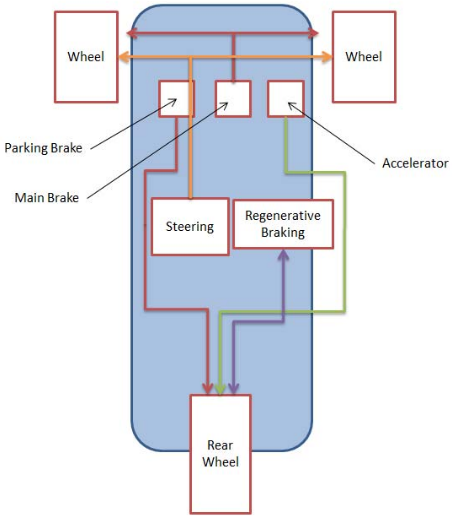


Figure 2.1: Mechanical Systems Top Level Design

2.2.2 Solar Array

The Solar Array System will help run the car by charging the battery and working as a parallel power source to the motor while in motion. The Solar Array System will be mounted to the upper surface area of the solar car. Through the carbon fiber top the solar array system will be connected to Energy Conversion System.

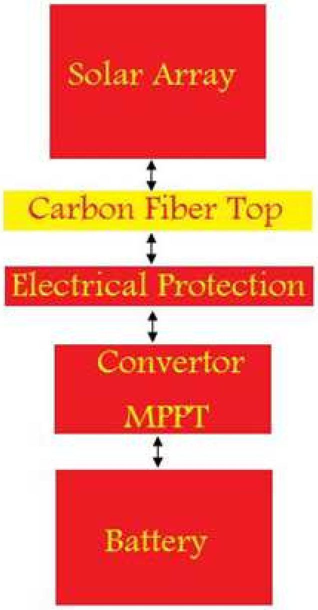


Figure 2.2: Solar Array System Top Level Design

2.2.3 Energy Conversion

The DC-DC boost converter will be responsible for stepping up the energy from the solar panels to a set value of 24V or less at the batteries. Such feat will be accomplished with the help of a Maximum Power Point Tracker algorithm through a microcontrollerŠs PWM. The algorithm will allow for maximum output as well as efficiency. The STEVAL-ISV005V2 is a demonstration board specially built to test the converters, in this case, the SPV1020 interleaved DC-DC boost converter. Its usefulness will come into play when individually testing the converter before connecting it to the rest of the subsystem.

2.2.4 Battery System

To determine the battery needs of the car, the team first looked at the motor specifications and chose battery options from these specifications. The motor is rated at 48V so the initial thought process was to obtain batteries that could supply 48V. Further research and discussions led to the discovery that the motor is capable to operate at 24V and is proven to be more efficient at a lower voltage. The trade off to a lower voltage level is a loss in acceleration abilities however, since the race is about efficiency and not speed this is not an issue. Mechanical calculations determined that the batteries would need a capacity of 6.71 Ah for the race. Taking into account a general rule that batteries should not be drained past 80% capacity lead the team the decision of using a 20Ah battery pack.

2.2.5 Motor/Motor Controller

The motor selected for the Solar Car this year is not based on speed and acceleration but efficiency. Due to the limits of the voltage on the system set out by the SEMA, the normally used Nu-Gen 96V motor and controller will not be used. The nominal voltage limitation is 48V, therefore a 48V, 800W rated motor was selected. This motor is a in-wheel hub motor from Kelly Controls, and a motor controller with regenerative braking capabilities will be used.

2.3 Subsystem Requirements

2.3.1 Chassis

The chassis will be a monocoque structure. It will be made of aluminum honey-comb panels. Aluminum honey comb was chosen because of its very high strength to weight ratio as well with its modulus of elasticity. A decision matrix was done to weigh the benefit to cost of using this material, see Table 2.1. It receives these qualities through having a strong honeycomb shape in the direction of force as seen in Figure 3.4. Because of its geometry it has a limitation of being flat sheets. This causes a limitation on the structure of the chassis. Therefore the new design is made of mostly shapes cut out of sheets as seen in Figures 3.1, 3.2, 3.3. The connections between the sheets are done with carbon fiber to increase the smoothness of the overall structure. The smoothness is needed to create a more aerodynamic body.

Table 2.1: Decision Matrix for Chassis Material

Scale: 1-5	Price	Weight	Performance	Looks	Total
Aluminum - Carbon Fiber (CF)	3	2	4	4	3.1
Honeycomb CF Monocoque	3	4	4	4	3.6
Wood/Plastic	5	3	2	3	3.55
Weighting	0.4	0.25	0.25	0.1	

The body will also need to have necessary attachment points for all the necessary components, the mechanical components can be seen in Figure 2.1. The rest of the electronic components will have bulkheads separating them from the driver. These will be made of carbon fiber to reduce weight. The body will also have to have a hatch that has easy access to all of the electronics.

The chassis was also made to the specifications found in Figure 3.2. These were done to fit the driver and components comfortably but still be as compact as possible. Having it as small as possible will reduce drag on both rolling resistance and wind resistance to further efficiency.

COMSOL will be used to make sure the chassis will be able to withstand the forces of the components. The file will be imported and the internal stresses will be minimized through the changing of geometry's to make sure the chassis will not have a catastrophic failure.

2.3.2 Suspension

A decision matrix was made for the suspension to decide what type of suspension the solar car should have, see Table 2.2. This decision matrix was formulated on the aspects of weight, price, size performance and complexity. The performance was actually considered low in this case because it will be driven on a smooth race track. The main consideration was the weight which was given a high weighting to its value. In the end rigid turned out winning in the decision matrix because of its light weight and low price. We will investigate if a mild small suspension can easily be implemented in case we do want to drive this car on the streets.

Table 2.2: Decision Matrix for Suspension

Scale: 1-10	Price	Performance	Complexity	Weight	Size	Total
Coil Over	5	8	4	2	3	4.05
Rigid	9	1	8	8	9	7.4
Carbon Fiber	3	7	5	9	8	6.6
Weighting	0.25	0.15	0.1	0.3	0.2	

The rigid suspension has been found on most SEMA battery division cars. This is because it is light weight and it is a competition of efficiency. The suspension will be made as light and small as possible. It will be made of aluminum and carbon fiber to reduce weight. This will be stress tested with ComSol before manufacturing to make sure it is still strong enough to support the weight of the vehicle. An example of a rigid suspension can be seen in Figure 3.5

2.3.3 Steering

A decision matrix was made to decide on the steering that should be used, see Table 2.3. Three types of steering were considered including differential, front wheel steered, and rear wheel steered. The decision matrix came out with front wheeled steering being the winner because of the performance, complexity, and weight aspects. The steering will also have to meet the SEMA regulation of 6m turning radius. The Ackermann steering formula will be used to find the appropriate max steering angle needed.

Table 2.3: Decision Matrix for Steering

Scale: 1-10	Price	Performance	Complexity	Weight	Size	Total
Differential	6	8	3	5	9	5.95
Front	7	6	7	7	5	6.55
Rear	5	4	6	8	7	5.9
Weighting	0.2	0.25	0.2	0.25	0.1	

The steering mechanism will be a lightweight aluminum tie rod steering. The front wheels will pivot from a connecting rod around a rigid hold point, see Figure 3.7. The connecting rod will be pulled in and out by the twisting of the steering column. The use for lightweight materials such as Carbon Fiber will be looked into more for the making of the shafts.

2.3.4 Braking

There will be two independently activated braking systems: one for the front wheels and one for the rear wheel. Both the front and rear braking will be done using pneumatic braking. However, the rear braking will be similar to a parking brake and will stay clamped once pressed. Only until a second press is made will it release its grip. Both of the braking systems will be pressed using foot pedals as seen in 2.1.

The brakes will be made of aluminum to reduce weight and will be disk caliper brakes. Because of the low weight of our overall system bicycle brake calipers are most cost efficient, as seen in Figure 3.6. These are low weight which is beneficial to our car.

2.3.5 Roll Bar

The roll bar design that we will be implementing in our design is basically a simple metal or carbon fiber hoop positioned behind the driver, and possibly an additional smaller hoop in front of the steering wheel. Both hoops will have supporting arms Figure 3.8 and be bolted to the inside bottom of the vehicle chassis. This roll bar must extend in width beyond the driver's shoulders and 5 cm around the driver's helmet when he is seated in the normal driving position with the safety belts fastened Figure 3.9. Dimensions of the driver's shoulder width and seated height (with helmet on) will be collected and implemented in the roll bar's design before construction. This roll bar will be designed to withstand a minimum static load of 700 N (approx. 70 kg) applied in any direction without deforming. Materials will be purchased based on the final design and manufacturing of the roll bar will be carried out by a skilled machinist. Before being constructed, the roll bar will be stress tested in a program such as Creo to ensure that it can at least handle 700N of stress in any direction without deformation, the requirement set forth by the Shell Eco Marathon. It will also be tested after its completion to withstand a weight of approximately 158 lbs (approx. 700N) in any direction without deformation. If the roll cage ends up being comprised of carbon fiber, layers can be added to the bar by the team if necessary. The material that we will be using is not definite, although chromoly steel (steel alloyed with chromium and molybdenum) is the most likely candidate, having an excellent strength-to-weight ratio, simple to machine, not overly-expensive, and being considerably stronger and harder than standard 1020 steel. In the case that the bar is constructed out of carbon fiber, thin aluminum tubing would be coated in epoxy resin and incased several layers of carbon fiber. Below is the decision matrix used to arrive at our conclusion.

Table 2.4: Decision Matrix for Roll Bar Material

Scale: 1-10	Weight	Machinability	Cost	Safety	Total
Aluminum	8	7	8	3	5.9
Chromoly Steel	6	9	7	8	7.3
Carbon Fiber	10	3	6	6	6.9
Titanium	8	2	2	9	6.6
Weighting	0.3	0.1	0.2	0.4	

2.3.6 Hatch

The hatch for the vehicle cockpit will be of a bubble shape and constructed of a special light-weight, impact-resistant, see-through plastic-like material. A material had to be chosen that will not create dangerous plastic shards (if impacted) that could potentially injure the driver, per Shell standards. There are two main hatch designs we are considering at this time: one in which the bubble is firmly mounted to the car as part of the chassis and the driver must get out by opening the car chassis as a whole Figure 3.10, and one in which the bubble can be opened directly via hinges and seals down onto the car surface via a rubber seal formed around the plastic edges Figure 3.11. A decision has yet to be reached as to which design will be implemented.

If the bubble is part of the chassis, then no rubber seal or hinges will be necessary, and the driver will be well insulated and water-tight. However, this will require that electronic locks are employed so that the driver can get out of the car, and the design of the car must be so that the driver can lift the top of the car chassis unassisted without too much trouble to escape the car within 10 seconds in the case of an emergency, per Shell standards. If the bubble is not part of the vehicle chassis, it will be connected to the car cockpit via hinges so that it can open outward easily to the front or back of the cockpit (pending final hinge placement). A latching device that can be opened from both the inside and outside of the vehicle will be installed to keep the bubble securely closed on the vehicle top. It is also feasible to use an electronic lock for this application as well. Button-activated electronic locks are ideal for our design due to their cost-effectiveness and the fact that they allow both the team outside the car and the driver inside the cockpit to lock and unlock the hatch immediately, which is imperative for unassisted driver evacuations and conversely team extraction of driver. Despite which design is selected, it will be ensured that the total weight of the bubble presents no issue for the driver when it comes to escaping the car unassisted, and the hinges will have removable pins so that car chassis top or the bubble hatch can be removed in their entirety Figure 3.12.

The solar car operator must have access to a direct arc of visibility ahead and to 90° on each side of the longitudinal axis of the vehicle at all times, so it is essential that the material selected for the bubble have optimal clarity. Once the bubble is mounted on the vehicle, this required line-of-sight will be tested by placing cinder blocks on the ground (standing on end) 180° around the front of the car at a 4 meter radius (one every 30°). The driver will sit strapped into in the vehicle with the hatch closed and, only moving his head, will confirm that he can see all seven blocks without difficulty, thus satisfying a 180° range of vision thru the cockpit. Side mirrors will be installed on each side of the cockpit to assist with posterior view. Once the car construction is nearing its completion, with suspension and wheels installed, and the driver cockpit nearly completed (with a minimum of the driver's seat, safety belt, and cockpit bubble completed) the team will measure the success of solar car emergency evacuations, one where the driver must escape himself in 10 second or less, and the other in which the team must extract the driver in an equally timely fashion.

With respect to the material that the cockpit bubble will be constructed of, there were two primary choices: acrylic or polycarbonate. Acrylics are employed in things such as the barriers at a hockey rink that protect the crowd from stray high-velocity pucks or overly-rambunctious players. Polycarbonates are implemented in even more heavy duty cases, such as bullet-proof riot shields. Both are very light-weight materials. The decision matrix used to make our choice is displayed below.

Table 2.5: Decision Matrix for Hatch Material

Scale: 1-10	Impact Resistance	Machinability	Cost	Clarity	Total
Lexan Plycarbonate	10	9	5	9	8.55
Acrylic(Plexiglas)	5	5	9	10	7.65
Weighting	0.35	0.1	0.2	0.35	

As can be seen here, Lexan polycarbonate was our champion. The type of Lexan we are thinking of using is Lexan 9030, which is the standard sheet grade. Lexan 9030 combines high impact and temperature resistance with optical clarity and can be utilized for secondary glazing behind existing glazing for economical protection against breakage. It can be sawed, drilled, and bent easily without the risk of cracking and breakage and meets the highest impact performance required by the European Norm prEN356 for security glazing. A steel ball of 4.11 kg with a diameter of 100 mm is freely dropped from different heights onto the glazing specimen and must impact the specimen 3 times. Lexan 9030 reached the highest standard required by the test at a thickness of 5 mm and above Figure 3.13.

Table 2.6: Classification table for the resistance of security glazing products according to European Norm prEN356

Category of Resistance	Drop Height (mm)	Total Number of Strikes	Code designation for category of resistance	Impact energy per stroke
P1A	1500	3 in a Triangle	EN 356 P1A	62 J
P2A	3000	3 in a Triangle	EN 356 P2A	123 J
P3A	6000	3 in a Triangle	EN 356 P3A	247 J
P4A	9000	3 in a Triangle	EN 356 P4A	370 J
P5A	9000	3x3 in a Triangle	EN 356 P5A	370 J

Lexan 9030 is also suitable to vacuum forming, making it ideal to form our bubble hatch to exact parameters. It allows deep draw ratios, equal wall thickness distribution and it can be formed into complex shapes using standard thermoforming equipment which is equipped with its own sandwich type of heating devices. The process can be seen in Figure 3.14.

2.3.7 Solar Array

The solar car will use the 125X125mm mono-crystalline solar cells with a voltage rating of 0.6V and 6A rated current the solar cells and the cell setup can be seen in Figure 3.16 and Figure 3.17. The mono-crystalline cells chosen provide IV characteristics shown in Figure 3.15. The solar panel's electrical performance is shown in Table 2.7. Since solar panels are affected by solar irradiation values in W/m^2, a irradiation profile is given in Table 2.8, and just for completeness a table giving temperature coefficients specific to the mono-crystalline cells is given in Table 2.9.

Table 2.7: Solar Cell Electrical Performance

Efficiency Cell (%)	Power (W)	Max Current (A)	Min Current (A)	Short Circuit Current (A)	Max Voltage (V)	Open Circuit (V)
18-18.19%	2.67-2.7	5.07	4.19	5.42	0.53	0.628
17.8-17.00%	2.64-2.67	5.02	4.87	5.4	0.528	0.628
17.6-17.79%	2.61-2.63	5.02	4.86	5.37	0.524	0.625
17.4-17.59%	2.59-2.61	4.98	4.83	5.34	0.522	0.624
17.2-17.39%	2.56-2.59	4.93	4.79	5.3	0.522	0.623
17-17.19%	2.53-3.56	4.91	4.77	5.29	0.518	0.621
16.8-16.99%	2.5-2.53	4.88	4.73	5.26	0.516	0.620
16.6-16.79%	2.47-2.5	4.85	4.7	5.23	0.513	0.619
16.4-16.59%	2.44-2.47	4.82	4.67	5.21	0.511	0.618
16.2-16.39%	2.41-2.44	4.79	4.64	5.18	0.509	0.616
16-16.19%	2.38-2.41	4.76	4.61	5.15	0.506	0.615

Table 2.8: Solar Cell Irradiation Profile

Irradiance (W/m^2)	V_pm	I_pm
1000	1.000	1.000
800	0.992	0.799
600	0.979	0.598
200	0.922	0.193

Table 2.9: Solar Cell Temperature Coefficients

Current Temp Coefficients	$\alpha(I_sc)$	0.03%/°C
Voltage Temp Coefficients	$\beta(V_oc)$	-0.32%/°C
Power Temp Coefficients	$\gamma(P_max)$	-0.42%/°C

Each one of the 125X125mm mono-crystalline solar cells will be cut into three pieces using a high beam laser. This step will double the voltage of the solar cell by three; however this process will reduce the current by factor of three; the three cell module can be seen in Figure 3.17. After this process the solar car team will end up with a voltage rating of 1.8V and 1.7A rated current. Testing of every single module will take place after procuring the solar cells. The available space, a total surface area of 0.17 square meters set out by the SEMA rules, on the solar car only allows ten modules to be mounted to the body of the car, Figure 3.18.

The modules will be connected in one of the following ways either ten series modules in the array string, supplying 18V rated at 1.7A rated, or two parallel five series modules in the array string, supplying 9V rated at 3.4A rated. Both circuit configuration can be seen in Figure 3.19. No matter which way the solar modules will be connected they deliver 25W of rated power.

Each of the solar modules will have a ”Solar Junction Box” consisting of one diode. This diode will be used to solve partial shading and loss of delivered power. At the terminating end of the solar array will be another junction box with one diode to serve as a protection diode for the unwanted flow of back current into the modules. The solar junction box and the circuit with the diodes can be seen in Figure 3.19 and Figure 3.20. The specifications for the solar junction box are shown in Figure 3.21.

The team will mount the modules on the front end of the car. The array mounting will be accomplished by rivet gun and punch of rivets. Four rivets will be used to mount the solar modules one at each corner of the modules, underneath each of the modules the team will drill a circular hole to allow the wires to get throw the body easily. Two color coded wires will be connected to the cells to show the positive and negative sides of each module. There will be no need for a final protective layer over the car because of the EVA encapsulation.

The diodes used will be Schottky barrier rectifiers that can handle a maximum of 1000V and 7A. The diodes will have a built in carrier inside the box. The box will have positive and negative side where the modules will be connected to the diode. By the end of next semester each solar module will be connected to its own diode box.

The team is currently working on the solar array portion of simulation using Matlab, Simulink and Plecs softwares. Full testing of the simulation has not been completed yet because all components of the system have not being fully amalgamated into the simulation. The simulation allows for testing different irradiation levels and the possibility of shading can be modeled with by-pass diodes.

2.3.8 Energy Conversion

2.3.8.1 Boost Converter Topology A DC-DC boost converter is used to bring the voltage of the solar array 12V maximum to the voltage of the batteries 24V in order to act as a dual source during operation of the solar vehicle, and to charge the batteries when the vehicle is not in use. Figure 3.22 illustrates a typical boost converter circuit topology, including a DC input, an inductor, a switch, a diode, a capacitor, and a load.

The Boost converter is realized using a power MOSFET and is controlled by the PWM from the microcontroller. The duty cycle of the PWM can be changed to allow variations of the output voltage given a particular input voltage, or in this case, to maintain an output voltage given fluctuations in input voltage. This mechanism will be utilized to hold the output voltage of the MPPT to as near the battery voltage as possible.

2.3.8.2 Choice of MPPT algorithm There are two common algorithms for maximum power tracking. The Perturb and Observe method involves periodically perturbing and comparing the terminal voltage to its previous value. If the power of the previous data point is not equal to that of the current data point, the voltage is compared to its previous value and an adjustment in duty cycle is made accordingly. Figure 3.23 below illustrates the perturb and observe flow chart algorithm.

A second method for tracking the maximum power point is the Incremental Conductance method. This method involves comparing the derivative of the power curve with respect to voltage to zero. If the derivative is positive then the current point is on the left of the max power point on the V-P curve and the duty cycle is adjusted up. If the derivative is negative then the current point is on the right of the max power point on the V-P curve and the duty cycle is adjusted down. The flowchart for this algorithm is shown below in Figure 3.24.

2.3.8.3 Implementation Choices Due to not only simplicity but efficiency as well, the team found it more beneficially to purchase a boost converter. Consequently the choices of the boost converter will affect the choice of the MPPT implementations. The choices are presented in the following sections and a comparison matrix is shown.

2.3.8.3.1 SPV1020 The monolithic 4-phase interleaved DC-DC boost converter from ST Microelectronics is designed to maximize the power generated by photovoltaic panels independent of temperature and amount of solar radiation. Optimization of the power conversion is obtained with embedded logic which performs the MPPT (max. power point tracking) algorithm on the PV cells connected to the converter. The built-in MPPT algorithm used is Perturb and Observe.

2.3.8.3.2 2M72442 A Programmable Maximum Power Point Tracker Controller from Texas Instruments, this chip is capable of controlling up to four PWM channels for basic converter and creates a solution for an MPPT configured DC-DC converter with efficiencies up to 99.5%. This controller is also specially made for PV cells and was deemed necessary considering the boost converters are also manufactured by Texas Instruments.

2.3.8.3.3 TPS55340, TPS61170, LMR64010, LMR62014 Among the best presented by Texas instruments, these boost converter/step up regulators are good for the designs and only differ and output voltage capabilities. They all offer very high efficiency at relatively higher current. All converters offer overcurrent protection, undervoltage lockout, thermal shutdown, and soft-start. The figures below present the efficiency to output current at various input voltage with an output voltage of 24V, desired case for the project, for the TPS61170 converter in Figure 3.27 and LMR64010 in Figure 3.28. The matrix diagram below presents the pros and cons of the converter as well as the prices from favorable distributors.

Table 2.10: Comparison Matrix for Boost Converter Options

Component	Pros	Cons	Mouser	DigiKey
SPV1020	-Built-in MPPT Algorithm -Control over input and output maximum voltage -Ideal for solar energy applications -Safe	-May not work within voltage ranges needed	\$9.85	\$15.69
TPS55340, TPS61170	-greater than 94% Efficiency	-Separate MPPT controller must be purchased (SM72442)	\$4.79	\$5.52
*LMR64010,*LMR62014	-Wide Input Voltage, Safe		\$1.35	\$1.72
SM72442			\$8.89	\$9.17

*These can be purchased with a demo board for \$20.06

2.3.9 Battery System

2.3.9.1 Battery Pack For determination of a 24V, 20Ah battery pack needed to power the car, the battery chemistry to use had to be decided. The decision matrix Table 2.11 below shows the three types of lithium batteries considered. All three of the batteries have similar performance and safety attributes so what it came down to is the size, weight, and cost. The lithium iron phosphate (LiFePO4) batteries from Electric Rider, Figure 3.29, have been chosen due to its small dimensions of 6 x 10.25 x 3.5 inches, weight of 10 lbs, and cost of under $500 including shipping.

Table 2.11: Decision Matrix: Battery Selection

Scale: 1-10	Price	Performance	Safety	Size	Weight	Total
Elite Power Solutions (LiFeMnPO4)	8	7	6	4	6	6.3
Electric Rider (LiFePO4)	7	7	7	8	8	7.5
Electric Rider (LiMnCO2)	3	9	7	8	8	6.5
Weighting	0.3	0.1	0.1	0.2	0.3	

2.3.9.2 Battery Management System - BMS It is required for all lithium batteries to have proper battery management systems to protect the risk of damaging cells and potential to catch fire. Rules from the competition require the BMS to have cell over/under voltage limits, over current limit, over temperature limit. The battery pack to be purchased from Electric Rider includes a BMS that will protect and monitor the individual cells and entire pack.

2.3.9.3 Battery Charger The battery pack from Electric Rider also includes a lithium battery charger that supplies a 4A current to recharge the batteries, as shown in Figure 3.30.

2.3.9.4 Battery Display/Monitor During car operation the team would like to be able to easily monitor the battery pack. Turnigy's 130A Watt Meter and Power Analyzer will be purchased for a visual display of the batteries health and performance levels. This device is rated for 60V, 130A, 6554W and 65Ah which are well within our battery specifications. At $30 and with its small size and weight, it is the perfect option for a visual display of the battery performance levels inside the car during operation. Figure 3.31 shows the device display and Figure 3.32 shows the connection with the batteries and motor to monitor performance.

2.3.10 Motor/Motor Controller

2.3.10.1 Motor Determining the motor specifications required the use of simple physics calculations. The equation shown below (2.1) using specifications from Table 2.12. Table 2.13 shows the mechanical power needed at the wheels, the ampere-hour rating, and watt-hour need to move the car at a constant speed of 20 mph.

$$P_d = C_r mg + mg\sin(\theta) + \frac{1}{2}\rho_a C_d A_f v^2 \tag{2.1}$$

Table 2.12: Mechanical Power Specifications for Constant Speed

Parameter	Value
Power at Wheels (P_d)	? W
Mass (m)	136.08 kg
Rolling Resistance (C_r)	0.0025
Gravity (g)	9.81 m/s^2
Road Incline (θ)	0°
Air Density (ρ_a)	1.225 kg/m^3
Drag Coefficient (C_d)	0.15
Fontal Area (A_f)	1.3 m^2
Velocity (v)	67.76 m/s

Table 2.13: Mechanical Power Calculation Table

Parameter	Value
Weight	300 lbs
Velocity	20 mph
Power (mech)	143.9702 W
Amperage	5.9988 A
Watt-hour rating	161.0405 Wh
Amp-hour rating	6.71 Ah

These values determined are the maximum values needed to keep the car moving at a constant speed. To determine the starting torque needed for the motor (2.1) is used adding a $m * \frac{dv}{dt}$. Determination of exact starting torque seems trivial, since its calculation would include minimal changes to the previous equation, yet usually the starting torque or stall torque is determined when the car is on a incline of say 20°. The solar car will never have to compensate power for such an angle, nor will it ever need to speed up or accelerate quickly to get up to speed. The team foresees the acceleration to be gradual and the torque/current ratio to increase by a maybe a factor of 10. Therefore the true calculation of starting torque will not be considered in this paper.

Since only a maximum of approximately 150W is needed to keep the car moving at a constant speed, and SHOW TORQUE NEEDED TO MOVE is required to move the car from a dead stop a motor from Kelly Controls, LLC was selected, shown in Figure 3.33. This motor is an in-wheel brushless DC motor. Figures 3.34 and 3.35 show the motor's voltage, current, power and torque characteristics under a nominal 48V system. Using the assumption that the motor will be able to run at a 24V nominal level, provided the battery system can produce a higher current, seems within reach of our goals. A schematic showing the labeled connections to the controller is shown in Figure 3.36 The motor dimensions are shown in Figure 3.37

2.3.10.2 Motor Controller

Kelly Controls, LLC produces a matching motor controller for their motors. Since we are not going to be running the motor greater that 200W at any time even through stall, the KEB48201X is going to be used to provide the three phase current and voltages to spin the motor shown in Figure 3.38. Kelly KEB48201X programmable e-bike/electric bike BLDC controller provides efficient, smooth and quite controls. Motor speed controller can work with relative small battery, but provide good acceleration and hill climbing. BLDC motor speed controller uses high power MOSFET, PWM to achieve efficiency 99%. In most cases, Powerful microprocessor brings in comprehensive and precise control to BLDC motor controllers. This programmable brushless motor controller also allows the team to set parameters, conduct tests, and obtain diagnostic information quickly and easily.

2.3.10.2.1 Main Features and Specifications

- Extended fault detection and protection. The LED flashing pattern indicates the fault sources.
- Monitoring battery voltage. It will stop driving if the battery voltage is too high and it will progressively cut back motor drive power as battery voltage drops until it cuts out altogether at the preset ”Low Battery Voltage” setting.
- Built-in current loop and over current protection.
- Configurable motor temperature protection range.
- Current cutback at low temperature and high temperature to protect battery and controller. The current begins to ramp down at 90 degree C case temperature, shutting down at 100?C.
- The controller keeps monitoring battery recharging voltage during regenerative braking, progressively cutting back current as battery voltage rises then cutting off regen altogether when voltage goes too high.
- Maximum reverse speed is configurable to half of max forward speed.
- Configurable and programmable with a host computer though RS232 or USB. Provide free GUI which can run on Windows XP/2000, Windows 7 and Vista(recommend using Kelly standard USB to RS232 Converter).
- Provision of a +5 volt output to supply various kinds of sensors, including Hall effect type.
- 3 switch inputs which are activated by connection to Ground. Default to throttle switch, brake switch and reversing switch.
- 3 analog inputs 0-5V inputs that default to throttle input, brake input and motor temperature input.
- Configurable boost switch. Enables the maximum output power achievable if the switch is turned on.
- Configurable economy switch. Limits the maximum current to half if the switch is turned on.
- Maximum reverse power is configurable to half power.
- Enhanced regen brake function. A novel ABS technique provides powerful and smooth regen.
- Configurable 12V brake signal input, instead of motor temperature sensor.
- Optional joystick throttle. A bi-symmetrical 0-5V signal for both forwarding and reversing.

- Configurable motor over-temperature detection and protection with the recommended thermistor KTY83-122.
- 3 hall position sensor inputs. Open collector, pull up provided.
- Optional supply voltage 8V-30V.
- Frequency of Operation: 16.6kHz.
- Standby Battery Current: < 0.5mA.
- 5V Sensor Supply Current: 40mA.
- Controller supply voltage range, PWR, 18V to 90V.
- Supply Current, PWR, 150mA.
- Configurable battery voltage range, B+. Max operating range: 18V to 60V.
- Analog Brake and Throttle Input: 0-5 Volts. Producing 0-5V signal with 3-wire pot.
- Full Power Operating Temperature Range: 0? to 50? (controller case temperature).
- Operating Temperature Range: -30? to 90?, 100? shutdown (controller case temperature).
- Peak Phase Current, 10 seconds: 150A.
- Continuous Phase Current Limit: 60A.
- Maximum Battery Current: Configurable

2.3.10.2.2 Connections to the motor controller are shown in Figure 3.39 and descriptions are in Table 2.14. Along with five metal bars there is a 14 pin rugged connector label J2, Table 2.15 and Figure 3.40 show their specs.

Table 2.14: Front Panel Connections Description

B+	Battery Positive
B-	Battery Negative
A	Output U/1/A Phase
B	Output V/2/B Phase
C	Output W/3/C Phase
J2	Motor Control Connection

Table 2.15: J2 Pin Definition

1	PWR: Controller Power Supply
2	RTN: Signal return, or power supply ground
3	RTN: Signal return
4	12 V high0level brake and motor temperature input
5	Throttle analog input, 0-5V
6	Brake analog input, 0-5V
7	5V supply output, 40mA
8	Microv SW: Throttle switch input
9	Reversing switch input
10	Brake switch input
11	Hall phase C
12	Hall phase B
13	Hall phase A
14	RTN: Signal return

2.3.10.2.3 Standard Wiring to the KEB controller is shown in Figure 3.41. Note: the battery voltage can be used for controller supply.

2.3.10.3 Motor Accesories

2.3.10.3.1 Controller Heatsink As necessary component to keep the controller cooled during operation is a heatsink, which will be attached to the bottom of the device. Figure 3.42 shows a picture of the heatsink.

2.3.10.3.2 KEB Assembly Kit Figure 3.43 provides a simple and easy way to connect the KEB motor controller to the rest of the system, including input to regenerative braking, throttle pedals, and motor.

2.3.10.3.3 Throttle/Brake Pedal Kelly Controls, LLC also provides a series throttle pedal, 0-5V. This pedal is a hall sensor pedal which can control both braking and acceleration, shown in Figure 3.45. Two pedals will be installed into the car. One for acceleration, and one for braking. Kelly will provide the cable for regenerative braking, which there website does not show.

2.3.10.3.4 Motor Control Box Figure 3.44 shows the control box for startup, direction and braking commands. This box will simply control how the KEB motor controller will act and how to function. Connection specifications have not be provided by the vendor, yet the Assembly Kit has a connection for this device.

2.3.10.3.5 J2 Connector The J2 connector is simply to connection from the motor to the controller. Shown in Figure 3.46, this connectors specs are also shown in Figure 3.36.

3 Design of Major Components

3.1 Block Diagrams of Components and subsystems

3.1.1 Chassis

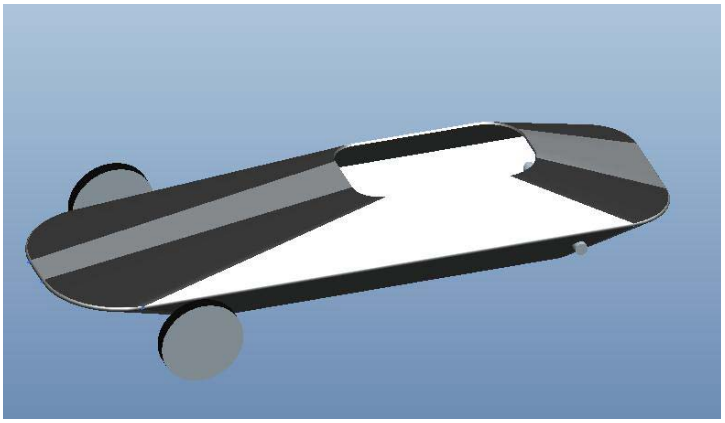


Figure 3.1: ProE Chassis Design Side

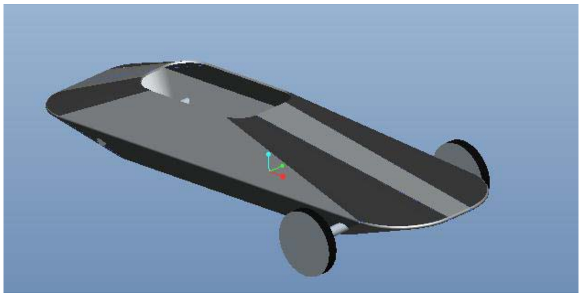


Figure 3.2: ProE Chassis Design Front

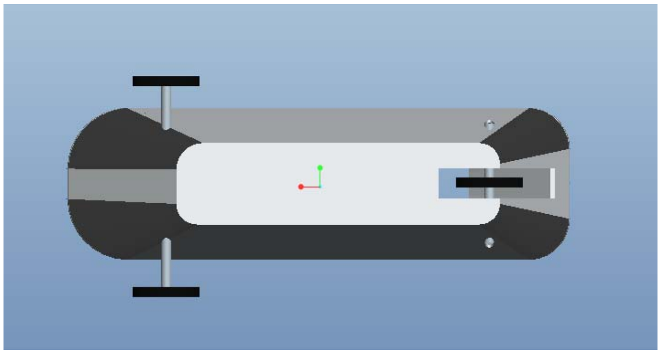


Figure 3.3: ProE Chassis Design Bottom

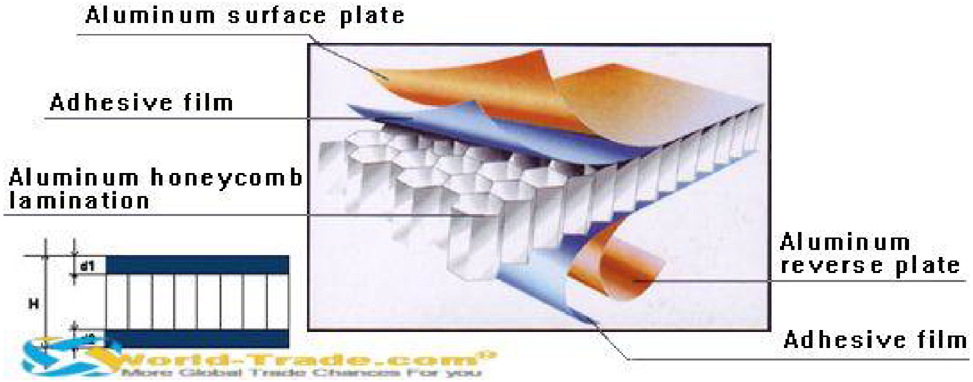


Figure 3.4: Aluminum HoneyComb Carbon Fiber

3.1.2 Suspension

Figure 3.5: Rigid Suspension Example

3.1.3 Braking

Figure 3.6: Brake Calipers

3.1.4 Steering

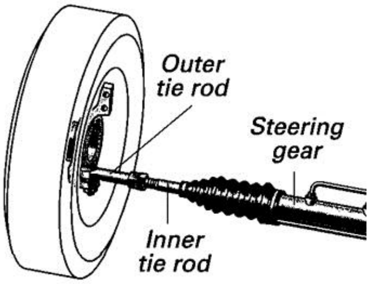


Figure 3.7: Steering at the Wheel

3.1.5 Roll Bar

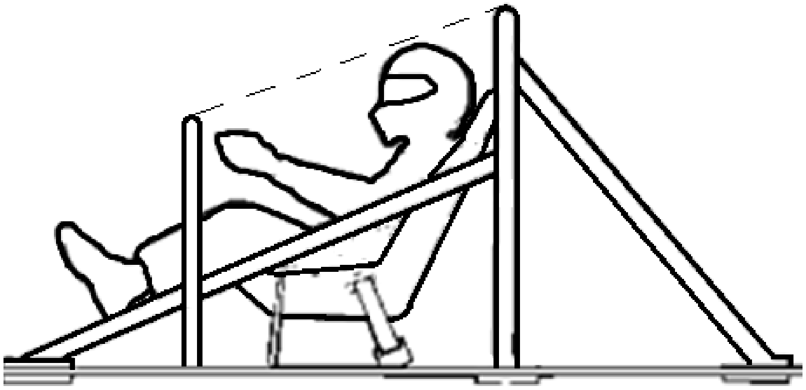


Figure 3.8: Roll Bar Example

Figure 3.9: Roll Bar Example - Showing dimension and distances

3.1.6 Hatch

Figure 3.10: Previous Year's Car from SEMA - Hatch Example 1

Figure 3.11: Previous Year's Car from SEMA - Hatch Example 2

Figure 3.12: Removable Pin Hinge

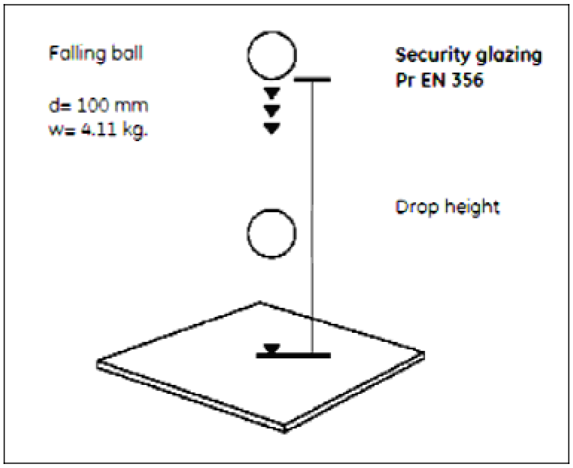


Figure 3.13: Security Glazing Test

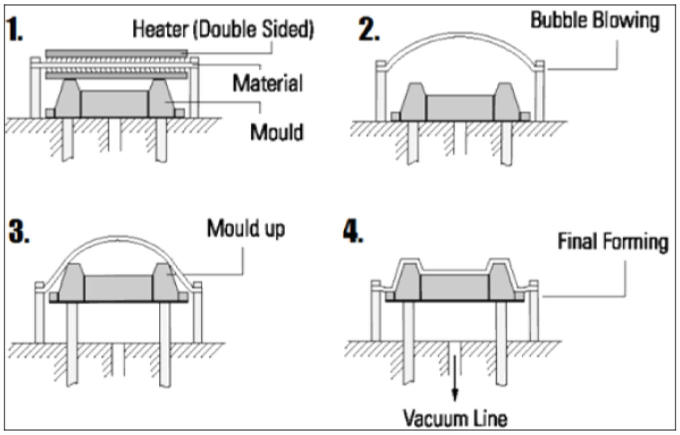


Figure 3.14: Vacuum Forming Process Options

3.1.7 Solar Array System

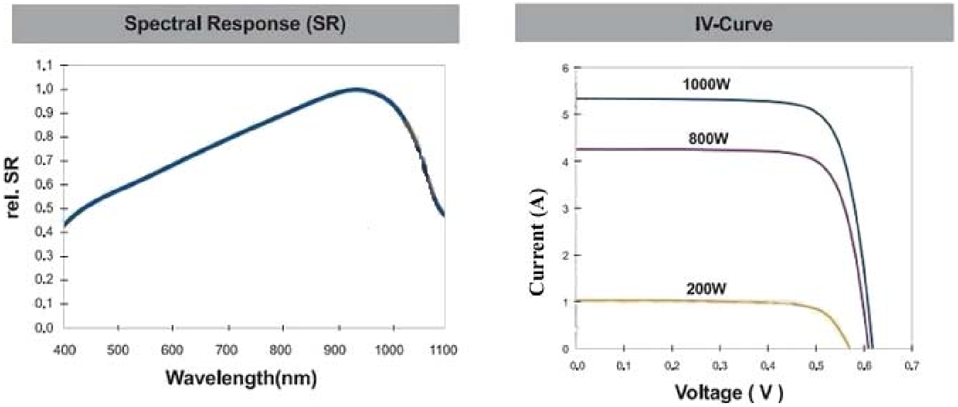


Figure 3.15: 125x125mm Mono-Crystalline IV Profile

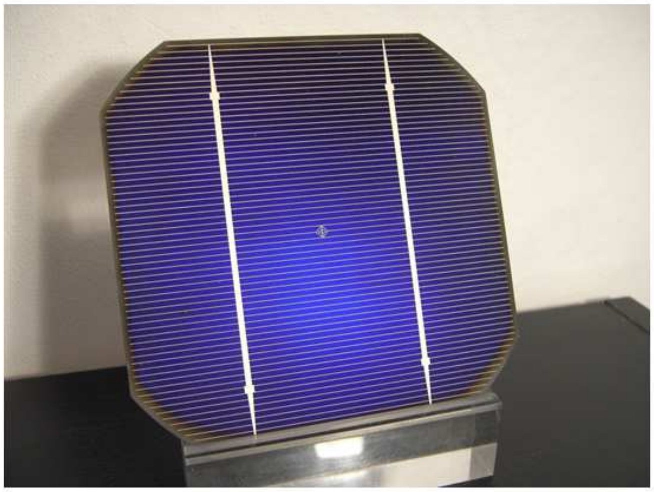


Figure 3.16: 125x125mm Mono-Crystalline Solar Cell

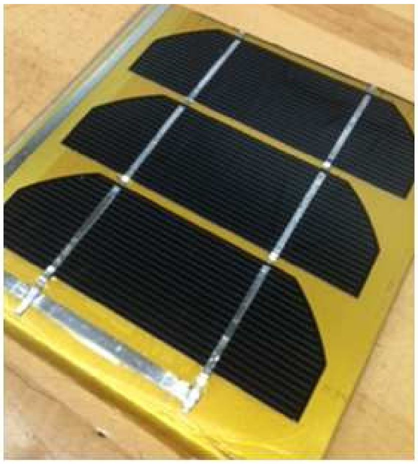
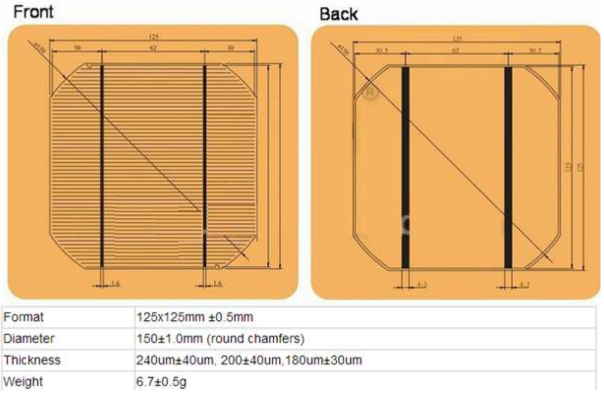


Figure 3.17: Three Mono-Crystalline Solar Module provided by SunnyLand Solar



Format	125x125mm ±0.5mm
Diameter	150±1.0mm (round chamfers)
Thickness	240um±40um, 200±40um,180um±30um
Weight	6.7±0.5g

Figure 3.18: Mono-Cystalline Dimensions

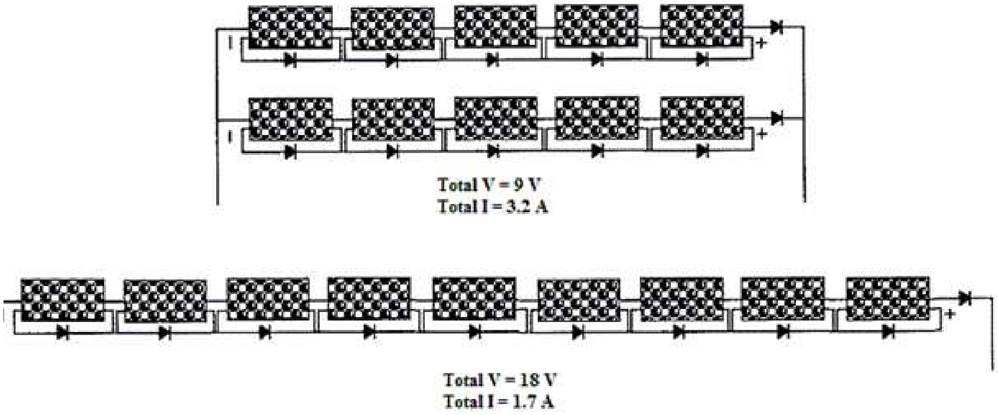
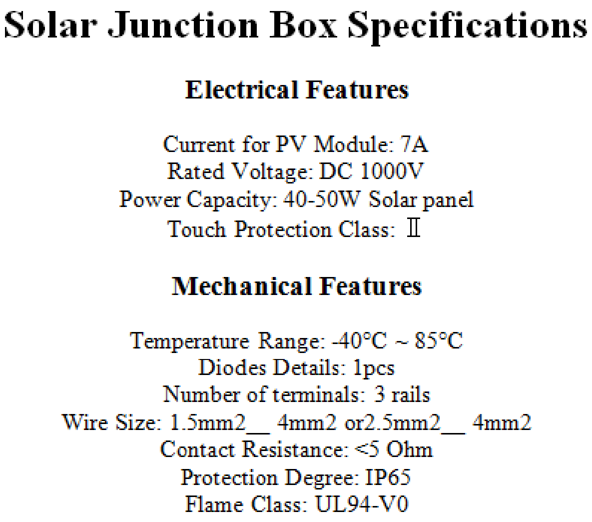


Figure 3.19: Solar Array Configuration Options

Figure 3.20: Solar Junction Box



Solar Junction Box Specifications

Electrical Features

Current for PV Module: 7A
Rated Voltage: DC 1000V
Power Capacity: 40-50W Solar panel
Touch Protection Class: Ⅱ

Mechanical Features

Temperature Range: -40°C ~ 85°C
Diodes Details: 1pcs
Number of terminals: 3 rails
Wire Size: 1.5mm2__ 4mm2 or2.5mm2__ 4mm2
Contact Resistance: <5 Ohm
Protection Degree: IP65
Flame Class: UL94-V0

Figure 3.21: Solar Junction Box Specifications

3.1.8 Energy Conversion System

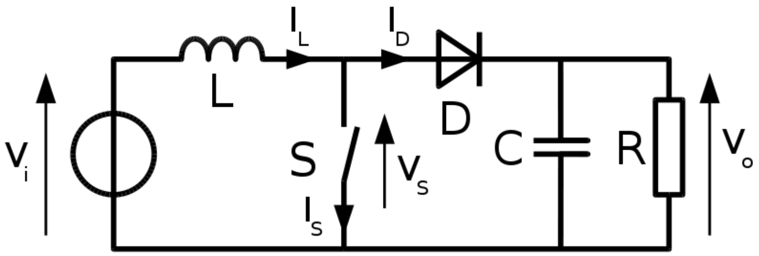


Figure 3.22: Boost Converter Topology

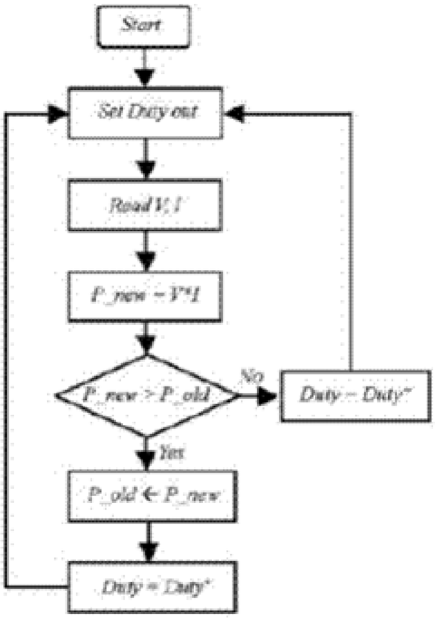


Figure 3.23: Perturb and Observe Algorithm Flowchart

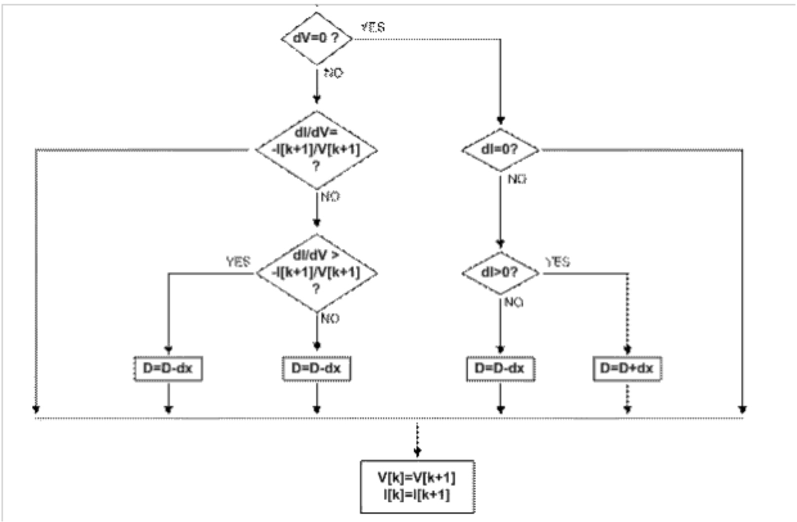


Figure 3.24: Incremental Conductance Algorithm Flowchart

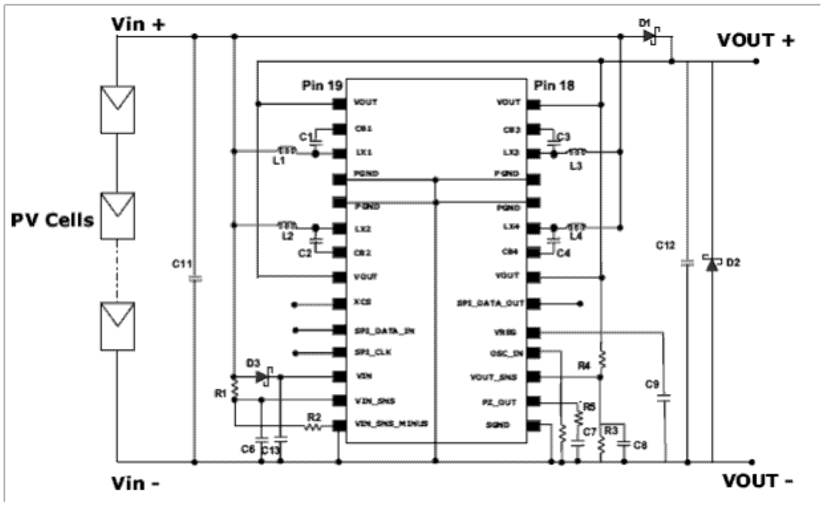


Figure 3.25: Application Circuit of SPV1020

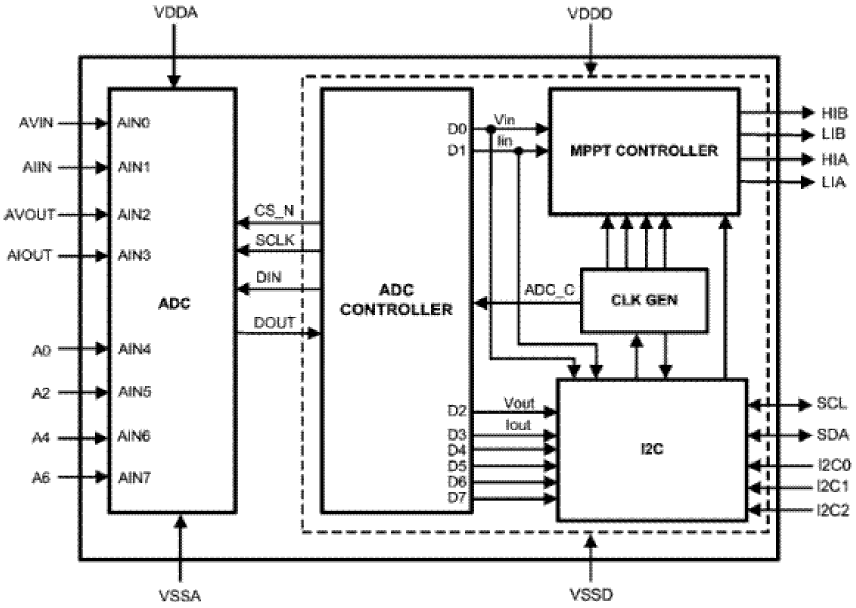


Figure 3.26: SM72442 - MPPT Controller Block Diagram

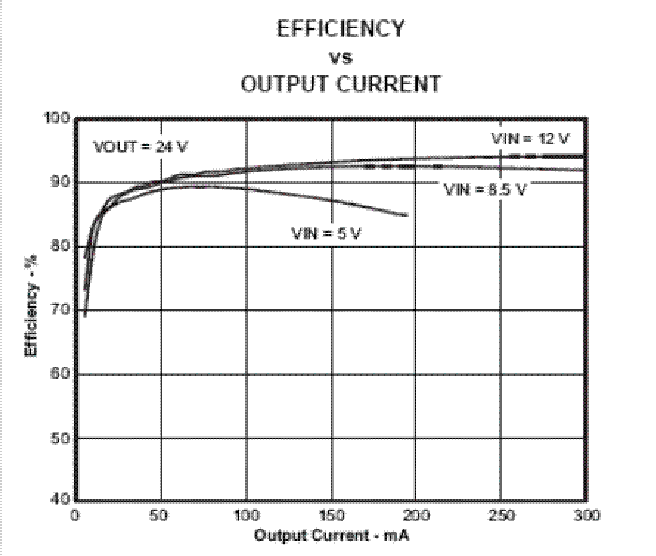


Figure 3.27: TPS61170 - Efficiency Curve

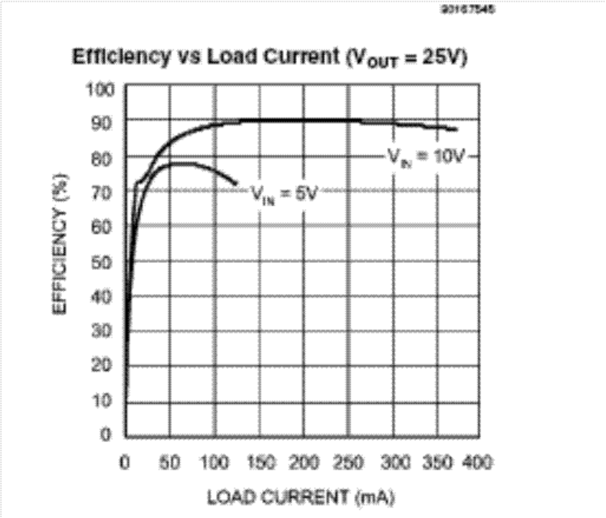


Figure 3.28: LMR64010 - Efficiency Curve

3.1.9 Battery System

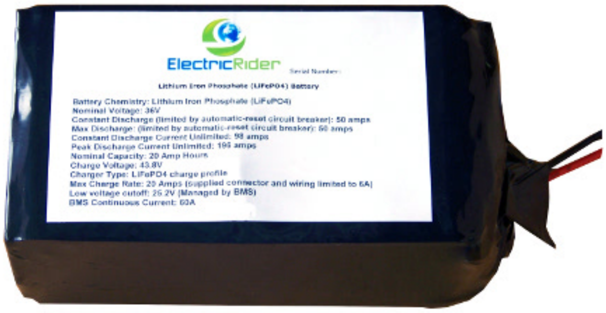


Figure 3.29: Electric Rider LiFePO4 Battery Pack

Figure 3.30: Lithium Battery Charger

Figure 3.31: Turnigy Watt Meter and Power Analyzer

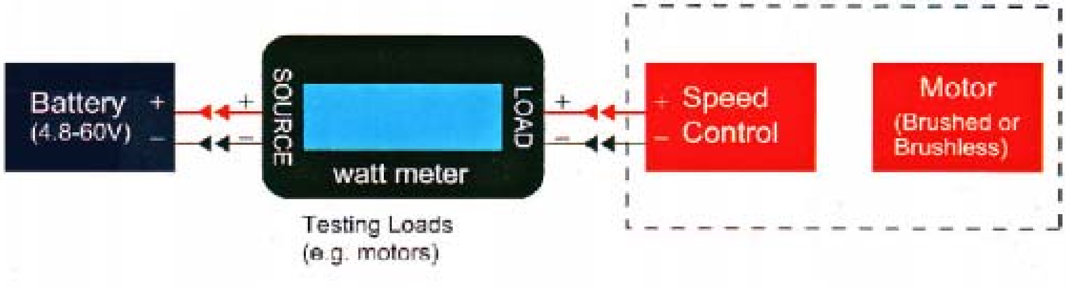


Figure 3.32: Turnigy Monitor Connections

3.1.10 Motor

Figure 3.33: 48V, 800W BLDC Motor with Regen

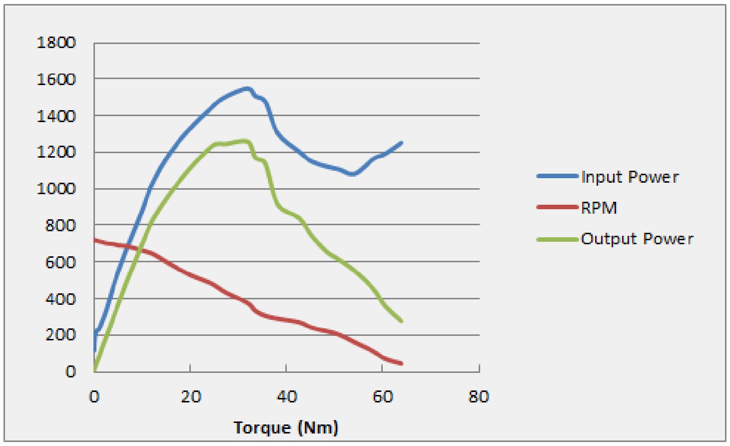


Figure 3.34: Motor Torque vs Power Curve

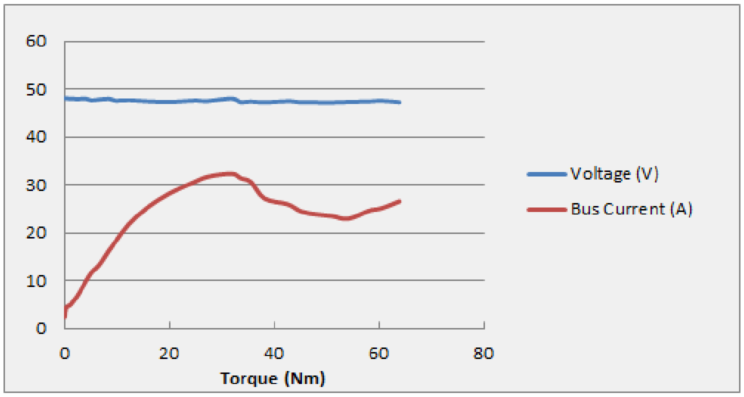


Figure 3.35: Motor Torque vs Voltage/Current Curve

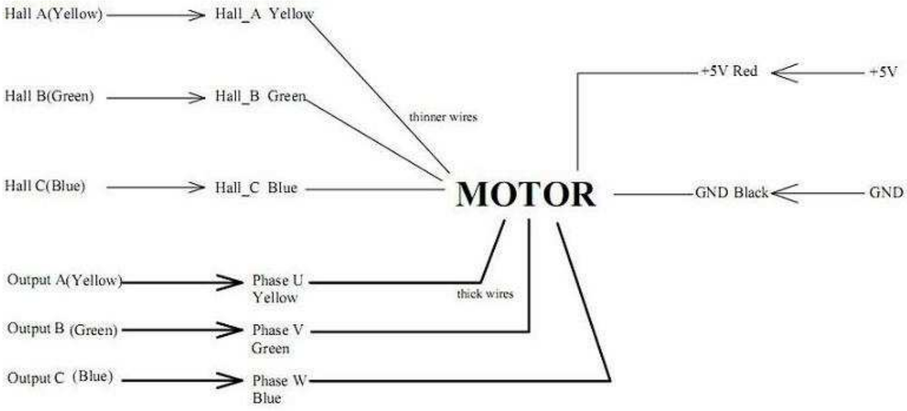


Figure 3.36: Motor Wiring Connections

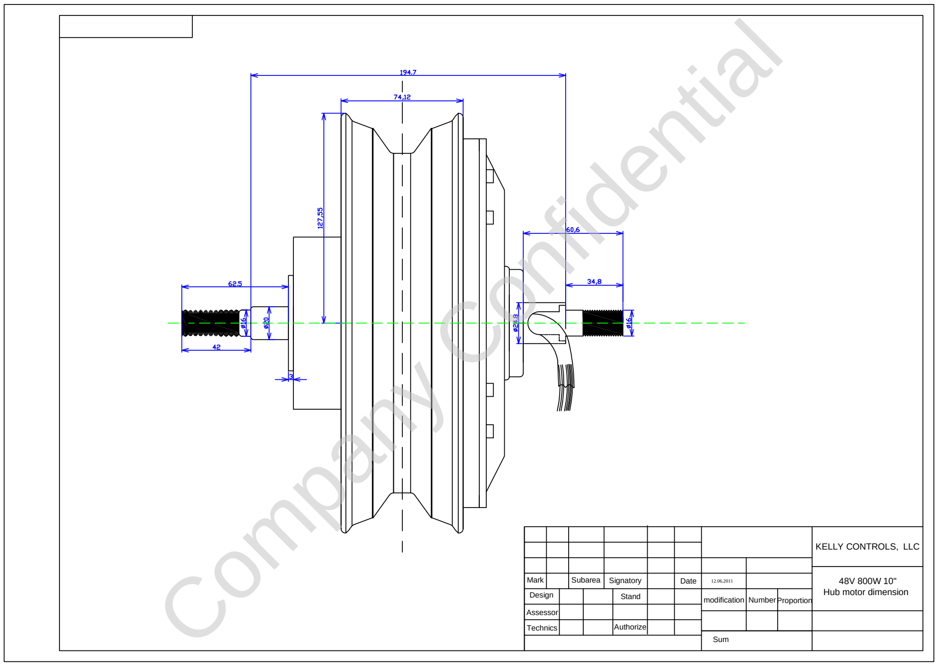


Figure 3.37: Motor Physical Dimensions

Figure 3.38: KEB48201X Motor Controller

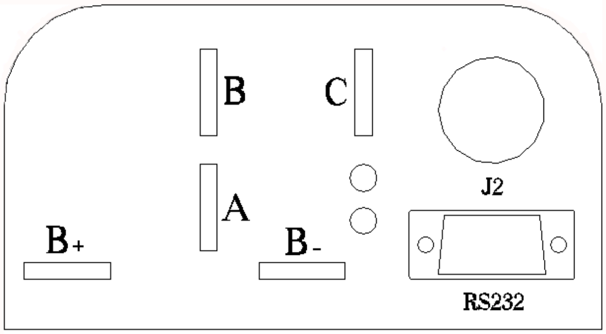


Figure 3.39: Front Panel of KEB Motor Controller

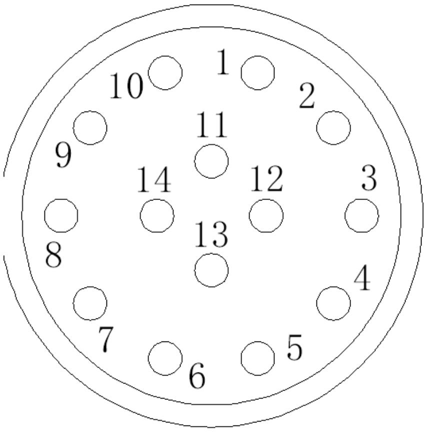
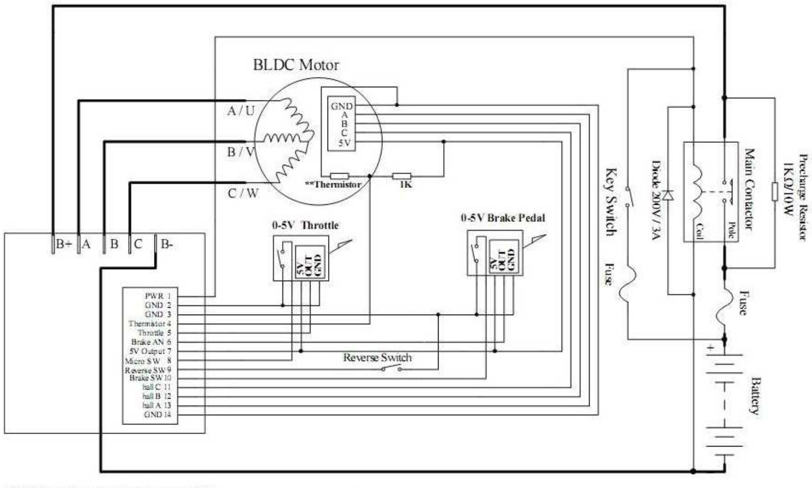


Figure 3.40: J2 connector of KEB



NOTE: Potentialmeter can be used to output 0-5V.

Figure 3.41: KEB Motor Controller Standard Wiring

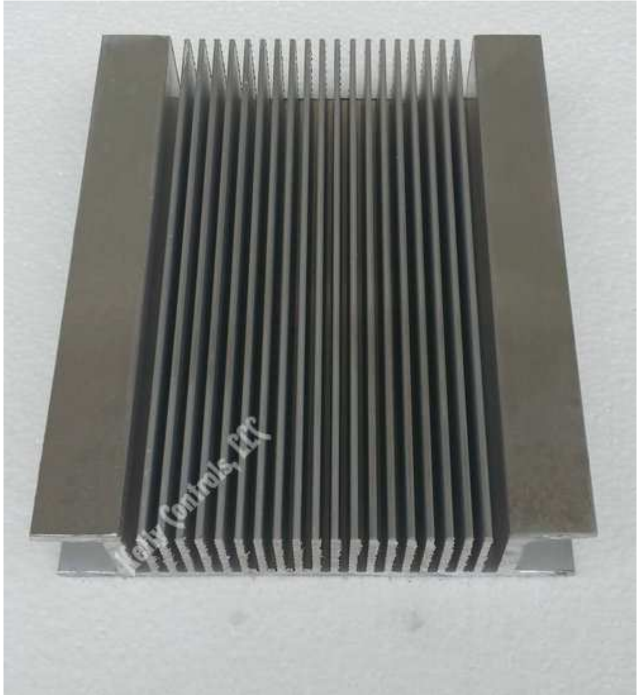


Figure 3.42: KEB Controller Heat Sink

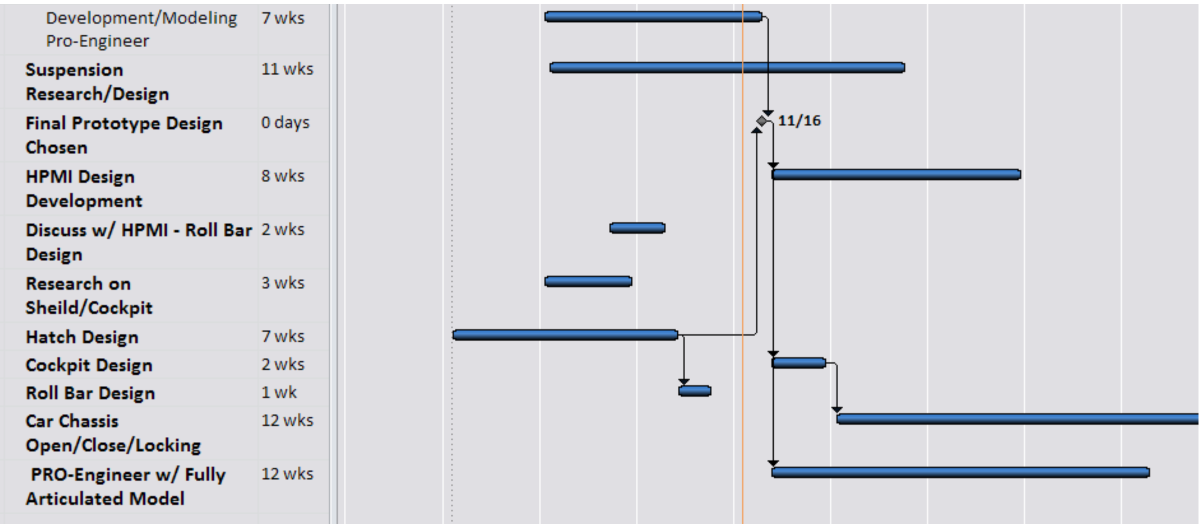
Figure 3.43: KEB Assembly Kit

Figure 3.44: Motor Control Box

Figure 3.45: Series Throttle Pedal

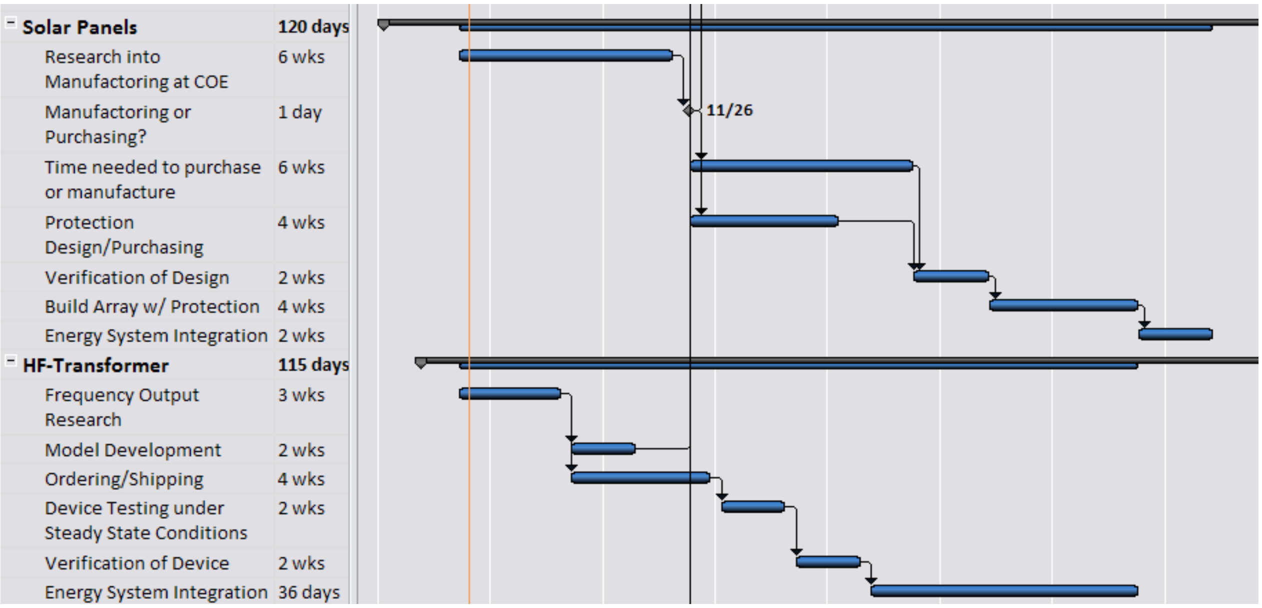
Figure 3.46: Motor J2 Cable

4 Schedule



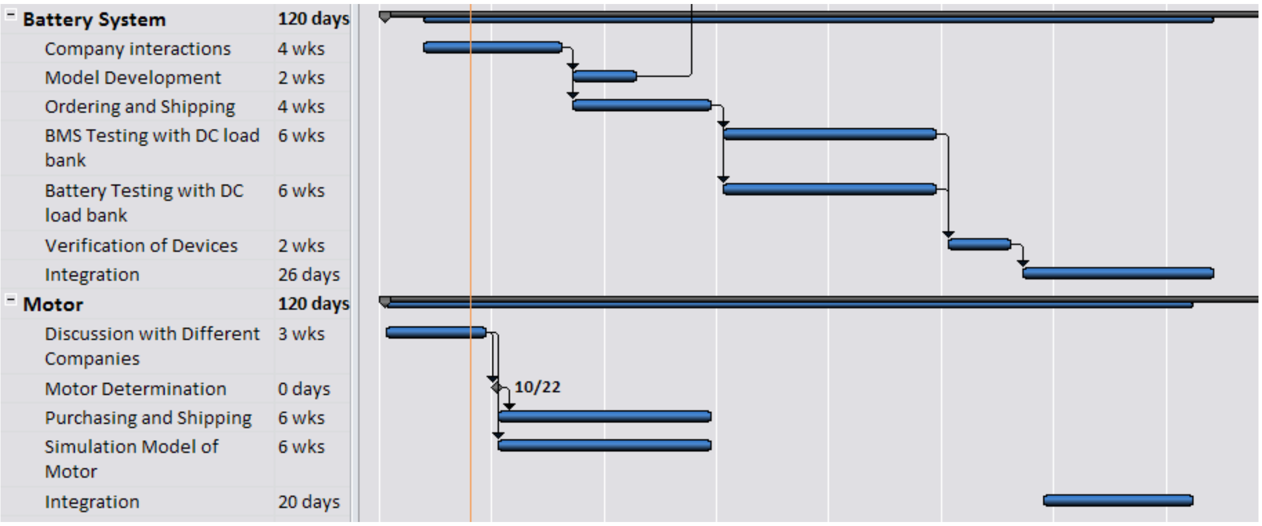
Development/Modeling Pro-Engineer	7 wks
Suspension Research/Design	11 wks
Final Prototype Design Chosen	0 days
HPMI Design Development	8 wks
Discuss w/ HPMI - Roll Bar Design	2 wks
Research on Sheild/Cockpit	3 wks
Hatch Design	7 wks
Cockpit Design	2 wks
Roll Bar Design	1 wk
Car Chassis Open/Close/Locking	12 wks
PRO-Engineer w/ Fully Articulated Model	12 wks

Figure 4.1: Documentation and Mechanical Schedule



Solar Panels	**120 days**
Research into Manufacturing at COE	6 wks
Manufacturing or Purchasing?	1 day
Time needed to purchase or manufacture	6 wks
Protection Design/Purchasing	4 wks
Verification of Design	2 wks
Build Array w/ Protection	4 wks
Energy System Integration	2 wks
HF-Transformer	**115 days**
Frequency Output Research	3 wks
Model Development	2 wks
Ordering/Shipping	4 wks
Device Testing under Steady State Conditions	2 wks
Verification of Device	2 wks
Energy System Integration	36 days

Figure 4.2: Electrical Schedule: Part 1



Battery System	**120 days**
Company interactions	4 wks
Model Development	2 wks
Ordering and Shipping	4 wks
BMS Testing with DC load bank	6 wks
Battery Testing with DC load bank	6 wks
Verification of Devices	2 wks
Integration	26 days
Motor	**120 days**
Discussion with Different Companies	3 wks
Motor Determination	0 days
Purchasing and Shipping	6 wks
Simulation Model of Motor	6 wks
Integration	20 days

Figure 4.3: Electrical Schedule: Part 2

5 Budget Estimate

Table 5.1: Budgetary Estimates as of November

Part	Cost
Chassis Manufacturing	$3000.00
Suspension Manufacturing	$1000.00
Steering Manufacturing	$400.00
Braking Integration	$50.00
Roll Bar Manufacturing	$500.00
Hatch Design	$500.00
Latching/Locking Mechanism	$50.00
Solar Cells*	$0.00
Solar Array Manufacturing*	$0.00
Solar Junction Box (x2)	$25.00
Boost Converter*	$0.00
MPPT Controller*	$0.00
Battery System including BMS	$550.00
Hub Motor	$179.00
Motor Controller	$169.00
J2 motor cable	$19.00
Motor Heat Sink	$19.00
Compact Assembly (motor)	$89.00
Motor Control Box	$39.00
Throttle/Brake Pedal (x2)	$138.00
TOTAL	$6727.00

*-Items donated or received for educational purposes.

6 Overall Risk Assesment

6.1 Technical Risks

6.1.1 Solar Cell Encapsulation

6.1.1.1 Description The wrong way of encapsulation and mounting of the solar array could allow them to be exposed to the outside elements. This includes wind, outside atmosphere, flying objects, high speed and sun damage.

6.1.1.2 Probability: Moderate
The chances of the vehicle being exposed to wind, outside atmosphere, flying objects, high speed and sun damage is moderate. This is due to the SEMA rules where the car must be able to function at any weather condition.

6.1.1.3 Consequences: Moderate
In the current stage the solar modules will be riveted to the upper body of the car which will allow the team to replace any nonfunctional solar modules easily. Replacing the modules help not lose power from the damaged modules.

6.1.1.4 Strategy EVA protection will be used on the solar cells to increase the physical strength. Aluminum plate will be used at the bottom of the solar modules make the installation process easier.

6.1.2 Solar: Diode Protection

6.1.2.1 Description Current flowing back into the solar module, and the partial shading of the any of the solar cells on the array. This might cause damage to the solar cells in a way where replacing them become necessary.

6.1.2.2 Probability: Moderate

6.1.2.3 Consequences: Moderate
It's possible that one of the cells or couple of them get shaded by clouds, trees or leaves.

6.1.2.4 Strategy A protection Diode, and bypass diodes as described previously will be used to keep the modules safe from current feedback, and stop the effect of shading.

6.1.3 Energy System Electrical Wiring

6.1.3.1 Description The wiring of the solar array, MPPT, motor controller, and motor are all subject to the risk of failure. The improper wiring or improper choice of wiring can cause the wires to burn up. Improper use of components outside the ranges specified within the data sheet could propagate high/low voltages or high currents delivered to other components in the system.

6.1.3.2 Probability: Moderate
This risk is apparent in every decision made because the replacement of a damaged component is not feasible. Since the team is well aware of the risk it is less likely to happen.

6.1.3.3 Consequences: Severe

The consequences could be severe possibly damaging all electrical components if something were to be wired incorrectly or improper gauge selected. This would also lead to budget and scheduling risks.

6.1.3.4 Strategy

6.1.4 Proper Wiring of Motor/Motor Controller Setup

6.1.4.1 Description Although the connections from the motor to the motor controller, motor controller to battery seems trivial.

6.1.4.2 Probability: Low

Technical documents provided describe proper connections.

6.1.4.3 Consequences: Severe

Improper connection will result in damage to either the controller, motor or battery system. Budget does not allow for purchase of another motor.

6.1.4.4 Strategy Reading instructions sent by distributor will allow for ease of connection.

6.1.5 Chassis - Aluminum Honey Comb

6.1.5.1 Description The aluminum honey-comb might be harder to connect than previously thought.

6.1.5.2 Probability: Low

We have a sample of joined aluminum honey-comb that was joined using carbon fiber. Also we will be having assistance in the manufacturing process.

6.1.5.3 Consequences: Medium

The 3D representation and simulations will be done for this material. If we would have to change to a different material it would put a strong time delay on the build.

6.1.5.4 Strategy Making sure the process of joining the aluminum honey-comb is approved by an experienced machinist.

6.1.6 Chassis - Car Strength

6.1.6.1 Description The predetermined strength of the car could be weaker than predicted.

6.1.6.2 Probability: Low

We are assessing the strength through Pro E and ComSol to accurately depict it.

6.1.6.3 Consequences: High
If the strength of the chassis cannot support the weight the chassis will break. This will put us back many months and some money.

6.1.6.4 Strategy A safety factor of 2.0 Ű 3.0 will be implemented to make sure that it will not break under the load.

6.1.7 Suspension

6.1.7.1 Description If the ride is too harsh from the suspension being rigid vibrations could cause things to fail.

6.1.7.2 Probability: Low
We will be riding at low speeds on flat ground which does not have a lot of vibrations.

6.1.7.3 Consequences: Medium
If vibrations caused a major component to fail it could set us back money and time.

6.1.7.4 Strategy If we have a vibration sensitive object we will implement a vibration reducing agent such as rubber to preserve the object.

6.1.8 Braking

6.1.8.1 Description If the brakes are not strong enough to hold the car in place.

6.1.8.2 Probability: Low
The stopping force will be calculated before purchase.

6.1.8.3 Consequences: Low
New brake calipers will have to be ordered.

6.1.8.4 Strategy The stopping force required will be calculated and a safety factor of 2.0 will be added to it.

6.1.9 Steering

6.1.9.1 Description The steering could be under the design requirements.

6.1.9.2 Probability: Low

6.1.9.3 Consequences: Low
A longer arm would have to be fabricated.

6.1.9.4 Strategy Calculate the required angle of turning and have it turn 10 degrees past this mark.

6.1.10 Battery Management System

6.1.10.1 Description Lithium batteries require a proper battery management system to protect individual cells and the entire battery pack from over/under voltage, over current, and over temperature. Ineffective BMS may result in damaging the battery pack.

6.1.10.2 Probability: Moderate
At this moment it is unknown what the protection limits are for the given BMS and how it will respond when a limit is reached. However, this company has been around for over 10 years and has sold their battery packs to other teams in the Shell Eco Marathon so the BMS should work as expected.

6.1.10.3 Consequences: Severe
How the battery pack is arranged as a pre-built system, if even one of the batteries goes bad it will be impossible to replace it. A whole new battery pack would need to be purchased. Safety is very important. We do not want someone to be driving the car and have the batteries catch fire which is a definite possibility if the BMS does not work correctly.

6.1.10.4 Strategy Extensive testing on the BMS will need to be conducted to determine the protection limits and what will happen when each limit is reached.

6.1.11 Roll Bar

6.1.11.1 Description Possibility of roll bar failure.

6.1.11.2 Probability: Low
The design of the solar car chassis and tire placement is such that the likelihood of the entire vehicle overturning during operation is low. Also, the vehicle will not be traveling at high speeds, nor negotiating any extremely sharp turns. Regardless, in the unlikely event that the car somehow overturns, due to the fact that the roll bar will be designed with a good factor of safety, the light design of the car, and the added protection of the shatter resistant polycarbonate Lexan hatch, the chances of the roll bar failing are minute at best

6.1.11.3 Consequences: Catastrophic
In the unlikely scenario that the roll bar outright fails during actual operation of the vehicle, this would be considered catastrophic. Needless to say the car would suffer extensive damage due to the roll and continued momentum, and the driver could potentially incur a variety of injuries despite his protective gear.

6.1.11.4 Strategy The team stress analysis with Creo and physical testing with weights before final roll bar installation.

6.1.12 Hatch

6.1.12.1 Description Possibility of polycarbonate failure.

6.1.12.2 Probability: Very Low
In the improbable scenario that a hard object should impact the hatch with substantial force, it is extremely unlikely that the hatch will shatter due to the material properties.

6.1.12.3 Consequences: Severe
If the hatch was to somehow crack or shatter, it would cause both schedule and budget risks.

6.1.12.4 Strategy The purchase of a substantially thick Lexan polycarbonate, around 8mm, in and of itself should prevent the hatch from ever shattering.

6.2 Schedule Risks

6.2.1 Chassis - Manufacturing Time

6.2.1.1 Description The chassis will take a longer time than this year to complete

6.2.1.2 Probability: Medium
We are inexperienced in making these complicated structures out of advanced materials.

6.2.1.3 Consequences: Medium
If we do not finish the chassis structure in time we will be unable to implement any other pieces onto it.

6.2.1.4 Strategy Help from a more experienced maker will be used to aid us in the fabrication of our car.

6.2.2 Delivery of Parts for Solar Array

6.2.2.1 Description The delivery of the Solar Junction Box could be delayed due to postal reasons. As mentioned before those solar junction boxes will be used for both the protection circuit and the bypass diode.

6.2.2.2 Probability: Low
The chance that the solar array delays the process of building the car is most likely impossible. The team will make sure to build the solar array as soon as possible, however sometimes some delays could happen.

6.2.2.3 Consequences: High
Even with the chances off solar array to fail is almost impossible, the consequences of the system failing is really high. If the solar array fails the car would not be able to be completed. If the solar system fails the car won't be able to charge since the solar system is the only source of charging. As result the car won't be able to make to the SEMA since it's one of the major parts of the car.

6.2.2.4 Strategy In order to ensure that all the solar system does not fall behind in schedule the team will order the solar junction box before Christmas Break to assure that the team will have it by the New Year.

6.2.3 Solar Cell Damage

6.2.3.1 Description Damage of existing cells and modules after the completion of the array building process.

6.2.3.2 Probability: Low

After talking with Mr. Ian Winger from SunnyLand Solar, he assured the team that the solar system will be ready by the next year.

6.2.3.3 Consequences: High

Even with the chances off solar array to fail is almost impossible, the consequences of the system failing is really high. If the solar array fails the car would not be able to be completed. If the solar system fails the car won't be able to charge since the solar system is the only source of charging. As result the car won't be able to make to the SEMA since it's one of the major parts of the car.

6.2.3.4 Strategy To make sure the solar module done as soon as possible the team will work on them during the Christmas break to assure that they ready by the new semester.

6.2.4 Maximum Power Point Tracker

6.2.4.1 Description One of the most vital components of the project next to the motor and PV array is the maximum power point tracking system (MPPT). Without this component the vehicle would remain a divided two part system with the solar cells and the battery/motor being separate.

6.2.4.2 Probability: Low

The probability of this component and its sub-parts setting the vehicle behind schedule is low. The part will be manufactured and order relatively early to avoid delay.

6.2.4.3 Consequences: Catastrophic

While the probability of the MPPT or its sub-components failing is low, the consequences of the system failing could be catastrophic to the outcome of the vehicle and delay the milestones. If the system or its components fail, the car would not be a complete system and would consist of a battery and motor with solar cells that are connected to nothing. If any subsystem of the MPPT fails it could damage other portions of that system. Without this major component the vehicle will not be able to use solar energy.

6.2.4.4 Strategy The strategy the team has come up with to keep the probability low is to simulate, simulate, and re-simulate to ensure that the MPPT will work together and have no chance of failing and damaging other components. Other methods of preventing this would be to test each of the components to make sure the team is not putting a damaged component into the vehicle.

6.2.5 Suspension

6.2.5.1 Description If the suspension is not finished in time the steering will also be delayed

6.2.5.2 Probability: Low

It is easy to manufacture

6.2.5.3 Consequences: Low

We could focus on another aspect of the car while still working on the suspension.

6.2.5.4 Strategy An easy , fast suspension will be made so that it does not interfere with other parts

6.2.6 Roll Bar

6.2.6.1 Description The completion of the roll bar may be delayed due to unforeseen complications in design or carbon fiber application or necessary size and design adjustments as the car comes together.

6.2.6.2 Probability: Low

The manufacturing of the roll bar should not prove challenging or time consuming for a skilled metal-worker. The design is simple and small scale. If there were to be some unforeseen problems with the fabrication of the roll bar that would cause its development to be drawn out, this would not significantly hinder or affect the development of the rest of the solar car nor would it affect its scheduled completion.

6.2.6.3 Consequences: Low

6.2.6.4 Strategy The team will be certain of the final design and begin manufacturing of the roll bar frame ahead of schedule so that it is definitely completed and installed properly on time, and any problems that arise will not create a time-constraint issue.

6.2.7 Hatch

6.2.7.1 Description Possibility of late delivery of Lexan polycarbonate bubble due to postal reasons.

6.2.7.2 Probability: Low

6.2.7.3 Consequences: Moderate

It is ideal to have the hatch in our possession as soon as possible so that we can match it to the cockpit hole in the vehicle chassis as we build it.

6.2.7.4 Strategy An effort will be made to order the Lexan hatch as soon as possible, perhaps even during Christmas break, so that it arrives as soon as possible in January.

6.3 Budget Risks

6.3.1 Carbon Fiber

6.3.1.1 Description Carbon Fiber is used extensively through our project. The price of Carbon Fiber is very high.

6.3.1.2 Probability: Low

We are under budget at the moment due to the decrease of the electrical component price.

6.3.1.3 Consequences: Low

Carbon Fiber can be easily exchanged with aluminum just with an increase in weight.

6.3.1.4 Strategy Getting a rough estimate of the budget for buying all of the carbon fiber.

6.3.2 Braking

6.3.2.1 Description The price for the aluminum and/or carbon fiber might exceed budget

6.3.2.2 Probability: Medium

A lot of aluminum and carbon fiber is needed to make these parts.

6.3.2.3 Consequences: High

We will have to settle for steel which will add a considerate amount of weight.

6.3.2.4 Strategy Budget the price for the aluminum and carbon fiber before so that we do not run over budget.

6.3.3 Carbon Fiber Roll Bar

6.3.3.1 Description It is uncertain approximately how many sheets of carbon fiber will have to be purchased to accomplish the desired strength requirements of the role bar if it were to be made of carbon fiber.

6.3.3.2 Probability: Low

In the event that many sheets of carbon fiber need to be purchased, this should not create any substantial strain on the car's allocated funding.

6.3.3.3 Consequences: Low

The team may have to spend a bit more than previously thought for additional carbon fiber rolls.

6.3.3.4 Strategy Always shop competitively. The team will compare price verses quantity for multiple vendors and check to see if it is possible that anyone would like sponsor the car by donating carbon fiber.

6.3.4 Hatch

6.3.4.1 Description Final price of Lexan polycarbonate bubble is more expensive than anticipated.

6.3.4.2 Probability: Moderate

Lexan polycarbonate is a wonderful material, employed in bulletproof glass even. As such, it has a substantial price tag and can be costly to form.

6.3.4.3 Consequences: Moderate

The hatch may end up being more expensive than anticipated, and this could create a small budget strain.

6.3.4.4 Strategy Always shop competitively. The team will compare price of the material, its fabrication into the bubble shape required, and the shipping times and prices for different vendors.

6.4 Summary of Risk Status

So far many risks described will not throw the entire project off course. Using necessary safety measures during testing will prove useful. For the mechanical engineers, this car will required proper attention to detail in strength, and time. For the electrical engineers, setting up testing using proper electrical safety and wiring prove the most important based on risk analysis.

7 Conclusion

With the term coming to a close, the solar car year 1 goals are on their way to being completed on time. Several pertinent tasks have been completed. Some of these tasks include: final chassis desing in ProE, procurment of solar panels for testing, energy conversion system parts have been delivered ready to test, battery system chosen an in the process of being ordered, and motor/motor controller parts have been chosen ready to be ordered. A COMSOL based car is in the works for stress testing and aerodynamic testing. The latch and hinge system will be chosen based on COMSOL tests. As the fall semester comes to a close the group will be focusing on ordering parts before the Christmas break and testing parts as they are received from shipments.

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