Solar Powered Electric Bicycle

A senior project by Joe Debruynkops

Purpose:
The purpose of my project is to create a solar powered vehicle that is useful for college students.

Introduction

The fields of research for my major are Photovoltaic Technologies (solar power) and Geography. For my senior project I have focused mostly on the photovoltaic side of things, but geography still applies as well. Solar technology has been rapidly developing in recent years, with prices of solar panels and related parts quickly dropping in price. This has helped solar power expand more than expected and made it more affordable for everybody. Despite these recent changes in solar technology, it is still mostly used for a few different purposes, specifically residential, commercial, and utility-scale solar arrays and farms. In my opinion, the innovation regarding uses for solar panels has lagged behind the innovation to make the panels themselves cheap and ubiquitous.

I believe that there are a lot of recently created opportunities to create innovative solutions using solar panels. This is what led me to the idea of a solar powered electric bike. Electric bikes are one of my favorite types of vehicles because they are relatively fast, relatively cheap, and easy to park. I currently ride an electric bike to school every day, but one issue I have with it is that I have to plug it into a wall outlet to charge. Not only is this slightly costly, but also the majority of the electricity that I use to charge comes from nonrenewable sources. I thought that because an electric bike doesn't use a whole lot of energy and I ride it around in the sun a lot, that it would be a good idea to charge it with solar panels rather than grid energy.

But, the motivation to create a solar powered electric bike isn't just based on technology. Everybody needs transportation of some type or another, but I think there is a transportation niche that has not been filled yet that a solar powered electric bike would occupy. For most college students, people choose to either drive a car, ride a bike, walk, or take public transit. Cars are pretty convenient, but they come at very high costs individually and to the environment so they are not affordable for most students. Bikes are great too, but they can require excessive physical effort to operate, especially if you are carrying cargo.

So what is the solution? This is what I set out to discover on the journey of completing my senior project. Through the process of 4 different user surveys, multiple digital designs, and two real world designs, I was able to learn what factors are important to college students when considering transportation. Based on my initial research, I thought that a trailer based solar powered electric bike design would be optimal. After constructing it and receiving feedback, it became clear that there was room to improve the design. This was when I decided to iterate and build the solar powered electric bike 2.0. Throughout the following sections I will switch back and forth between referencing **Solar Bike 1.0** and **Solar Bike 2.0** to give readers a feel for my process.

Application/Product

Here's the basic premise: You enjoy the transportation benefits of an electric bicycle while also never having to charge it.

I'll outline how a typical day using the vehicle would go:

Solar Bike 1.0:
You would ride the solar powered electric bike to school in the morning and park it in a bike rack for your first class. Before you leave the bike you would quickly fold up the side panels so they face directly up to the sky. While you're in class the bike would fully charge itself and would be ready to ride 15+ more miles to wherever you want to go. Because you have this luxury maybe you decide to ride to the grocery store to do your shopping for the week. As you're riding to the grocery store you are charging the battery additionally at about 50W - 100W which powers you further than you would normally be able to go. After you're done grocery shopping you Simply put all your groceries in the bikes storage area and head on home. You park your bike in a sunny spot and let it charge up in the afternoon hours so it's ready to go again in the morning!

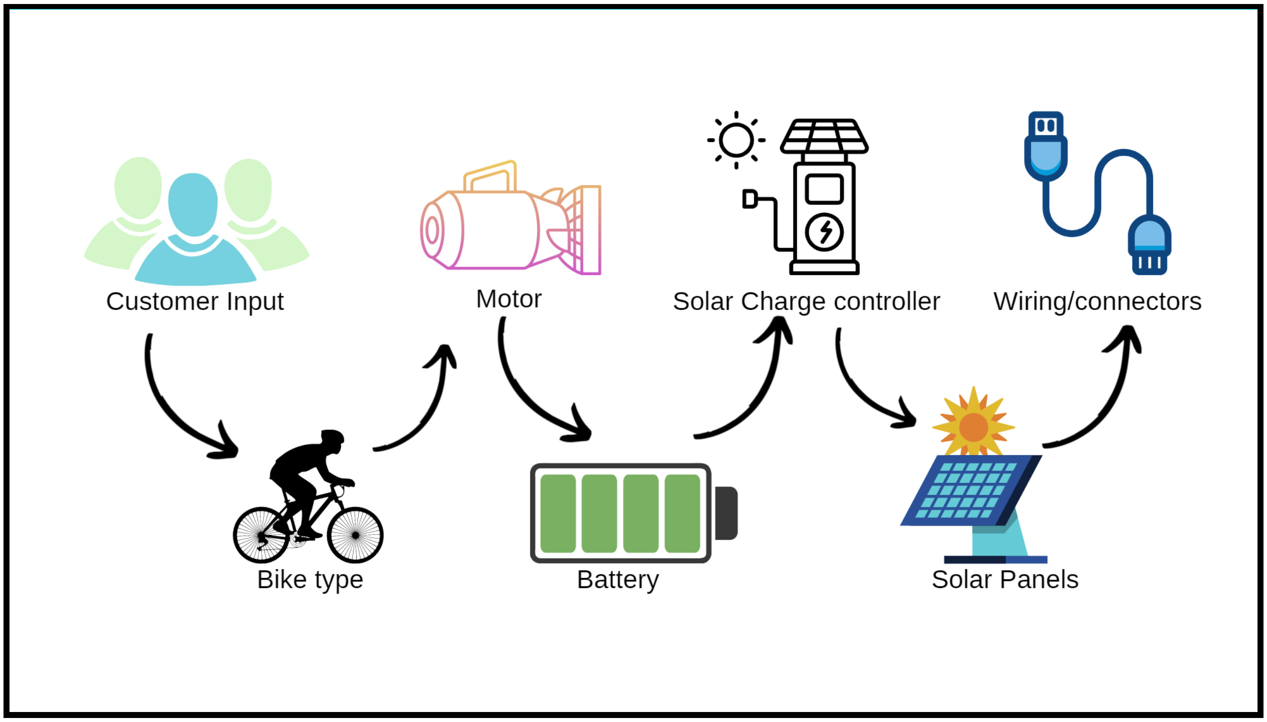
Solar Bike 2.0:
Riding solar bike 2.0 has almost all of the benefits of the first version, but without many of the downsides. First of all, you don't have to worry about folding the two side panels up to the sky In order for it to have maximum charging because it only has one panel. Second, it is much more easy to maneuver and comfortable to ride. This is because you don't have a trailer behind you rattling around. Lastly, the one downside of this version is that you have less storage space than the previous version.

Background

Factors to consider when building a solar powered e-bike:

Overview:
A solar-powered electric bike is essentially a normal electric bike that is modified to be able to be charged by solar panels. When designing a solar-powered electric bike it is important to consider many factors both in the physical design and electrical design.

Electrical Design (Same for both versions):
Basic Conceptual Design Process: (Start with customer input, end with wire sizing)

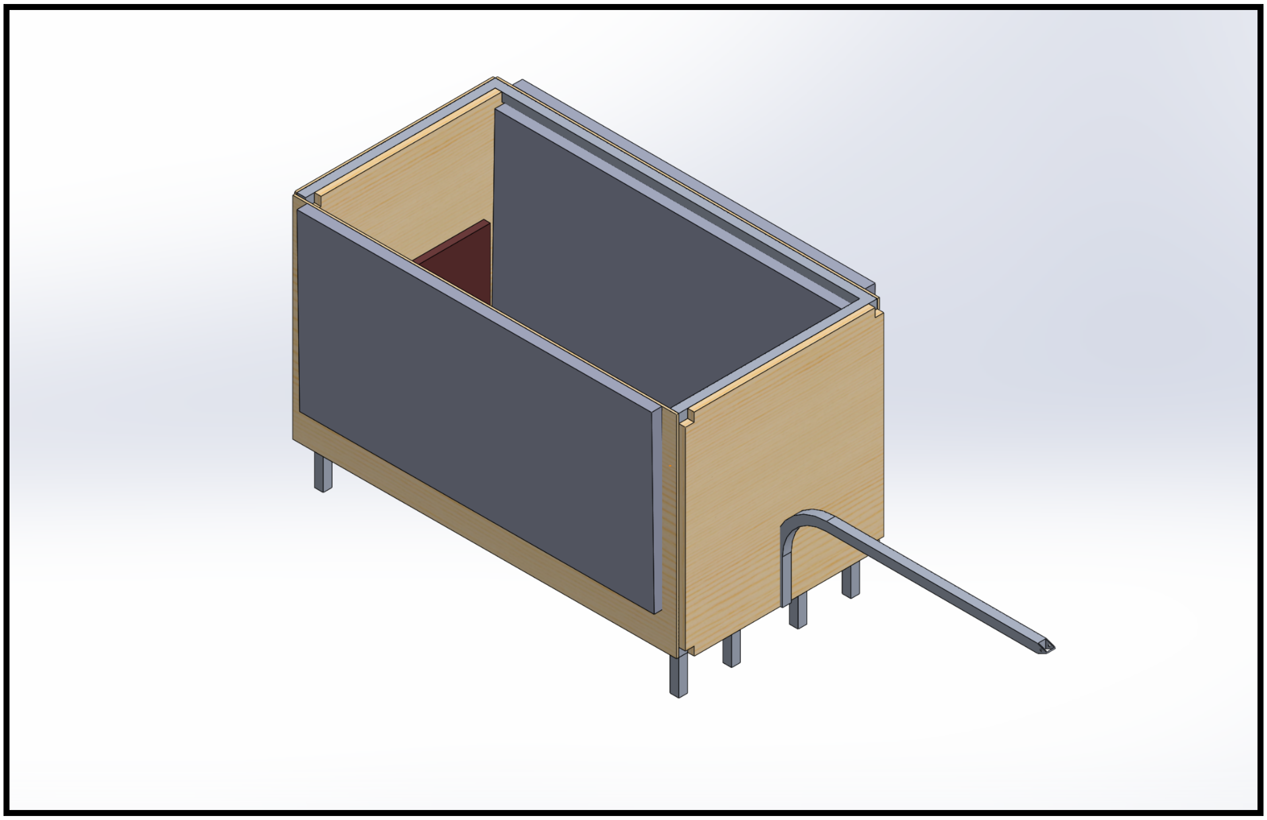


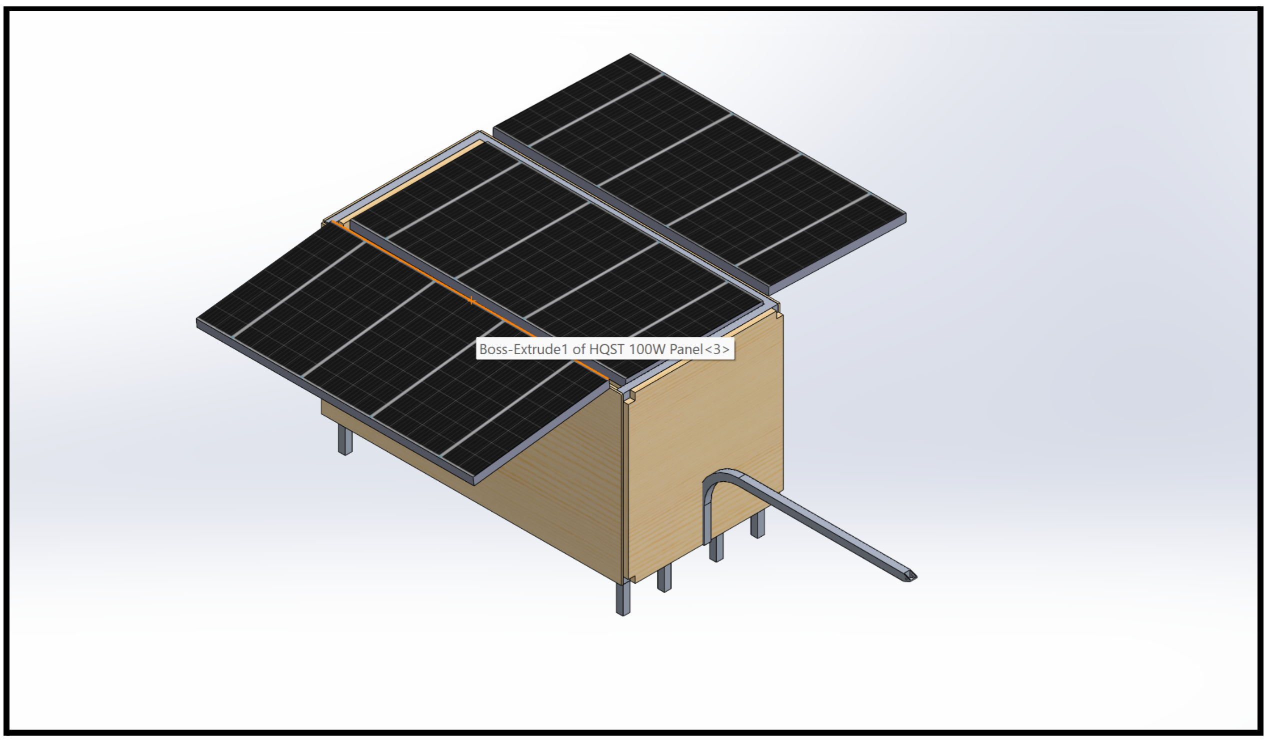
- In reality the process is more complicated than that
- It is important to get customer feedback at multiple steps along the way
- It's not easy to find the exact part that you want, and often building your own component is not an option. Take the solar charge controller for example, there are limited options that would work well for a bike application and are reasonably priced. Given this, I had to make sure my battery would be able to accept the output voltage, even though this represents going backwards in the flow chart.
- It is also important to consider the physical dimensions of components, especially the solar panels, battery and motor.

  Physical Design:

Solar Bike 1.0:

- I created two different designs, the first was a trailer that held the solar panels that was towed behind the electric bike. The second was a canopy of solar panels above the riders head.
- After getting customer feedback and considering the physics of the two designs I decided to go with the solar powered trailer because it would be safer, and able to carry more cargo.
- The width of the bike overall is very important because bike lanes are usually not super wide. Designated bike lanes along streets are usually 6 ft across (I measured them), but other bike lanes such as the one going out to Los Osos are much narrower, about 3 ft across. Because of this I knew my design must be less than 3 feet in width.

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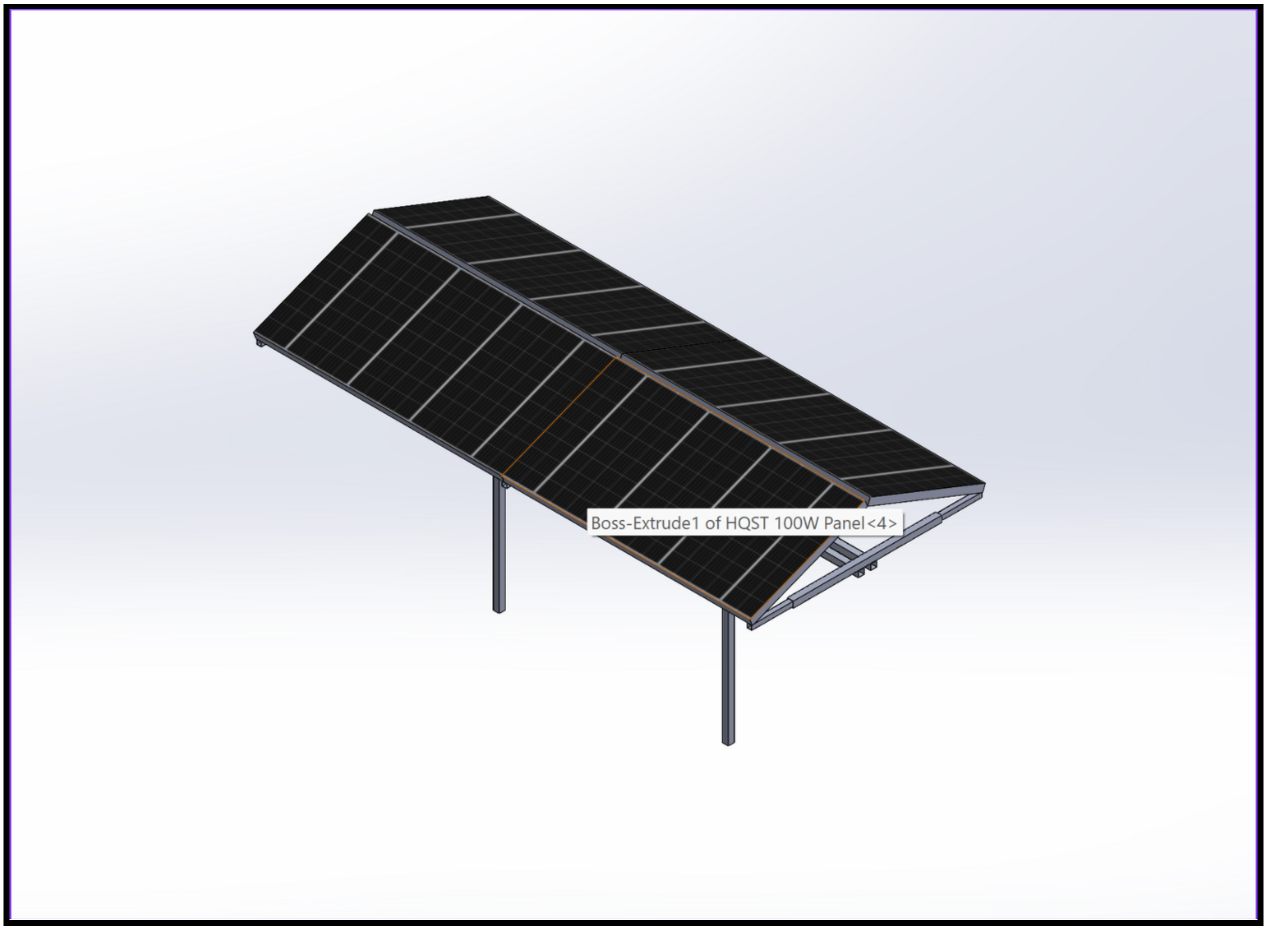
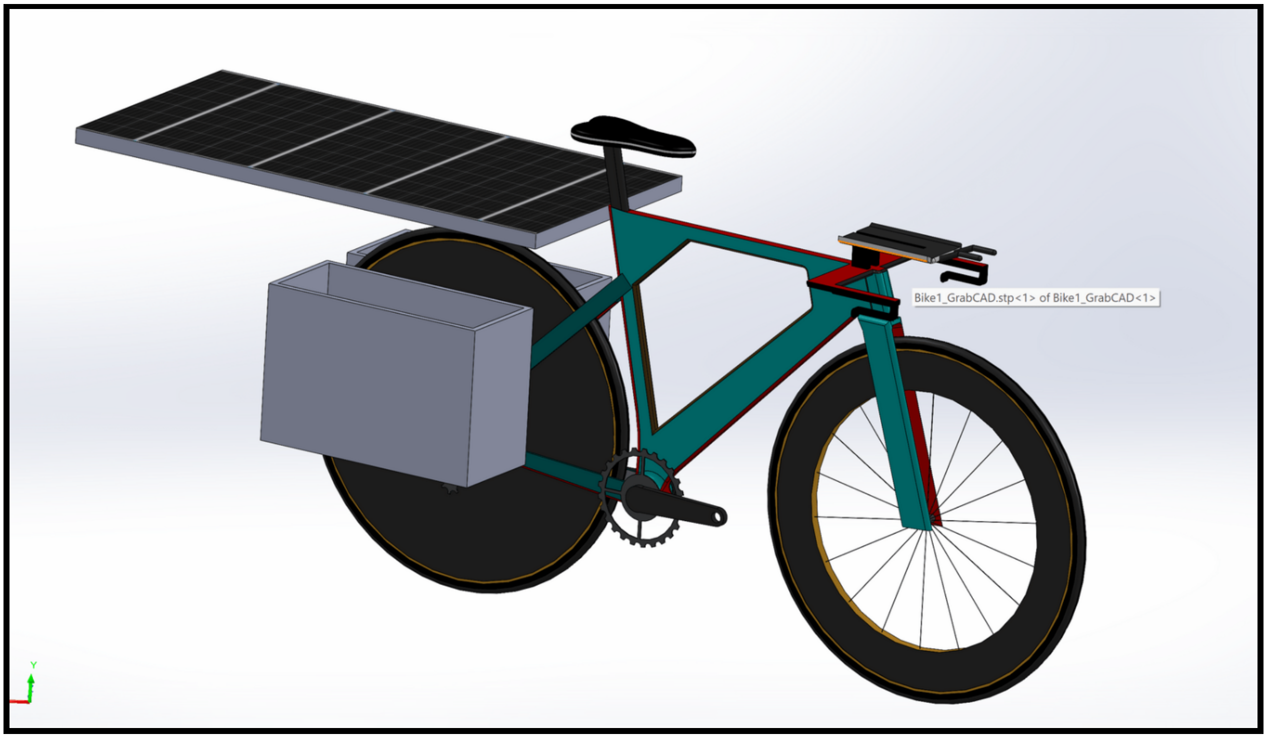


Solar Bike 2.0:

- I created this design after recieving feedback on the first version.
- It is much simpler, cheaper and easier to build
- There is only one solar panel, and no moving parts aside from normal parts of a bike that move.
- The solar panel can be easily attached to a rear rack on any bike using square aluminum tubing and zipties
- Milk crate panniers can be attached to the sides of the rear rack using simple carabiners.



Other Factors:

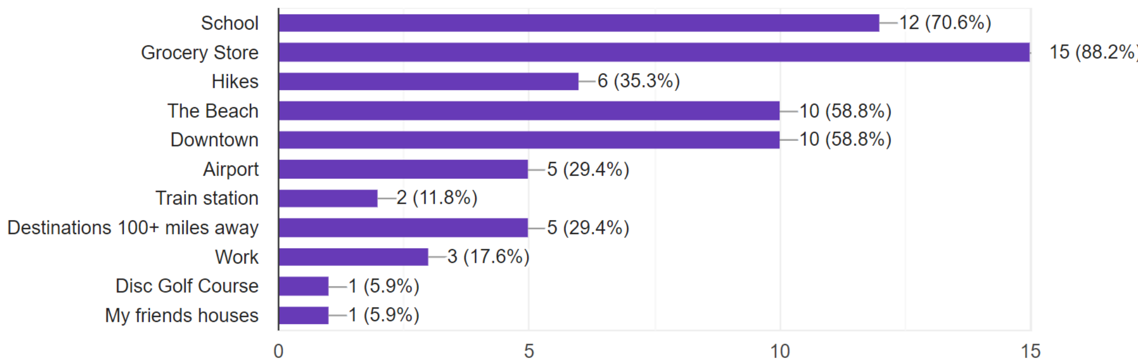
- Usage
    - How far does the rider need to go? This would determine how large of a battery pack is needed.
    - What times of day are they riding? This would also change battery pack size.
- Location (latitude, time of year)
    - Users at higher latitudes would possibly need a design with more panels

Design

I started my design with getting input from my customers, college students. I created a survey that was designed to get the most information from respondents about things that were important. The goal was to find what people wanted the end result to be like and then work backwards to create my design from there. Here are some screenshots from my survey:

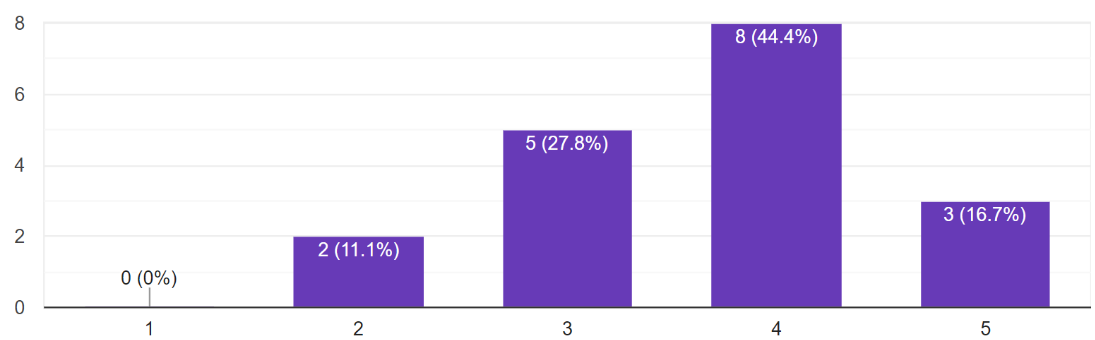
What places do you FREQUENTLY need/want transportation to? (please add others if they are not listed)

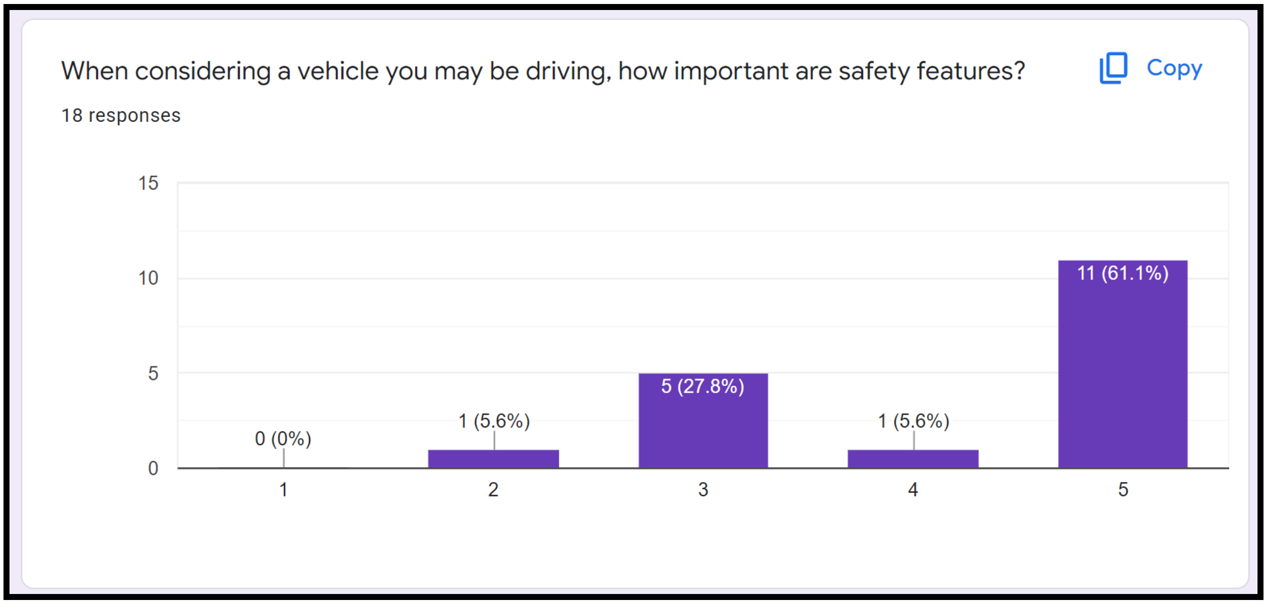
17 responses



How important is it that your vehicle is low cost?

18 responses





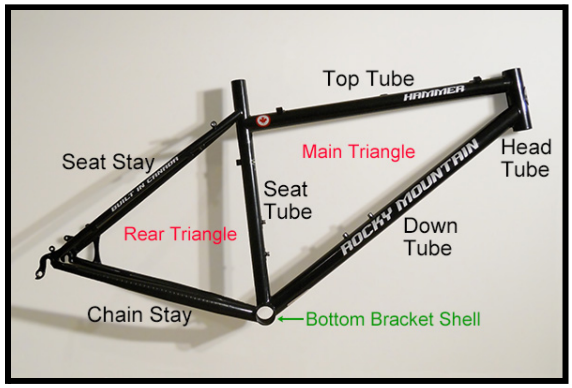
I asked a series of qualitative questions to capture people's desires for their vehicles, such as: “Imagine you could only have one vehicle (a bike is considered a vehicle). What would it look like? How many people would it be able to hold? What items would it be able to transport? How fast would it be able to go? Be as specific as possible.” and “What features would you like in an electric-bicycle type of vehicle to have? List as many as you can (e.g. safety, locking, pedal assist, etc.)” Here are some of the answers I recieved:

- Is able to be parked and lock automatically
- Comfy seat
- Built in basket
- Cup Holder
- To travel to school and the grocery store primarily
- Low cost is very important
- Safety features are very important
- Most people want a bike rather than a trike or surrey
- Want vehicle to hold 4-5 people + cargo
- Desire highway speeds >30mph
- Weather protection
- Simple and minimalistic
- Modularity
- Pedal assist
- Brakes
- Lights
- Saddle bags/Storage
- Speedometer
- Side mirrors
- Comfy seat
- A bell

- Shade
- Regen braking
- Cool Color (retro vibe)
- Bluetooth (for music)
- Convenience
- Tracking in case it got stolen
- 8-10 speed

Solar Bike 1.0:

Bike choice: Safety, price, and comfort were all important criteria of the respondents of my survey. I set off for Craigslist to find a bike that met these criteria. Based on the criteria, I was looking for something durable (steel frame) and had wide knobby tires, for good traction when braking and accelerating. Lastly, I aimed to find a bike that had a large "Main Triangle" for Battery Storage.



Motor Choice:
The two main types of electric bicycle motors are hub drive and mid drive:

Here is a table showing their pros and cons:

	Pros	Cons
Hub drive	- Very easy to install - Inexpensive	- Low torque - Basically "stuck in 3rd gear"
Mid-drive	- High torque (high acceleration)	- Slightly more expensive - Must take careful

	- Uses bike gears like a car transmission	measurements to install

From my customer input, I knew that people wanted to go fast (30+ mph). With a hub motor, your speed maxes out at about 20-22mph. With a mid-drive, you have much higher max speeds due to the bike gearing (30+ mph) and you have 3x higher torque which allows you to accelerate 3 times as fast.

The last thing to decide was the power of the motor, usually measured in watts. Because people wanted to go very fast, I knew I wanted to maximize the power, but I also had to consider California regulations. Here is an overview of small vehicle license requirements from the dmv:

TYPE OF VEHICLE	CALIFORNIA VEHICLE CODE SECTIONS (§§)	TYPE OF LICENSE	VEHICLE DEFINITION	EXAMPLE
Motorcycle	400, 12804.9(b)(4)	M1	A motorcycle is a motor vehicle with a seat or saddle for the rider and is designed to travel on not more than three wheels.	
Motor-driven cycle	405, 12804.9(b)(4)	M1*	A motor-driven cycle is a motorcycle with 149 cc or less motor size*. A motor-driven cycle does not include motorized bicycle.	
Motorized bicycle or moped (capable of no more than 30 mph)	406(a), 12804.9(b)(5)(A)(i)	Any class of license **	A two- or three-wheeled device, capable of no more than 30 mph on level ground, and equipped with fully operative pedals for human propulsion or having no pedals if powered solely by electrical energy, a motor producing less than four gross brake horsepower, and an automatic transmission.	
Electric bicycle	312.5(a), 12804.9(b)(5)(A)(i)	Not required	A bicycle equipped with fully operable pedals and an electric motor of less than 750 watts. There are three electric bicycle classes: Class 1 and 2 are capable of speeds of no more than 20 mph. Class 3 is capable of speeds of no more than 28 mph.	
Motorized scooter **Note**: Cannot be used for a skills test.	407.5, 12804.9(b)	Any class of license ***	A motorized scooter is defined as any two-wheeled device with an electric motor, handlebars, a floorboard for standing on when riding, and the option of having a driver seat which cannot interfere with the operator's ability to stand and ride and/or the ability to be powered by human propulsion.	

I wanted the vehicle to be classified as an electric bike because it is the only one that doesn't require a license and registration and will therefore be most cost effective and accessible to all college students. The downside of this is that the power is limited to 750W so speeds above 40mph are pretty much out of the question.

After considering all the points above, I decided on the "BAFANG 750W BBS02 MID DRIVE EBIKE MOTOR KIT" because it fit my requirements and was on sale.

Battery Choice:

Battery Choice is one of the most important factors to consider because it determines the range and it can also be most expensive. The factors to consider for battery compatibility are voltage, maximum current draw, and capacity. The voltage is important because it must match the motor's voltage which in my case was either 48 or 52 V. The maximum current draw is important because when the bike is operating at full power it will pull about 15 amps and the batteries need to be able to safely supply that current. Finally, the capacity is important to measure the range. Capacity is measured in Wh. Watts are a unit of power (energy/second) so when you multiply by time it gives you a unit of energy. Initially, I was thinking of building my own battery out of individual 18650 cells. I read a short book on doing it, but then decided that it was probably more trouble than it was worth for this project. I ended up buying 2 second hand batteries for a reasonable price and attaching them in parallel to provide about 600 Wh for the bike which should take it about 15 miles on a full charge. The batteries I purchased were used “LG-HB2 Battery Li-Ion 51v 6Ah”.

Solar Charge Controller:
There are two common types of solar charge controllers Maximum Power Point Tracking (MPPT) and Pulse-width modulation (PWM). MPPT trackers are much higher quality and provide better results compared to pulse-width modulation, which is generally only used for very cheap and low power applications. The charge controller is the interface between the power that the solar panels provide and the batteries. I needed to find one that was reasonably priced, that would fit on a bike, and would interface reasonably with both the solar panels and the batteries. Also, the voltage that the panels output is much less than the voltage that battery requires. In order to step up the voltage for a DC system, you need something called a buck converter. Luckily I was able to find a mppt solar charge controller with a built-in Buck converter for a reasonable price. I ended up going with the ELEJOY EL-MU400SP.

Solar Panels:
The main factors to consider when buying solar panels are the power output (watts), weight, and physical dimensions. My goal was to Produce as much power as possible. Initially, I wanted to have 400W so that the bike could be powered continuously by the sun, but I ended up with 300W. I used one rigid panel that weighed 15 lb, and two flexible panels that weighed 4 lb. I made these design choices so the forces on the trailer wouldn't be excessive. The panels I used were 100 watts each because this size of panel is much more manageable for something that needs to be narrow such as a bicycle. I had the option between Square panels and more elongated rectangular panels. I chose the elongated rectangular panels (40 in x 20 in) because they were better for a more narrow bike trailer.

Wiring:
After I figured out all components of my system, I then decided which gauge of wiring I was going to use based on the calculated current flowing through different wires. After calculating current you can use a wire sizing chart (such as this one: https://www.bluesea.com/resources/1437) to find the correct gauge. This is an important aspect to consider because if you use wire that is too thin it can become overheated, cause excessive resistance (and therefore voltage drop), and even cause a fire. I ended up using 12 gauge wire for all connections.

Solar Bike 2.0:

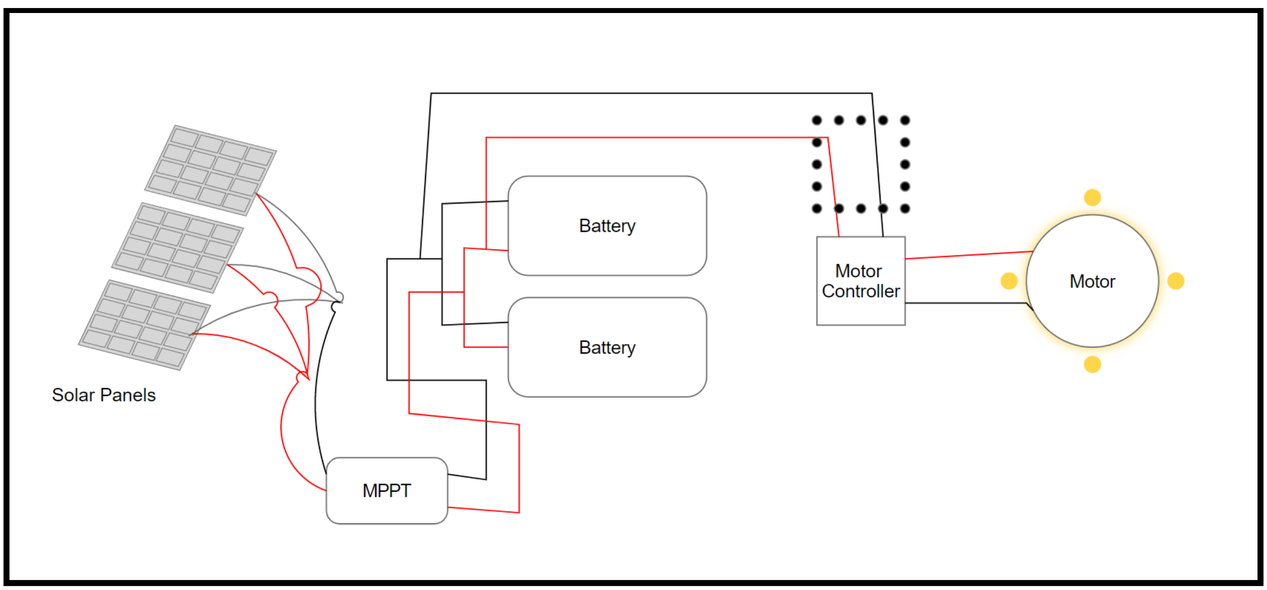
Bike choice:
I was able to an existing electric bike that had no batteries and also needed some work for $40 at the local Bike Kitchen. This was an unusually good deal. Because the bike had most of the

parts already in place, I did not have to make as many selections as first bike. This bike already had a hub motor, motor controller, and throttle.
Batteries:
I used 3 36V batteries connected in parallel. They were used scooter batteries. I had to use 36 volt batteries because that is what the motor and motor controller could accept.

Other parts:
I ended up 3 using the solar charge controller and the solar panel from the other bike. The wiring was very similar to the wiring for the Solar bike 1.0.

Implementation

Electrical implementation for both bikes:



Basic rules for designing your own system:

- If you have multiple panels, connect them in parallel so that if one panel is shaded, you don't lose a majority of your power output
- Connect the mppt output, the batteries, and the motor controller input all at one node.
- Make sure you double-check that all components will work together with the expected voltages and amperages

Physical implementation:
Solar Bike 1.0:

Installing the mid drive motor

Installing battery/electrical system into the battery compartment.

Mounting the plywood walls

The finished product!

Solar Bike 2.0:

I didn't take any pictures of the construction.

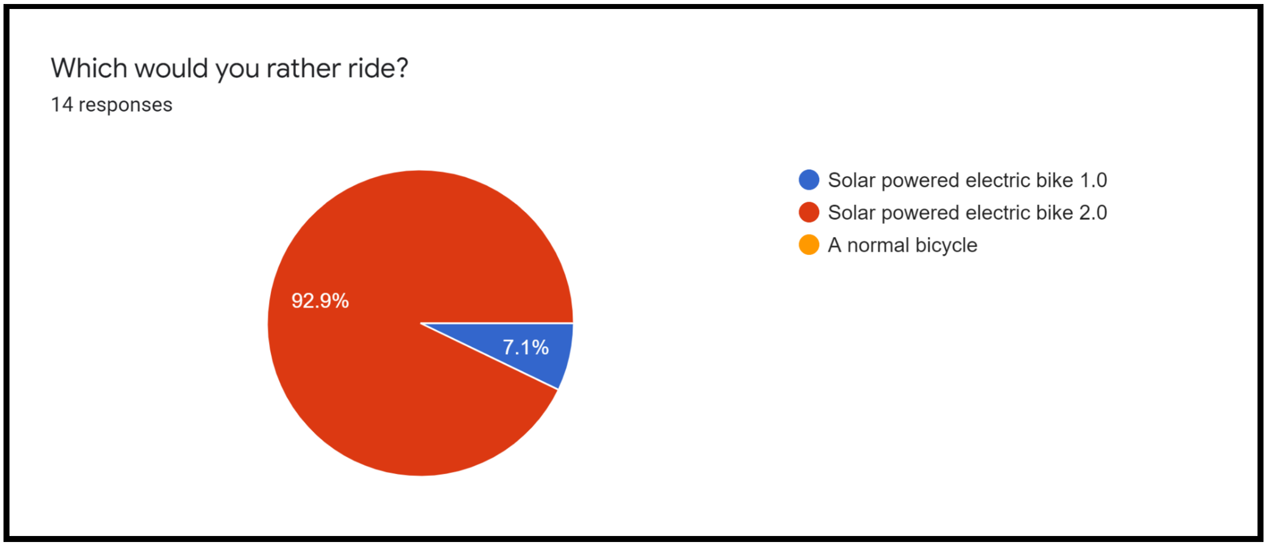
The finished product!

Analysis / Verification

Customer feedback:
Throughout the course of my project I created and received feedback on four different surveys. These surveys were distributed as widely as possible, but generally I got about 10 to 30 responses per survey. These surveys provided me with valuable information regarding what my user's wanted, and what changes they wanted to see in my design. The main purpose of each of my surveys are as follows:

1. Discover the transportation needs of college students. Link: https://forms.gle/C5RB8yYmUGtgJiCa9
2. Discover which of my two designs for solar bike 1.0 were better. Link: https://forms.gle/xyS8PHdc8a8daCD56
3. Discover what people thought of my completed solar bike 1.0. Link: https://forms.gle/sMrxW5sSjzcb6kSm9
4. Discover what people thought of my completed solar by 2.0. Link: https://forms.gle/zXPS2QVf1UQzBVSRA

My final survey confirmed the improvement of my design from version 1 to version 2:



Over 90% of people preferred the solar ebike 2.0. This confirmed to me that I had done valuable work.

Outside reviewer:
I had a meeting with my outside reviewer, Dr. Doug Hall, regarding the solar bike 1.0 design. He is an expert in photovoltaics, and electrical engineering. He was delighted by the design and verified that my electrical system made sense.

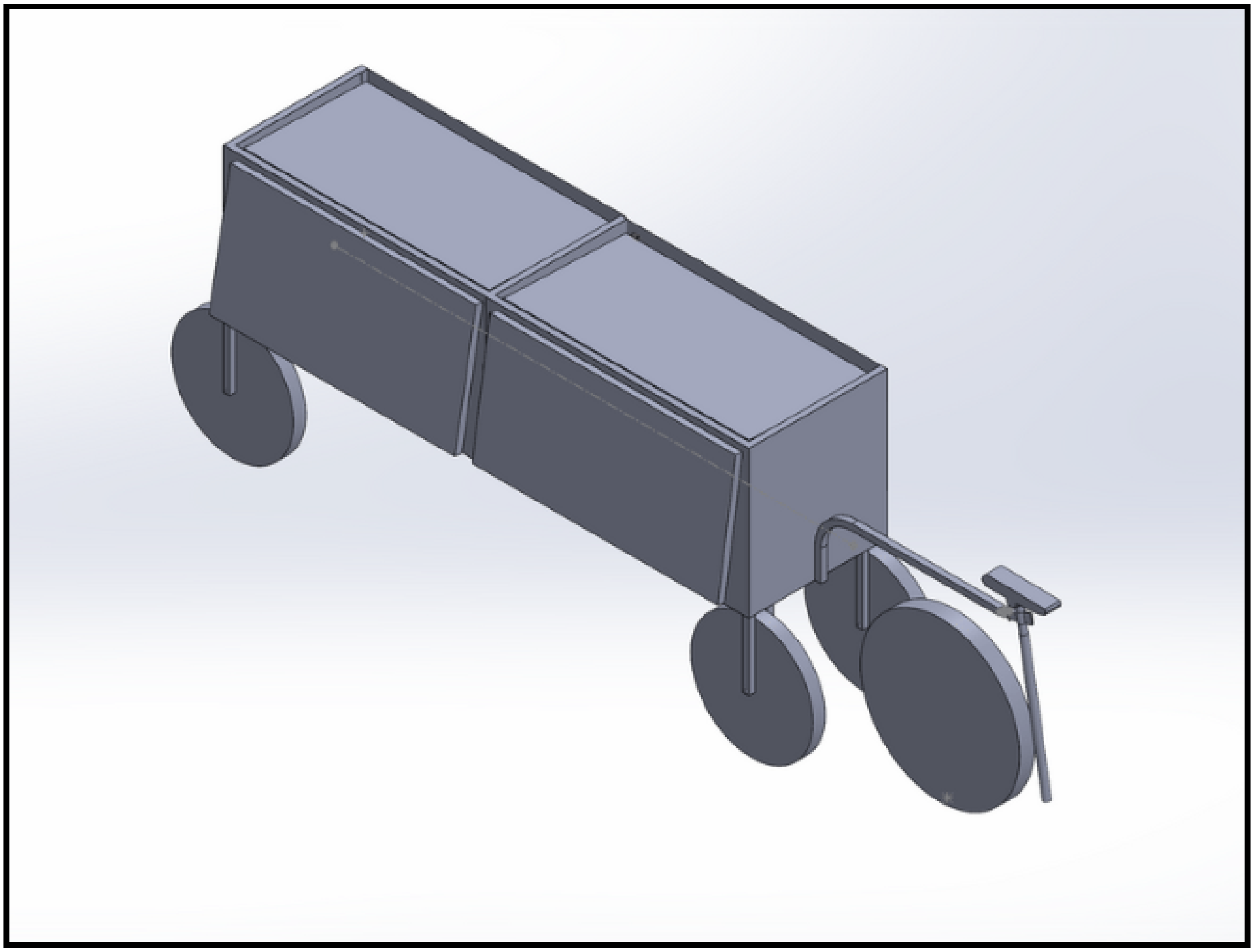
Connections

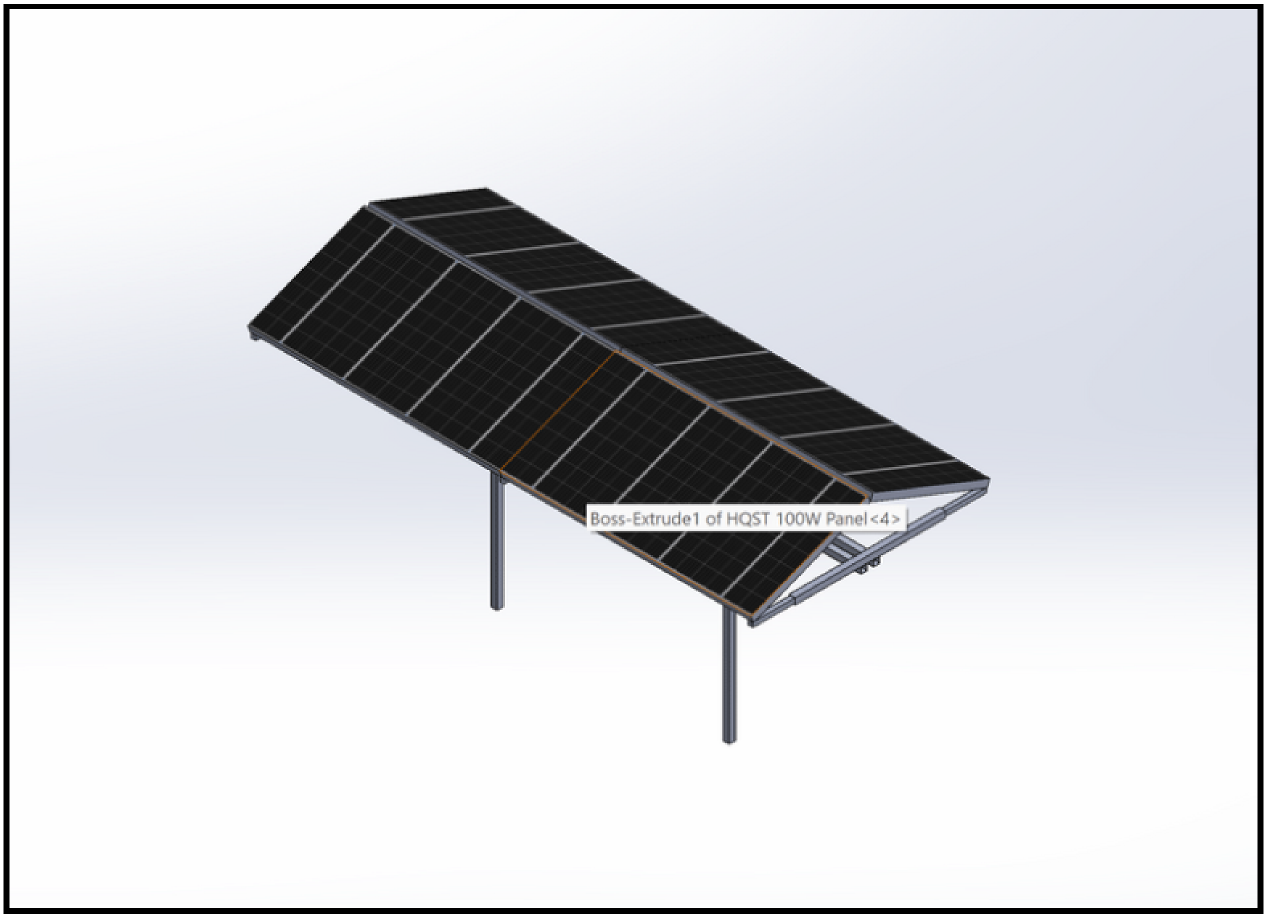
My area of study for my liberal arts concentration is Geography. My area of study for my engineering concentration is Photovoltaic Engineering (Solar Power). Although this project may seem very engineering focused, I think there is actually quite a bit of intersection with my liberal arts studies. In my geography classes we learn a lot about weather systems and the physical processes that happen on Earth, including the celestial geometry that leads to solar insolation in the first place. My understanding of how the position of the sun moves on a day-to-day basis and throughout the year was vital in the design of my project.

Additionally, I learned a lot about the importance of customer focused design in my LAES classes. I have tried to follow this method throughout my project by continuously going back to customers to get their input on different design choices. I think this has resulted in a better product.

Engineering

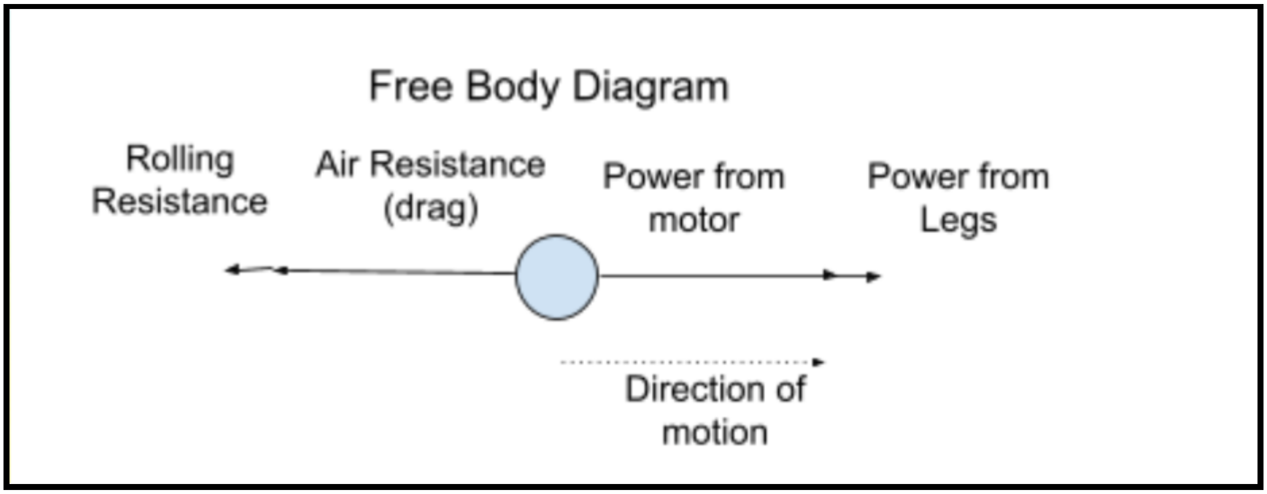
Technical:
3D modeling:
I used SolidWorks extensively in order to design my various iterations.

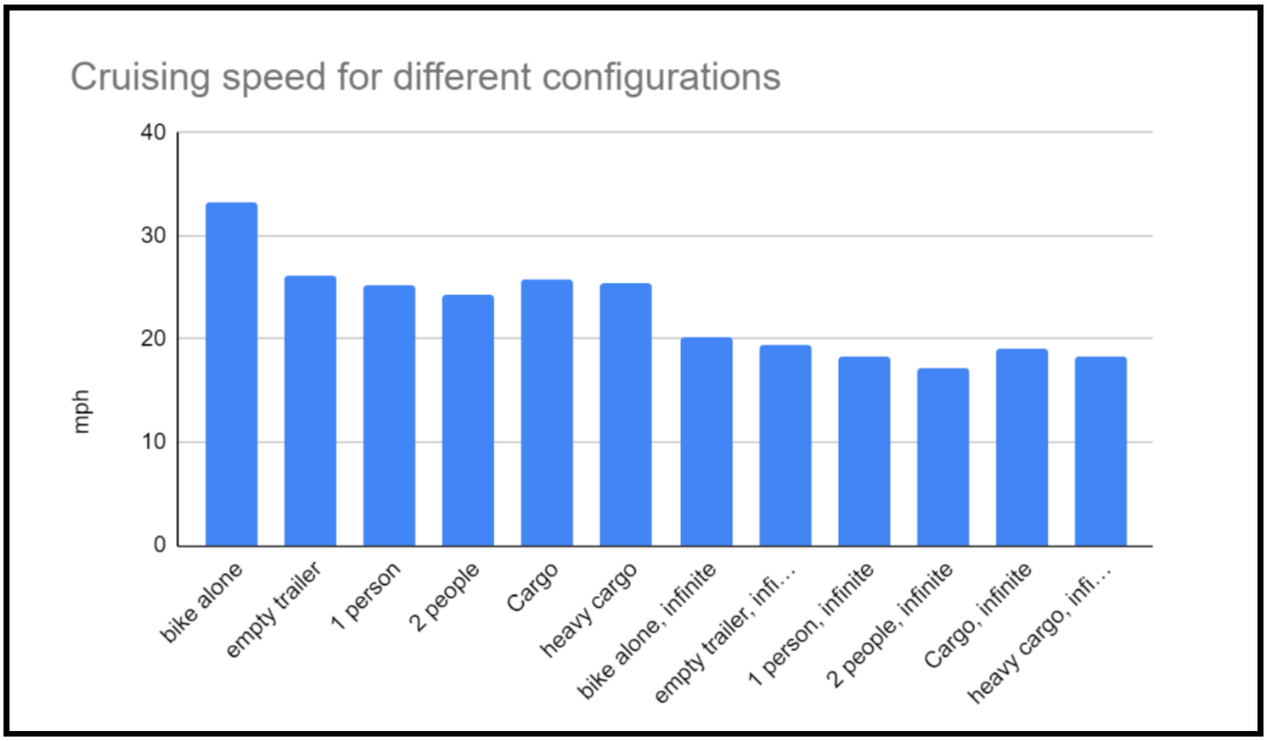




Performance Analysis:

- I used physics principles, equations for power, drag, and rolling resistance to calculate cruising speed
- The bike will go at least 17 mph even with 2 passengers
- The solar bike 1.0 can cruise at ~20 mph infinitely during the peak hours of the day





Humanistic Problem Solving:

- We all need transportation and we use <u>many different vehicles</u> depending on our situation
- What if there was a vehicle that could maximize the benefits of the different vehicles we use while minimizing the costs?
- **What if there was an affordable and sustainable vehicle that could do it all?** The engineering work that I did was driven by the need to solve this problem.

Related Work

I got a lot of inspiration for my project from various people who have done similar things and made videos about their creations on YouTube. Here are some links of videos that were particularly inspiring:

- Solar trailer inspiration:

https://www.youtube.com/watch?v=z0AG6oD6iqU&ab_channel=ExplorationBrothers

- My design differs because I used panels that fold out. Additionally, I have a different design for the trailer.

- Infinitely Powered solar E-bike

https://www.youtube.com/watch?v=7EyRqQhuwio&ab_channel=PeterSripol

- My design is very different than this, This would not be practical in real life.

- Primer on Solar Ebike Systems

https://www.youtube.com/watch?v=14yliWIykfg&t=437s&ab_channel=GrinTechnologies

- Informational

- Building a Solar Powered tricycle

https://www.youtube.com/watch?v=Ji3v9UKhvt8&ab_channel=TheRamblingShepherd

- I built a bike, rather than a tricycle. Nevertheless, this is a cool design.

Solar Bike 1.0:
My design utilizes a trailer on the back of the bike in order to hold the solar panels. This is similar to other designs, but mine is definitely unique, because it's based on the wants of college students. One feature that I have that I have not seen anywhere else is the ability to fold up the panels and have a human being able to sit in the back of the trailer.

Solar Bike 2.0:
Solar bike 2.0 is unique because it is incredibly simple and easy to build. There are very few parts that you need, and everything could be constructed using basic tools.

Future Work

Overview:
I was able to complete everything that I set out to complete. If I had more time and money, I would probably create a more technical design that is integrated with the bike frame and also try to meet more of the customer requests. For example, it would be possible to integrate solar cells into the frame of the bike itself, so that you would be harvesting solar energy without having a cumbersome solar panel on your bike. Aside from this, I feel like I was able to achieve what I set out to do and feel satisfied with my project.

Make a repeatable design:
If solar bicycles were to become a mainstream technology, or if someone wanted to start a business building them, they would need a systematic and repeatable method. Because I was focusing on iteration, I did not do this, but it would be a valuable thing to do.

Solar Powered Velomobile:
In my research, I discovered a vehicle called a velomobile. A velomobile is essentially a recumbent trike with a lightweight shell that increases aerodynamic efficiency. In doing my performance calculations, I realized how important aerodynamics are. When going 20 miles per hour, most of the energy you're producing is used to combat air resistance. Here is an example of a solar powered velomobile:

Conclusion

The initial question I set out to answer at the beginning was,"What if there was an affordable and sustainable vehicle that could do it all?" In retrospect, this was a very ambitious goal. This is essentially the question that vehicle makers have been trying answer for decades. My first design, Solar bike 1.0, had the potential to meet more customer needs but was inadequate because it was difficult to maneuver. Basically, by trying to make a vehicle that was capable of long-distance travel (100 miles+), I created a vehicle that was poorly suited for daily riding, which is most of the riding my users would be engaging in. This inspired me to create

Solar bike 2.0 which meets most of the day to day needs of users and is enjoyable/ easy to ride, but is incapable of long-distance travel. This is a major downside, but ideally a user could meet their longer distance transportation needs using public transportation. Although, I wasn't able to create a vehicle that could truly do it all, I still feel satisfied about my contribution to solar bike research design and implementation. In the end, I was able to build a bike that was cost-effective, easy to ride, and (most importantly) desired by my users. I am grateful that I was able to work on a project I was so passionate about, and learn so much along the way.