Electric Commuter Car with Roof-Mounted Solar-Panel
Updated for COVID-19 Campus Closure

<u>ECE 4012 Senior Design Project</u>

Solaire Rider
Dr. Habetler
Sponsored by: General Motors

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Table of Contents

Executive Summary

The Electric Commuter Car with Roof-Mounted Solar-Panel (Solaire Rider) is a small, light, two-person electric powered vehicle that is able to be recharged through solar and household wall power. The vehicle will work by having an electric motor directly connected to the driving axle which will power the vehicle as well as recharge the battery when coasting or stopping. Solar panels will allow the battery to recharge when the vehicle is in motion and parked. Lastly, an electronic gearbox will be used to simulate the feel of a manual transmission for car enthusiasts.

The reason for creating the Solaire Rider is to create a more environmentally friendly alternative to gasoline powered vehicles that anyone, from a daily commuter to car enthusiasts, can enjoy driving. Today's vehicles are much larger and heavier than necessary for a person's daily commute, which means more fuel is needed to get a person to where they need to go. With the world's supply of oil dwindling rapidly, the need for a smaller and lighter vehicle powered from an alternative source of energy is needed.

The Solaire Rider prototype will be a conversion from a gas powered, two-seater, go-kart into an electric powered vehicle. An existing go-kart will have its internal combustion engine and gearbox removed and be replaced with the electric power-train. The power-train will consist of an electric DC motor, a state machine electronic gearbox, a Tesla Model S battery module and solar panels. The expected outcome is a fully functional prototype that can be easily scaled up through the use of a larger motor and additional battery modules. The expected cost to create this prototype is approximately $435.

Electric Commuter Car with Roof-Mounted Solar-Panel

1 Introduction

The Solaire Rider project team will design and create a small two-seater commuter car prototype that is powered by electricity and recharged through solar panels. The team is requesting $435 of funding to develop a prototype of the electric commuter car.

1.1 Objective

The objective of the electric commuter car is to create a small vehicle that runs solely off electricity for short daily commutes around town. The vehicle will be small and light, able to seat up to two people for short distances with all the standard pedals and gear shift of a typical internal combustion powered vehicle. The power to drive the car will be an electric motor, controlled by a small computer to regulate the power output depending on what gear the car is in. The motor will draw energy from a large battery pack that is able to be recharged while driving and once reaching the destination through the use of regenerative braking and solar panels located on top of the vehicle. Additionally, the vehicle will feature a standard 120 V (Volts) wall plug for overnight charging.

1.2 Motivation

The motivation behind this vehicle is to reduce the carbon footprint and use of gasoline in the average person's daily driving. Today's vehicles are getting larger and larger, needing more fuel to travel the same distance as smaller vehicles. There is no reason that one person should be commuting to work and around town every day in a vehicle that is nearly twenty times their mass. This project looks to remedy this by creating an alternative that anyone from average person to a car enthusiast could easily adopt. A small light, full electric vehicle suitable for daily driving to replace the large gas-guzzling cars on today's roads.

1.3 Background

1.3.1 Battery

An electric vehicle requires a lot of power, and it is highly impractical to tether the vehicle to a household outlet in order to supply the required power. Therefore, a lightweight high-capacity battery with high output power is needed to propel the vehicle. The best and most commercially used battery type for this application is Lithium-Ion for their lightweight capacity, and ability to be re-charged when depleted. A single Lithium-Ion cell is insufficient to power the vehicle, for example the EM3 LIR18650 Lithium-Ion cell has a nominal capacity of 3,000 mAh and a nominal voltage of 3.78 V [1]. One must connect multiple cells of the same voltage and capacity into both parallel and series configuration to achieve the desired output. The connected cells are enclosed in a case and referred to as a battery module. The battery needed to be chosen first and foremost, because all of the components of the power-train depend on the choice of battery. Luckily, the Tesla Model S battery module meets all the necessary requirements, and was already on hand.

1.3.2 Motor

In the physical world, the AC motor and DC motor vary differently. DC motors have high efficiency and about 30% more efficiency than AC motors [2]. The disadvantage of having a DC motor is it can release lots of heat and require maintenance for replacing a new brush inside the motor, due to the friction of the brush of the DC motor. However, AC motor doesn't require a lot of maintenance for the motor because the AC motor is brushless.AC motor is much more complicated in control, because it is a multivariable coupling, time-varying, and non-linear system. DC motor is much simpler in control because it is a linear system.

1.3.3 Solar-Panel Charging Circuit

There is a traditional and advanced version of PV-battery charging systems. Traditionally, PV cells and batteries are separated, and these two independent parts are connected with wires. However, this used to be expensive as well as huge and inflexible. Furthermore, there is an energy loss through wires. To make remediation, the advanced design combines panels and batteries into a single unit. By doing this, the system's volume is minimized and their efficiency also increases. There are three types of integration in advanced system:

1. Three-electrode configuration with common anode
2. Three-electrode configuration with common cathode
3. Two-electrode configuration.

Although it has been improved by an integrated method, there are still challenges in low efficiency, capacity, and stability of solar-powered batteries [3].

2 Project Description, Customer Requirements, and Goals

The team will design and install a new electric power-train system for an existing internal combustion two-seater go-kart. The new power-train will consist of a motor, lithium-ion battery, charging circuit, solar panel, and electronic gearbox. The motor will be a single electric motor connected directly to the drive axle on the go-kart. The motor will also be configured to function as a generator, able to regain energy to the battery when the vehicle needs to slow down. The lithium-ion battery will be a single Tesla Model S battery module with included charging circuit. The solar panel will be mounted to the roof of the vehicle to capture energy while parked outside and driving. Lastly the electronic gearbox will be a small computer controlling the power signal sent to the motor to create different torque and maximum speed outputs depending on the gear the vehicle is set to be in. Project goals of this vehicle include:

General

- Reach a minimum range of one kilometer
- Able to seat two people

Motor

- Able to achieve a cruising speed of 30 miles per hour
- 2-3 horsepower
- 2-3 kilowatts

Battery

- Output enough power to drive a 24 V, 2 horsepower electric motor
- Enough capacity to drive for at least 1 kilometer
- Able to be safely charged and discharged

Electronic Gearbox

- Allows manual control of the motor’s torque and speed through six separate states/gears

3 Technical Specifications

There are five major components which affect the overall performance of the vehicle. Table 1 shows the battery specification, Table 2 and Table 3 display the solar-panel and controller specification respectively, Table 4 specifies the DC motor, and Table 5 shows the go-kart frame specification. To charge at the proper rate, approximately 18 hours to fully charge, as defined from equation 1 in section 4.1, three 100W panels are needed. A 4 kW, 24 V, 3100 RPM DC motor will be used to reach a cruising speed of roughly 30 mph.

Table 1. TESLA BATTERY SPECIFICATIONS

Features	**Specification**
Capacity	232 Ah, 5.3 kWh
Height	3.1 in
Width	11.9 in
Length	26.2 in
Weight	55 lbs.
Bolt Size	M8
Voltage nominal	3.8V/Cell, 22.8V/Module
Charge voltage cut-off	4.2V/Cell, 25.2V/Module
Discharging cut-off	3.3V/Cell, 19.8/Module
Maximum Discharging Current (10 sec.)	750 A

Table 2. SOLAR-PANEL SPECIFICATIONS

Features	Specification
Size (Height x Width x Length)	40 x 1 x 27 in
Amperage	5.6 A
Material	Polycrystalline Silicon
Weight	3.5 lbs.
Solar Panel Type	Monocrystalline
Voltage	12 V
Wattage	100 W
Number of Panels	3
Features	Flexible, Outdoor, Weatherproof

Table 3. SOLAR-PANEL CONTROLLER SPECIFICATIONS

Features	Specification
Size (Depth x Height x Width)	9.37 x 6.81 x 2.85 in
Amperage	30 A
Voltage	24 V
Wattage	780 W

Table 4. MOTOR SPECIFICATIONS

Features	Specification
Size (Length x Width x Height)	35 x 15 x 15 cm
Weight	17 kg
Output Power	4 kW
Voltage	24 V
Type	DC Motor
Torque	10 N*M
Speed	3100 RPM

Table 5. GO KART BODY SPECIFICATIONS

Features	Specification
Size (Length x Width x Height)	58.5 x 43 x 36 in
Weight	330 lbs.
Wheelbase	50 in
Weight Capacity	400 lbs.
Ground Clearance	4 in

Note: Since the provider hasn't given us the specification of the product, this is the specification of a similar product.

4 Design Approach and Details

4.1 Design Concept Ideation, Constraints, Alternatives, and Tradeoffs

The solar-powered electric car is composed of three main parts. First, the solar-panel, which dictates the rate of charging and therefore indirectly impacts the range. Second, the main fuel source, the battery. The battery has to have enough capacity to carry the kart at least one kilometer. The third main part is the motor which is chosen to match the battery voltage and to produce enough torque to overcome the kart's own mass. Also, torque and speed of the motor is directly related to the voltage and current input from the battery. To understand the interaction between solar-panel and battery, a diagram showing how the charging circuit works is shown below in Figure 1.

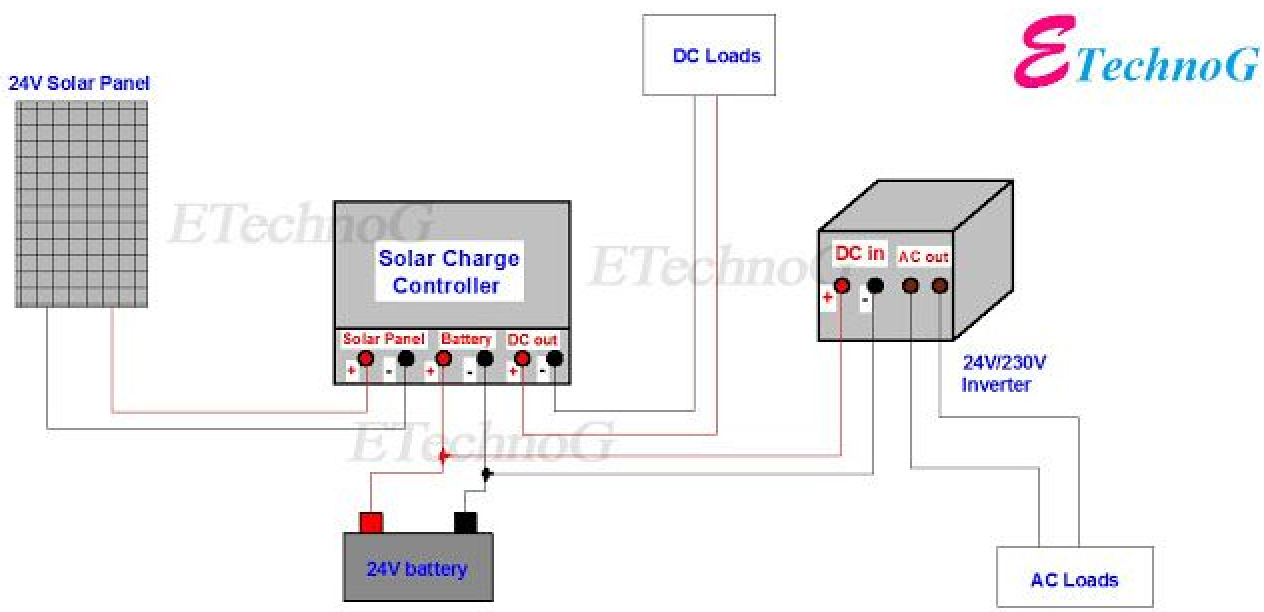


Figure 1. Diagram showing the interconnection between solar-panel and charging circuit [4].

According to Table 1 and 2, the battery capacity is specified as 5.3 kWh and the given solar-panel is 100 W. With three solar-panels the total estimated time for charging is approximately 17.67 hours, according to Equation 1.

$$Charge/Discharge\ Time(hr) = Battery\ Capacity(Wh)/Wattage(W) \quad \text{(Eq. 1)}$$

The DC motor will produce a maximum 3100 RPM and with the go-kart's 11-inch diameter wheels the go-cart can travel at 45.35 mph [5] according to Equation 2 and 3. However, once installed on the go-kart the total speed will be lowered due to the combined weight of the frame and riders.

$$Circumference(miles) = 2\pi * Radius \quad \text{(Eq. 2)}$$

$$Go\ Kart\ Speed(mph) = Motor\ Speed(RPM) * Circumference(miles) \quad \text{(Eq. 3)}$$

The biggest consideration on this project was choosing between an AC or DC electric motor. While an AC motor does not require as much maintenance as a DC motor, the solar-panels only generate DC output. This means that an inverter would need to be added to operate the AC motor, as seen Figure 1. Adding an inverter would add to the cost of the prototype, increase the overall weight of the go-kart, and create an additional point of failure.

Consideration has been given to custom building a solar-panel controller instead of using a pre-built one, however, most controllers are highly specialized to the panel and normally integrated into the panel. Additionally, fabricating a controller would take additional time and resources which seems outside the scope of this prototype.

The initial plan was to design our own frame for the vehicle but due to time, budget and team member skillset this was unfeasible. A prebuilt two-seater go-kart frame provides all required safety equipment while still allowing for customizations. Emission standards that affect most vehicles currently on the road today are not a consideration in the design for the proposed vehicle will have no emissions due to running purely off electricity.

4.2 Engineering Analyses and Experiment

The prototype will be testing into two parts: motor control (speed and acceleration) and charging circuit. Once the preliminary testing is complete the pieces will be assembled together and prepared for full systems testing.

The motor controller will be written in C and programmed into a microcontroller. A test input voltage will be applied to the motor, and the controller will measure the voltage, current, speed and acceleration of the motor to ensure it meets the design specification and hand calculations at that input. The controller will also be measuring the output voltage and current from the charging circuits to ensure the power matches that of the battery. Microcontroller implemented feedback will be used to ensure voltages and currents do not exceed their operating limits for both motoring and charging.

4.3 Codes and Standards

According to the Georgia Department of Driver Services, all commercial vehicles less than 25 years old must include:

1. Service Brakes
2. Parking Brake
3. Steering Mechanisms

4. Lighting Devices and Mechanisms (headlights, blinkers, etc.)
5. Horn
6. Windshield
7. Windshield Wipers
8. Coupling Devices (alignment)
9. Rear Vision Mirrors
10. Emergency Equipment (airbag, seatbelt, etc.)
11. Doors
12. Frame
13. Tires (must have at least 4/32 of an inch of tread on front tires and at least 2/32 of an inch of tread on all other tires).

The maximum speed limit for the different roads is shown in Table 6.

Table 6. SPEED LIMITS IN GEORGIA

Area	**Speed (mph)**
Urban or Residential Districts	30
Unpaved County Roads	35
Rural Interstate	70
Urban Interstate or Multi-Lane Divided Highway	65
Other	55

5 Project Demonstration

Using a DMM one of the engineers can measure the output voltage and current from the battery to the motor in each gear. Using that information one can solve for and plot the average output torque, speed, and power. One can then reference the output power to the 5.3 kWh, 250 Ah battery specifications and solve for the range achievable in each gear. After determining torque, speed, power, and range for each gear the testing engineer will compare and validate the data with the project specifications. On the day of the Expo, one of the project engineers will put on a helmet and buckle in to perform a live demonstration of each gear.

6 Schedule, Tasks, and Milestones

The Gantt chart in Appendix A shows the tasks that need to be completed. The tasks highlighted in red are major milestones such as assignment deadlines, presentations, and the senior design expo, and as such are the highest risk for the project. Assembly and testing of the prototype are scheduled to take the most time in order for debugging and redesign if needed.

Appendix B is the team's CPM chart which shows the critical path, estimated time in days, and 37.4% probability calculation that our team will finish the project one week before the Expo.

7 Marketing and Cost Analysis

7.1 Marketing Analysis

The target market is primarily individuals who usually travel short distances with minimal cargo, and favor a more environmentally friendly option to a gasoline vehicle. There are currently no solar powered electric vehicles on the market today, however, there is a similar product that is scheduled to release in 2021 called the "Light-year One", but it cost around £107,000, or $139,000 [6]. Our product will be much smaller in size, weight, range, and price as the "Light-year One", which is more focused on long distance travel.

7.2 Cost Analysis

The total cost for the parts to develop a prototype is broken down in **Table 7.** The total cost for the parts is $3,213, however, the biggest ticket items, such as the go-kart, the battery, and the panels were donated free of charge. Also, estimations were made for the microcontroller, cables, and packaging.

Table 7. PROTOTYPE COST

Part	Cost ($)
Go-Kart Body	965 [7]
Tesla Model S Battery Module	1,580 [8]
WindyNation Solar Panel	233 [9]
Alibaba DC Motor	135 [10] bulk=130
Microcontroller & Booster Pack	50
Cables/Miscellaneous	150
Packaging/Shipping	100
Total Part Cost	3,213

Table 8 contains an estimation for the number of hours invested in different categories of the project per engineer. Labor costs were determined by using the average hourly pay for an entry level electrical engineer of $34/hr [11]. Multiplying the labor cost for four engineers comes out to be $25,160 for development labor.

Table 8. DEVELOPMENT HOURS PER ENGINEER

Labor	Number of Hours
Weekly Meetings	50
Report Preparation	45
Research	5
Software Design	25
Hardware Design	40
Assembly	10
Testing	10
Total	185
Cost at $34/hr [11]	6,290

Table 9 shows the total development cost of $79,026 for the project assuming 30% fringe benefits of labor and 120% overhead on materials/labor/fringe benefits.

Table 9. TOTAL DEVELOPMENT COST

Development Component	Cost ($)
Parts	3,213
Labor	25,160
Fringe Benefits, % of Labor	7,548
Subtotal	35,921
Overhead, % of Material, Labor, & Fringe Benefits	43,105
Total Development Cost	79,026

The production run will run five years, in which 5000 units will be sold, at a price of $10,000 per unit. The parts cost is estimated at a 10% bulk discount, and the labor cost was based on a technician getting paid $20/hr to assemble and test the unit. It was also estimated that marketing and advertising for the Solaire rider will be roughly 10% of the total input cost. To calculate the amortized development cost the total development cost of $79,026 was divided by 5,000 units to result in $16. Adding up all the costs is a grand total of $7,436, and at $10,000 per unit expected profit is $2,562 which is roughly 26% profit per unit sold. The production cost, profit, and sale price are shown below in Table 10.

Table 10. DECISION OF PRICE PER UNIT (based on 5,000 unit production)

Aspect of Development	Cost ($)
Parts Cost	2988
Assembly Labor	40
Testing Labor	20
Total Labor	60
Fringe Benefits, % of Labor	18
Subtotal	3066
Overhead, % of Material, Labor, & Fringe Benefits	3679
Subtotal, Input Costs	6745
Sales Expense	675
Amortized Development Costs	16
Subtotal, All Costs	7,436
Profit	2,562
Selling Price	$10,000

8 Status Pre-COVID-19

Before the start of this semester the team already secured a Tesla Model S Battery Module and an Orion Battery Management System from the ECE Senior Design Lab at Georgia Tech. The team had also obtained a gas powered, two-seater go-kart to use as the body of our vehicle from the project advisor Dr. Habetler.

Throughout the current semester the team had discussed, researched, and decided on a final parts list for the project based on price, performance, and compatibility with other parts, shown in *Table 11*. Most of these parts were ordered and delivered before Georgia Tech's campus closure. However, some parts did not arrive in time.

The DC Motor Controller the team originally borrowed from Van Leer (Model #: AX2850) was not the model for which the team hoped. The AX2850 is not capable of combining the two output channels into our one motor, so the team ordered the HDC2460s Brushed DC Motor Controller from Roboteq. Due to budget constraints the team chose to not buy solar panels, this meant that the Tesla Battery did not have any means to charge. To solve this problem, the team ordered a Lithium-Ion battery charger from Top Mobility.

Unfortunately, Georgia Tech's Atlanta campus had to close due to the 2020 COVID-19 outbreak. The DC Motor Controller and Lithium-Ion Battery Charger were in the process of being ordered when campus closed, which left the team without access to these essential parts needed to have a working project. Due to this setback the project has had to be adjusted and the steps moving forward are addressed and detailed in Section 9 COVID-19 Adjustments/Next Steps.

Table 11. PART LIST

Part	Model Number	Status	Price
Brushed DC Motor	ZD2973A: DC Motor 24V 4kW	Delivered	$235.00
DC Motor Controller	Roboteq XDC2460 Brushed DC Motor Controller	Shipped, Not Arrived before COVID-19	$535.00 + $16.32 Shipping + Taxes
Battery Management System	Orion BMS 2	Borrowed from Georgia Tech	Borrowed
Lithium-Ion Charger	Challenger Charger EMC-180 24V 5AH LI-ION Battery Charger	Shipped, Not Arrived before COVID-19	$58.00 + Free Shipping + Taxes
Lithium-Ion Battery	Tesla Model S Battery Module	Borrowed from Georgia Tech	Borrowed
Go-Kart Frame and Parts	Unknown	Borrowed from Dr. Habetler	Borrowed
DC Motor Flange Adapter	In-Contact with Granger About	In-process of obtaining before COVID-19	TBA
Solar Panel	WindyNation 100W Monocrystalline Flexible Solar Panel SOL-100-FV-01	Decided to omit based on budget	$223.90 + Shipping & Taxes
Solar Panel Controller	Genasun GVB-8 (Boost) GVB-8-Li-28.4V-RETAIL	Decided to omit based on budget	$190.00 + Shipping & Taxes
Raspberry Pi	Raspberry Pi 3 Model B 1GB RAM	Borrowed from Georgia Tech	Borrowed
Misc. Parts	Resistors, Diodes, Switches, Etc.	Borrowed from Georgia Tech	Borrowed

9 COVID-19 Adjustments/Next Steps

Without access to the DC Motor Controller and Lithium-Ion Battery Charger that was in the mail before campus closure, the team cannot assemble the vehicle off-campus as these are essential parts. To account for this and still complete this project on time, the team has decided to instead change our approach to a more simulation based plan instead of physical prototyping. The parts we will use for the simulations are the parts we already had or decided to get to keep within the budget and spirit of the original idea. One exception will be that the solar panel controller had us slightly over budget but due to the simulation we will be including them once again as it was in the original plans. One simulation will include the motor's speed and output torque using MATLAB and Simulink. The team is also planning on creating a block diagram for the top level view of the project, determine a potential range for the kart, and power draw and efficiency if possible. The goals are to create a plan of action to build our design as quickly as possible if given the opportunity. This means showing how everything would have connected and having a top-level overview of the code we would have created/finished given the opportunity. As of March 29, 2020 at 3:00 PM we have not heard back from our advisor on guidance of exactly how to continue. The 'Next Steps' listed here are mainly ideas between the group members on how to complete this project given the options our advisor had before Spring Break. They will be fleshed out, added to and have further guidance given after we get a response and attend the ECE 4012 Q&A session on Monday March 30, 2020.

10 Leadership Roles

Table 12. TEAM LEADERSHIP ROLES

Team Leadership	Christopher Hooper
Project Management	Moongyu Kang
Webmaster	Hong Yee Cheah
Expo Coordinator	Christopher Hooper
Documentation Coordinator	Daniel Bruce
Real-Time Coding	Hong Yee Cheah
Analog Design	Daniel Bruce
Mechanical Design and Assembly	Moongyu Kang

References

[1] EM3, “Lithium-ion Battery DATA SHEET” LIR18650 Datasheet, Sep. 2014

[2] C. Gonzalez, “What's the Difference between AC, DC, and EC Motors?,” machinedesign.com,Feb. 26, 2018. [Online]. Available: https://www.machinedesign.com/motion-control/what-s-difference-between-ac-dc-and-ec-motors [Accessed: Nov. 18, 2019]

[3] A. Gurung and Q. Qiao, “Solar Charging Batteries: Advances, Challenges, and Opportunities,” Joule, vol. 2, no. 7, July, 2018. [Online serial]. Available: https://www.sciencedirect.com/science/article/pii/S2542435118301430. [Accessed: Sep. 19, 2019].

[4] “Wiring Diagram of Solar Panel with Battery, Inverter, Charge controller and Loads.,” *ETechnoG*. [Online]. Available: https://www.etechnog.com/2019/01/wiring-diagram-of-solar-panel.html. [Accessed: Nov. 18, 2019].

[5] “Hoosier Road Race Kart Tires 22371R60A,” *Summit Racing Equipment*. [Online]. Available: https://www.summitracing.com/parts/HOO-22371R60A?seid=srese1&gclid=Cj0KCQiAn8nuBRCzARIsAJcdIfNdbdIRfaxczremyVQcS7y4W2cLdYFU7cXE6l4FvLfOJh46kT6qVi8aAgQYEALw_wcB. [Accessed: Nov. 18, 2019].

[6] G. Potts, “The Lightyear One is a long-range solar-powered EV,” Top Gear, Jun. 26, 2019. [Online]. Available: https://www.topgear.com/car-news/electric/lightyear-one-long-range-solar-powered-ev. [Accessed: Nov. 18, 2019].

[7] “Coleman Powersports Go Kart 196cc/6.5HP Coleman KT196 Gas Powered Off Road“, *Amazon*. [Online]. Available: https://www.amazon.com/Coleman-Powersports-196cc-KT196-Powered/dp/B01LB4ZKQ2/ref=sr_1_3?keywords=go+kart&qid=1574089572&sr=8-3. [Accessed: Nov. 18, 2019].

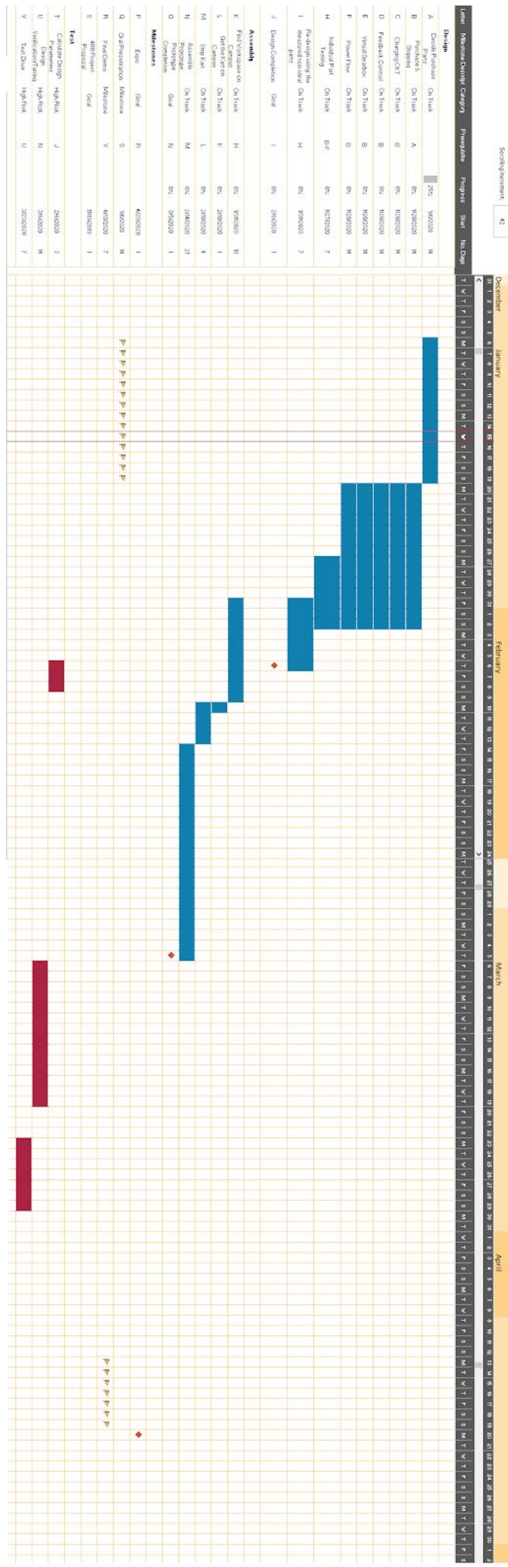
[8] “Tesla Model S Lithium Ion Battery 18650 EV Module - 22.8 Volt, 5.3 kWh,” EV West - Electric Vehicle Parts, Components, EVSE Charging Stations, Electric Car Conversion Kits, Feb. 24, 2017 [Online]. Available: https://www.evwest.com/catalog/product_info.php?products_id=463&osCsid=rp0cj2i33tp2j88tnj80dto4e5. [Accessed: Nov. 18, 2019].

[9] “WindyNation 100-Watt Bendable Flexible Thin Lightweight Monocrystalline Solar Panels (2-Pack),” The Home Depot. [Online]. Available: https://www.homedepot.com/p/WindyNation-100-Watt-Bendable-Flexible-Thin-Lightweight-Monocrystalline-Solar-Panels-2-Pack-SOL-100FV-02/307339623. [Accessed: 18-Nov-2019].

[10] “Electric Dc Motor 24v 4kw 3100Rpm,” Alibaba. [Online]. Available: https://www.alibaba.com/product-detail/Electric-Dc-Motor-24v-4kw-3100Rpm_60817220057.html?src=sem_ggl&mark=shopping&cmpgn=1666259716&adgrp=66971409960&locintrst=&locphyscl=1015254&ntwrk=g&device=c&dvcmdl=&position=1o2&pla_adtype=pla&pla_mrctid=140283378&pla_channel=online&pla_prdid=60817220057&pla_country=US&pla_lang=en&pla_group=293946777986&pla_localcode=&gclid=Cj0KCQiAtrnuBRDXARIsABiN-7C8lPhxTP3S4O5fa9S8Kfq-zz8r75fN7H3nBC5at0lhaEYrLn2YX3QaAlh1EALw_wcB#shopping-ads. [Accessed: 18-Nov-2019].

[11] “Hourly wage for Electrical Engineer I in the United States,” Salary.com. [Online]. Available: https://www.salary.com/research/salary/benchmark/electrical-engineer-i-hourly-wages. [Accessed: 18-Nov-2019].

Appendix A - Project Gantt Chart



Appendix B - PROJECT PERT CHART