Team Name: Zero

Solar Folder Capstone Final Report

ME 4723 Section A, ECE 4723 Section A

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Executive Summary

The consumer market for distributed solar is full of gaps which are created by three main problems. First, there is a large upfront cost for a system that produces sufficient power (i.e., more than would charge a cell phone or laptop): $20,000-$30,000 for a basic rooftop solar array. Second, homeowners are unable to install solar panels on their own because it requires specialized knowledge and training. Third, not all roofs are suited for solar power capture, often due to a small roof area or shade from foliage.

The proposed product will fill the gap between solar panel arrays costing tens of thousands of dollars that power a home, and portable panels costing a hundred dollars that can only charge a phone. Technical issues include producing enough power without excessive costs and weight, maximizing solar capture in small areas, designing a solar panel mount that is easy to install, and providing consistent power output for devices.

Significant research into initial designs ensured fewer costs as the product is developed. Market research included prior art and patent reviews, US consumer data analysis, and potential customer surveys. Ideation includes the 6-3-5 method and morphological charts. Quantitative design constraints were evaluated using a specification sheet, house of quality, function tree, and evaluation matrix.

The final design is a durable device that delivers energy at a reasonable price and follows many customer preferences for ease of installation. Further work is required to see the product arrive at a market ready stage. The power system was not designed or created due to limited power electronics expertise and budget constraints. Aesthetics need to be modified to fit typical middle class US homeowner expectations. Weight reduction modifications are needed to improve ease of installation. Additional design analysis is required to finalize ground mount capabilities of the product. The prototype meets most requirements detailed in the specification sheet, but weight, aesthetics, and ease of installations require further market feedback to confirm whether the created prototype is sufficient. The project team has created an initial prototype that show cases the successful preliminary design of the product.

I. Introduction and Background

Using eco-friendly resources is ultimately beneficial for solving the environmental problems plaguing earth. Therefore, creating more users of renewable energy is particularly important. According to a primary research survey, more than 87 percent of North American homeowners responded that renewable energy is important or very important, and no one responded to 'not important' or 'irrelevant' in the survey. However, about 90 percent of responses of the survey do not have solar power in home, even though the commercial applications of solar energy are well-known and widely implemented. The contradictory relationship is a result of difficulty of accessibility, convenience, and efficiency including a limited angle of incidence of incoming sunlight, installation issues, and local weather conditions, such as high winds, which limit the practicality of large apertures in certain areas.

The desired design helps to resolve the problems and inefficiencies of a normal panel by adjusting its position based on the angle of the sun. Finding the angle of incidence based on the declination of the sun, time of day, and latitude, will allow to position the panels for maximum solar power capture. In addition, the desired design optimizes modularity and a non-permanent mounting system that differs from the existing fixed-roof solar panels. The design process begins with customer requirements and the creation of an HOQ, and specification sheet.

The goal of the proposed project is to eliminate the need for professional installation of these solar panels and allow for a customer to purchase and install them independently. Furthermore, the solution will allow a wider range of customers to invest in the solar energy space by reducing the footprint of the solar panels as well as the overall cost, which will allow customers to immediately begin using sustainable energy. The proposed project will include a non-permanent mounting system which allows the solar panels to be transported and also prevents damage to homes. This project will appeal to a wide variety of customers including those who wish to get started with sustainable energy but do not have sufficient financial resources, those who want a mobile source of energy, those who want to save money on their electricity bill, those who desire a backup energy source (i.e., a generator) and those with electric vehicles who would like to recharge with sustainable energy. The project will be sure to address concerns with cost, ease of installation, stability of the panels once mounted, lifecycle of the product, weather resistance, and energy production and storage. While current “generator” type emergency products exist for cases of power outages [1] and development has begun on products which reduce the footprint of solar panels [2] [3], there are no products which exist to supplement home energy in a cost effective way that address the concerns above which create a barrier to entry for those wishing to step into the sustainable energy space.

II. Existing Products, Prior Art, and Patents

The commercial applications of solar power are well-known and widely implemented. Solar panels convert energy from the sun into electricity for industrial and household consumption. The panels are made of arrays of photovoltaic cells, which have a DC output and are wired in such that they produce a desired voltage and current. Photovoltaic (PV) cells are delicate on their own, and so must be protected in layers of surrounding material. This surrounding material is designed to meet a variety of needs, such as increasing the amount of energy captured, being of high durability, or having flexible properties. Solar panels are used anywhere with sufficient sunlight to provide electricity with no greenhouse emissions [4].

Solar panels have been arranged and marketed in a variety of creative configurations, each serving different needs. Some seek to enhance the amount of sunlight captured, often by tracking the sun across the sky [5] or by redirecting light not absorbed by the panels back to the panels [6]. Other products look to optimize portability, offering small and lightweight panels that can be easily attached to consumer devices [7]. Another approach to portability is to place the panels on a wheeled frame, which would allow for a larger device, and therefore more power output [8]. Some designs focus on the frame that supports the solar panels, which can also be made lightweight [9]. Such devices are often marketed as tools for emergency situations or backcountry power generation.

A few devices incorporate some form of folding mechanism, allowing panels to be deployed when needed, and stored otherwise. One notable design has a large array of panels that track the sun, but that can be folded up into a package roughly the size of a briefcase [10]. However, this device is intended for backcountry situations or remote areas and is not necessarily designed to be friendly to the average American suburban homeowner. Our product is designed to be moderately portable, as it should be easy to install, but does not need to be transported through the wilderness. It is designed to have medium-level power generation, around 1500 W, and is separate from the power grid.

There are several competing brands in this space. Specifically, the SolarPod is an entry level consumer device that is easy to install on both the ground and roof (Figure 3). The same company has also patented the “Z-RACK” for sloped roofs and “Z-LITE” for flat roofs. They both use no screw mounts. Instead, the design uses metal bars to balance the weight of one solar panel with the other across the apex of a roof (Figures 4, 5, and 6). For camping and more portable needs, the Jackery battery and solar generator is a prime example. The battery can hold 1500W, has an AC outlet, and includes four 100W panels for the cost of $2,699 (Figure 7). On a larger enthusiast level, there are the typical solar panel installation companies. Perhaps slightly more aesthetic is the well-known SolarCity, backed by Elon Musk, which aims to replace all the roof shingles with solar shingles (Figure 8).

Three unique products lead the pack in the backup portable generator category. Firstly, the Wagan Solar ePower Cube 1500 Plus model EL2547 is a device which costs $1650 and includes five panels which expand via foldable and sliding mechanisms. It is easily transported with built-in wheels and a suitcase-style handle (Figure 9). On a larger scale, Renovagen has three innovative products that combine as a quickly deployable solution for bringing clean energy to remote locations. It allows for a large solar array to be arranged in minutes with the use of proprietary flexible panels, a rollable container, and car powered setup (Figure 10 and 11). These products exhibit cutting edge tech; however, there still appears to be room for growth in this industry for an accessible entry level device.

Figure 1 and 2: Renogy 100-Watt Eclipse Solar Suitcase

Figure 3: SolarPod

Figure 4 and 5: SolarPod Z-RACK for Slanted Roofs

Figure 6: SolarPod Z-Lite for Flat Roofs

Figure 7: Jackery Solar Generator 1500

Figure 8: SolarCity Shingles

Figure 9: Wagan Solar ePower Cube 1500 Plus model EL2547

Figure 10 and 11: Renovagen FAST FOLD Solar Mat, Rapid Roll “T” and Rapid Roll “I”

III. Codes and Standards

City zoning and HOA codes greatly impact the design and use of our product. City zoning codes details what is or is not allowed on one’s property. For solar panels this often includes how the panels must be placed. There is no empirical source of aggregate data for this beyond reading each and every single city’s unique zoning code in the US. However, solar panels are a relatively new residential use technology which means that, more often than not, it is not explicitly mentioned in most zoning codes. This leaves a grey area in many jurisdictions on the legality of permanent solar panels. Many progressive and major city zoning codes do explicitly allow solar panels though. In such instances, physical form restrictions are applied to the solar panel installation depending on whether they are roof or ground mount solar panels. For the purposes of this project, solar panels that are large enough to cause any notice but are easily movable and stand on the ground will likely count as ground-mounted solar. That being said, the smaller the solar panel ground product, the less likely such zoning rules will be enforced. The safest way to use solar is to apply for and receive a permit from the city planning department. If the city denies a permit, one must apply for a variance. Form restrictions would include certain height limits, setback distances, and used land lot area limits. HOA codes are not legally allowed to apply as many restrictions as city zoning codes in most areas.

If a resident is a part of an HOA, the HOA is allowed to enforce certain restrictions on the installation of solar panels. Most often, this takes the form of requiring the solar panels to conform to the “character” of the neighborhood by either altering the appearance of the panels or placing them in a non-offensive manner to the eye [11].

IV. Customer Requirements and Engineering Design Specifications

Customer requirements are an important consideration to make sure the designed product appeals to a broad audience and meets expectations for use. Identified requirements include aesthetics, easy installation, low maintenance, functional, portable, lightweight, low volume, safe, durable, reliable, efficient, sustainable, compatible, and high quality. As the proposed product is aimed towards removing the need for professional installation, it is very important to make the solar panel product easy to install, low maintenance, and safe. Furthermore, this product must not be an eye-sore in order for customers to place it in their backyard or other area around their house which makes aesthetics a consideration. Beyond this, the product aims to be semi-permanent and thus will need to be lightweight and low volume enough for a customer to be able to easily install it. This includes having some attachment or design feature that makes it easy to pick up beyond just being lightweight and low volume. Lastly, the product must work well and as expected with minimal upkeep needs otherwise the customer will not see the value in purchasing such an energy-producing device. Solar energy is often seen as a way to save money and creating a product that only works for short-term use or in limited conditions would greatly reduce the customer base.

The design must complete a number of functions as identified in Figure 12. These functions include being carried, deploying, attaching/securing to a surface, accepting sunlight, generating power with sunlight, storing power generated from sunlight, delivering constant current/voltage output, resisting weather events, and condensing for carrying. To complete these functions, a number of engineering specifications are identified and quantified, as shown in Table 1.

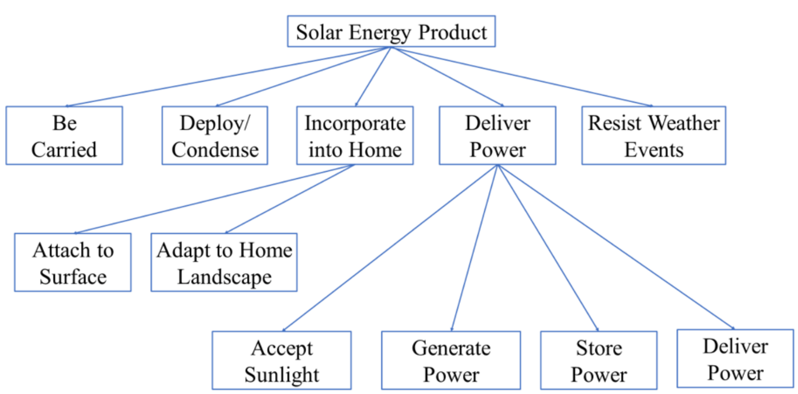


Figure 12: Function Tree

Table 1: Specification Sheet

Issued: February 14, 2022			
Change Date	**D/ W**	**Requirement**	**Responsible**
		Geometry	
1/29/22	W	Overall Volume (Shipped): 5ft x 4ft x 2ft	Team
1/29/22	D	Overall Volume (Deployed): 15ft x 15ft x 1ft	Team
1/29/22	W	Individual Panel Size: 5ft x 3ft	Team
1/29/22	W	Overall Shape: Pyramid	Team
2/8/22	D	Profile Height: <12 in	Team
		Kinematics	
1/29/22	W	Range of tracking angles: -45 to 45 degrees	Team
1/29/22	D	Average optimal angle: 30 degrees	Team
1/29/22	W	Time to reset to original angle: 30 minutes	Team
		Forces	
1/29/22	D	Overall design weight: < 150 Lbs	Team
1/29/22	D	Maximum Panel force on mount: 3.360 kN	Team
1/29/22	D	Maximum sustainable mount force: 13.5 kN	Team
1/29/22	D	Allowable panel impact pressure: 2400 Pascals	Team
		Energy	
1/29/22	D	Power output (Instantaneous): 1500 W	Team
1/29/22	D	Power output (Average): 1000 W	Team
1/29/22	W	Energy storage capability: 2.5 kWh	Team
		Material	
1/29/22	W	Mount material: steel	Team
1/29/22	D	Panel material: solar cells	Team
1/29/22	D	Fasteners: steel	Team
1/29/22	W	Cover material: plastic	Team
		Signals	
1/29/22	D	State of Panel light (battery charging vs. expending energy)	Team
1/29/22	W	Ability for panels to track sun	Team

		Safety	
1/29/22	D	Sharp edges: all radii >0.05 inches	Team
1/29/22	D	Weight: <150 Lbs	Team
1/29/22	D	Transportability: Requires no more than 2 people to transport	Team
1/29/22	D	Electrocution: <0.01% of customers	Team
		Ergonomics	
1/29/22	W	Installation time: 25 minutes	Team
1/29/22	D	Installation difficulty: rated <4/10 by panel of judges	Team
1/29/22	D	State of Panel light (battery charging vs. expending energy)	Team
		Production	
1/29/22	W	Assembly time: 25 minutes	Team
1/29/22	W	Number of pieces: <20	Team
1/29/22	W	Manufacturing cost: $1500	Team
		Quality Control	
1/29/22	W	Panel lifetime: 30 years	Team
1/29/22	W	Number of charging cycles: >1000	Team
1/29/22	W	Battery lifetime: 5 years	Team
1/29/22	W	Power output decline over time: <5% per year	Team
1/29/22	D	Mount failure: <1 per 1000	Team
1/29/22	W	Aesthetics: evaluated at 8/10 by panel of judges	Team
		Assembly	
1/29/22	W	Assembly Time: 25 minutes	Team
1/29/22	W	Number of people to assemble 2	Team
		Transport	
1/29/22	D	Can be carried by two people or less	Team
1/29/22	D	Weight: <150 Lbs	Team
1/29/22	W	Shipped dimensions: 5ft x 4ft x 2ft	Team
1/29/22	D	Enables easy carrying (handles or straps provided): rated >7/10 by panel of judges	Team
		Operation	

1/29/22	D	Self-sufficient operation (requires no user input)	Team
1/29/22	D	State of Panel light (battery charging vs. expending energy vs. panel off)	Team
		Maintenance	
1/29/22	W	Assembly time: 25 minutes	Team
1/29/22	D	Modular assembly available	Team
1/29/22	W	Required cleaning frequency: 2x per year	Team
		Costs	
1/29/22	W	Selling cost: $2000	Team
1/29/22	W	Manufacturing cost: $1300	Team
1/29/22	W	Assembly cost: $25	Team
		Schedules	
1/29/22	D	Report 1: 2/9/22	Team
1/29/22	D	Report 2: 3/16/22	Team
1/29/22	D	Final Presentations: 4/20/22	Team
1/29/22	D	Prototype 1: 2/25/2022	Team
1/29/22	D	Prototype 2: 3/25/2022	Team

These specifications are divided into two categories depending on if they are absolute requirements or simply desirable ones. Required specifications include having an overall deployed volume of less than 225 square feet and being capable of maintaining an optimized average angle of approximately 34 degrees (depending on location of household being used at). The design must weigh less than 150 pounds, and individual panels must be able to sustain 2400 Pascals of impact pressure while delivering less than 3.36 kN to the mount structure. The product must also be capable of creating a 1500 W peak power output and a continuous 1000 W output. The product must convey to the consumer when the battery is charging vs when the unit is delivering energy, and the safety of the product must be taken into consideration including edge radius of all corners, the amount of people required to transport, and the frequency of electrocution occurrence. The product must be self-sufficient (i.e., require no user input to function) and support modular assembly. This will reduce maintenance costs for the customer and also allow for upgrades or replacements to be made without having to replace the entire unit. Lastly, installation difficulty must be rated as less than 4/10 by a panel of judges to ensure the product is considered easy to install by a wide range of consumers.

Beyond engineering specifications that are created to evaluate the product independently, the product must also be compatible with multiple standards and zoning codes (discussed in Section III. Codes and

Standards). The product must be compatible with the majority of suburban outdoor spaces (i.e., not require excessive space or particular surface types/quality to be installed) and must be capable of producing both AC and DC output to work with a variety of household appliances. Attachment hardware must be widely available (purchasable at local hardware stores) to allow for customer maintenance to be performed and in case of lost pieces during installation. Installation and assembly must not require any specialty tools and the overall solution should prioritize use of sustainable and/or recyclable materials. Desirable specifications include having a product which allows for complete disassembly and either recyclability or reuse/take-back of each individual component to ensure that the ecological impact of the total product does not outweigh its green-energy production benefits.

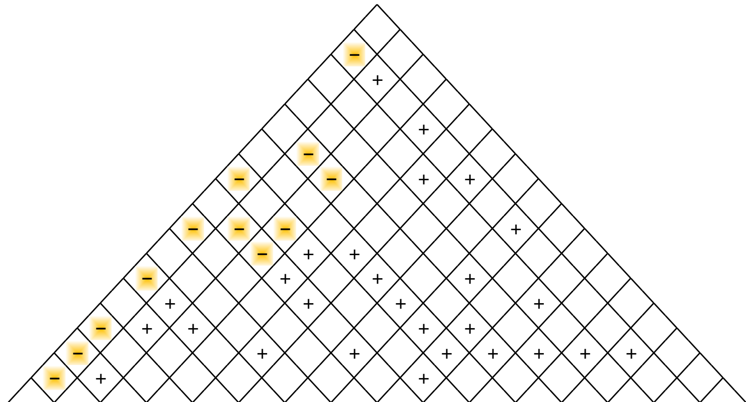
A House of Quality, as seen in Figure 13, is used as a design tool to make sense of the relationship between customer and engineering requirements.

Project: Solar Mount
Revision: 1
Date: 1/26/2022

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



Category	Weight	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		Direction of Improvement	◇	◇	◇	◇	◇	▲	◇	◇	◇	◇	◇	◇	◇	◇	▲	
		Customer Requirements (Explicit and Implicit) / Engineering Requirements	Cost	Size	Weight	Materials	Structural Intregrity	Energy Production	Forces (on panel, mount, etc.)	Signals	Safety	Ergonomics	Quality Control	Logistic Feasability	Autonomous	Assembly Options	Energy Storage	
	4	Aesthetics	○	○	▽	○	▽			▽		▽						
	8	Ease of Installation			●		○					●		●		●		
	7	Low Maintenance					○			▽		●			●			
	10	Functionality	○				○	●	●	●	○	▽	●		●	▽	●	
	8	Usable Life	○				●	○	●	○			○					
	2	Portability	▽	●	●	○	▽				●	▽		●		●	▽	
	5	Lightweight	○	●	●	●	▽		○		▽	●		●		○	▽	
	6	Small	○	●	○		▽	▽	▽			●		●		▽	▽	
	5	Safe to use			●		●				●	○	●					
	9	Durability (good over time)	○			●	●	●	●	○	○	▽	●		○		○	
	10	Reliability (consistently good)	○			○	●	●	●	○		▽	●		○		○	
	8	Efficiency						●		▽					●		○	
	5	Sustainability	▽		▽	▽		●		▽					▽		●	
	8	Quality	●			○	●			○	●	●	●	○	●	▽	○	
	8	Compatability with Environment		▽	▽	▽					○	○	▽	●	●	▽	▽	
		Target	Manufacturing cost: $200	Ovr. Volume (Deployed): 5 x 15 x 1 ft.	< 150 lbs	Mount/fasteners: steel; Cover: plastic	Maximum sustainable mount force: 13.5 kN	Power output (Avg.): 2.5 kWh	Allowable panel impact force: 13.5 kN	State of Panel light (battery charging vs. expending energy)	Sharp edges; all radii >0.05 inches	Installation difficulty: rated <4/10 by panel of judges	Mount failure: <1 per 1000	Enables easy carrying (handles or straps provided): rated >7/10 by panel of	Self-sufficient operation (requires no user input)	Modular assembly available	Storage capability: 2.5 kWh	
		Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	
		Technical Importance Rating	235	137	215	211	452	408	354	219	221	380	410	285	431	137	261	
		Relative Weight	5%	3%	5%	5%	10%	9%	8%	5%	5%	9%	9%	7%	10%	3%	6%	
		Weight Chart																

Figure 13: House of Quality (including Correlation Matrix and Relationship Matrix)

Among customer requirements, priority was given to functionality, reliability (consistency), and durability, as each category carried a weight of 9 or 10. Energy production and storage are to be maximized in this design as they are the primary use of solar panels, with the rest of the engineering requirements having certain attainable target values. After finding the relationship (strong, moderate, weak) to each customer and engineering requirement, it was determined that the structural integrity of the solar panel mount and the autonomy of the panels during operation were the two most technically important aspects of the design, with technical importance ratings of 452 and 431 respectively. The targets for each of these engineering requirements to meet for the final design are a maximum allowable mount force of 13.5 kN and no user input required for daily operation. If designed for autonomous operation, the solar panel mount would be able to display the state of each panel so that the user would be updated as to whether the panels are expending energy or battery charging. In addition, autonomy would be required for the solar panels to track the sun throughout the day in order to maximize energy creation. Most correlations between each engineering requirement are positive for this design, meaning a majority of the requirements will work with one another during the design and operation of the product. Cost, size, and weight are the three requirements that have some negative correlations with other requirements. As the weight and size of both the mount and the panels increase, both the production and selling cost of the product will both be increased. Similarly, premium materials such as carbon fiber or high-grade steels will be more expensive compared to cheaper materials when designing the solar panel mount system.

V. Market Research

When designing a new product with new customers, it is necessary to gather information regarding the market, customers, and product uses. The team first conducted secondary research to determine how much power is used by devices around the home. An estimate on the wattage needed by the average middle class American homeowner was calculated based off the appliances and electronics housing characteristics tables in the 2015 RECS Survey as provided by the EIA [12] [13]. The use case of this project requires factoring in the possibility of many devices being plugged in simultaneously. Certain devices and appliances were omitted from the calculation as they require excessive energy such as high wattage heating devices. These findings are further discussed in the above customer requirement and specification section.

Primary market research was conducted via a survey. This survey’s goal was to verify the hypothesized problems, determine the customers’ pain points, and determine the viability of our proposed solutions. This step is integral to the product’s success as creating a solution to a problem which customer’s do not prioritize means the product is not desirable. Target customers were identified as average income North American homeowners, and 55 survey responses were received from friends/family members.

When asked how important renewable energy is to these homeowners, 87% said that it is important or very important to them (Figure 14). A huge majority (85% of people) actively try to save money on their power bill (Figure 15). However, despite these figures, 93% do not have solar power (Figure 16). This confirms there is a large gap in demand that the team aims to capitalize on. The main hesitance to use solar power appears to be the upfront cost of installation. In order to address this, we aim to create a smaller entry level device to reduce the barrier to entry. The application areas rated most useful for the device are ranked as follows: continuous use (83.3%), stored for peak hour usage (57.4%), emergency generator (55.6%), electric vehicle power (33.3%), outdoor devices (24.1%), and camping/travel (20.4%) (Figure 16). The customers were also asked if portability is important to them. 43.6% felt "neutral" about it, with 38% agreeing/strongly agreeing it is important, and 18.2% disagreeing/strongly disagreeing (Figure 17). This is a significant finding as initial brainstorming sessions prioritized portability, but customer research shows that this is not a concern for most of the target market.

In terms of an ideal location, 81.8% of participants believe the roof is best while 14.5% prefer the backyard for this semi-permanent device (Figure 4). 67.3% said their personal roof is a good location with the largest concerns being HOA (10.9%), shade (3.6%), and aesthetics (3.6%) (Figure 18). Interestingly, 58% of people have 0-1 blackouts per year and 34.5% have 2-4. Despite that low number of blackouts, when asked if they are a concern 27.3% strongly agreed, 34.5% agree, and 23.6% were neutral. There seems to be a lot of uncertainty about pricing a 1500W solar power generator and battery, but an average price of $1628.23 was gathered ($50,475/31 valid participants). More surveying needs to be done after designs are finalized as several of the customers skewed the data with low prices. The key takeaways from these surveys that have impacted design are the main concerns regarding pricing, installation, and aesthetics. Also, the team is now questioning whether the original assumptions of creating a portable product for non-roof locations. Based on target customer feedback, it is clear there would be less demand than anticipated for such a product. As a result, the team has pivoted towards an easy to install device (yet not as portable) that can be used both on the roof and ground.

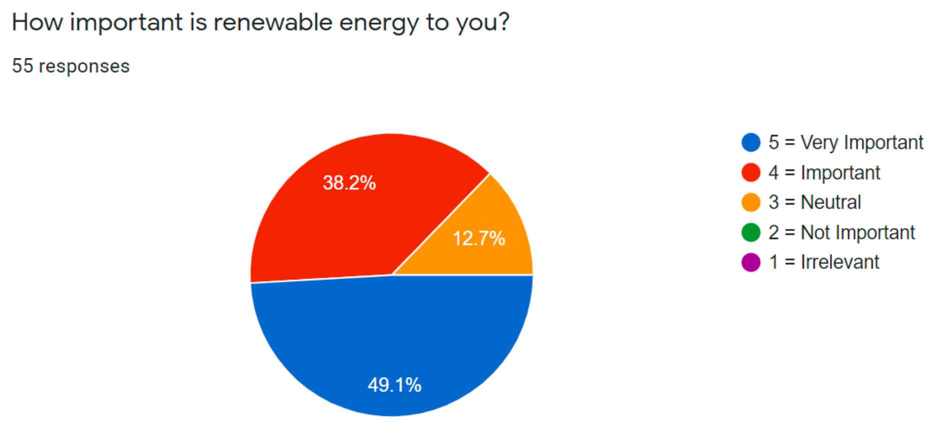


Figure 14

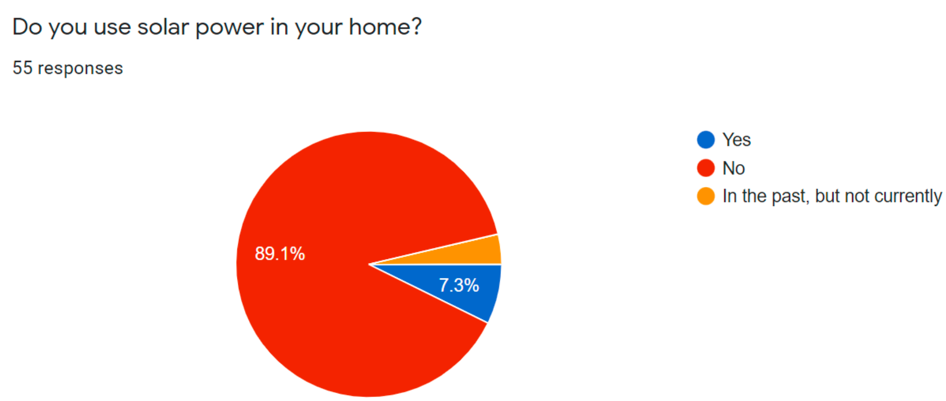


Figure 15

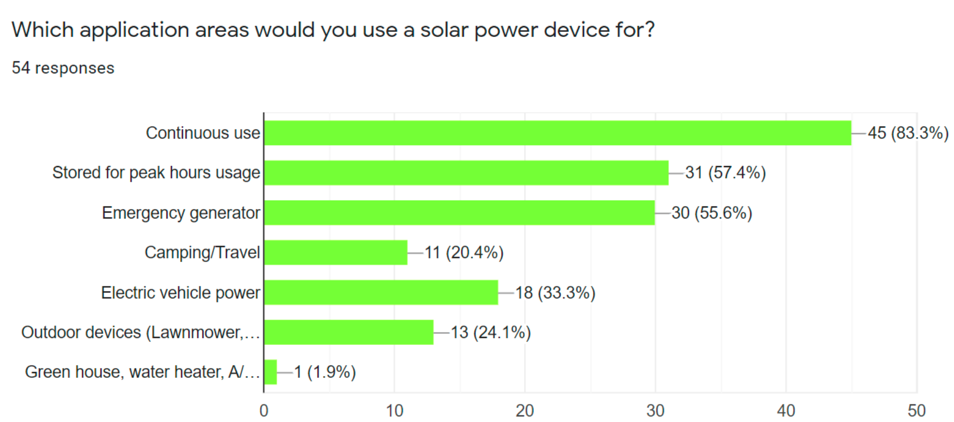


Figure 16

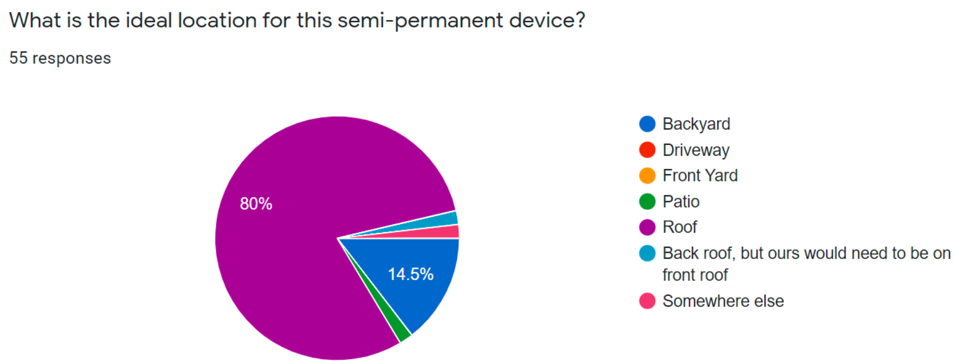


Figure 17

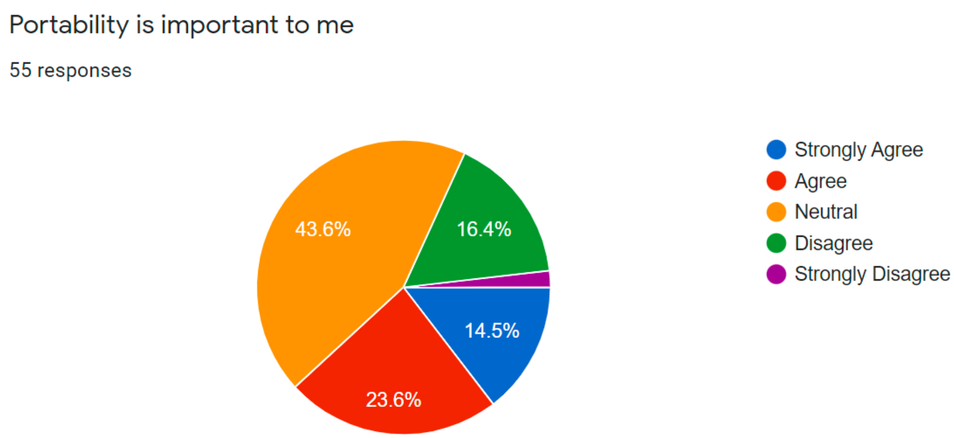


Figure 18

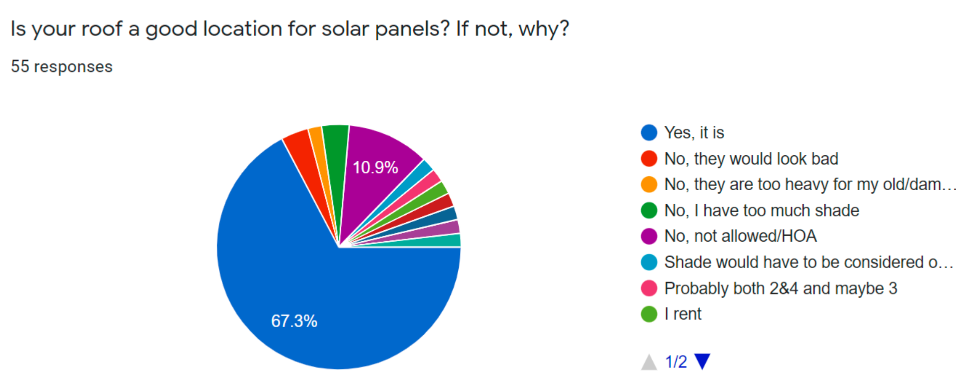


Figure 19

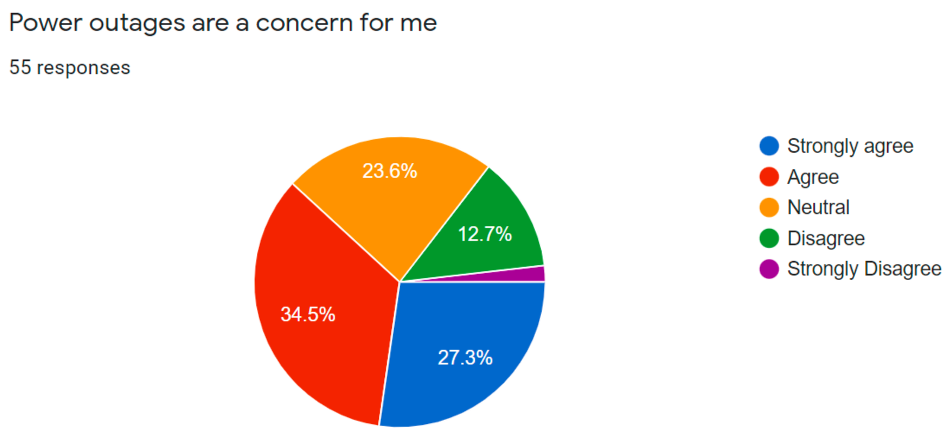


Figure 20

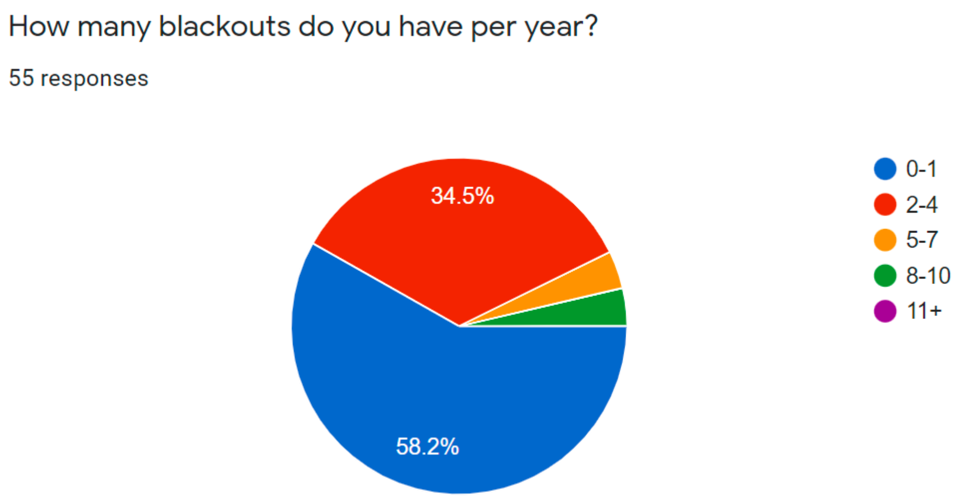
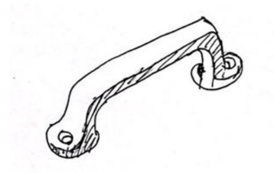


Figure 21

VI. Design Concept Ideation

The proposed product must be capable of completing multiple functions, as shown in Figure 12. Major functions include being carried, deploying, attaching/securing to a surface, accepting sunlight, generating power with sunlight, storing power generated from sunlight, delivering constant current/voltage output, resisting weather events, and condensing for carrying. These functions may be accomplished in a multitude of ways and possible solutions for each function are shown in the morphological chart (Figure 22).

<table>
<tr><th>Function</th><th colspan="3">Potential Solutions</th></tr>
<tr><td rowspan="2">Be Carried</td><td>Handle
</td><td>Roll on wheels
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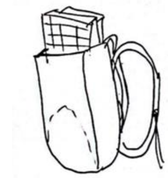</td></tr>
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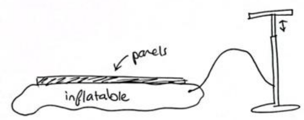
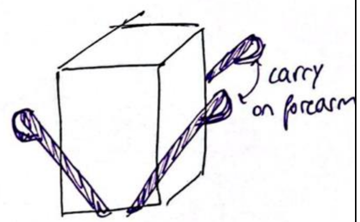
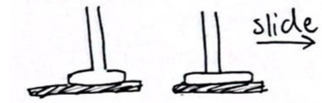
</td><td>Appliance Straps
</td><td>Moving Men
</td></tr>
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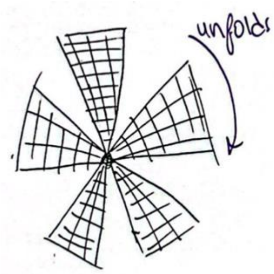
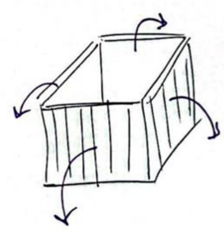
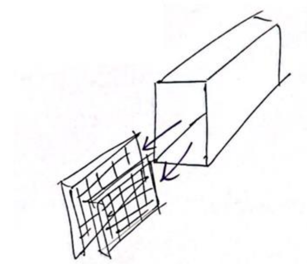
Condense</td><td>Flower fan out
</td><td>Box unfold
</td><td>container
</td></tr>
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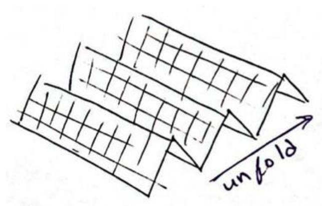
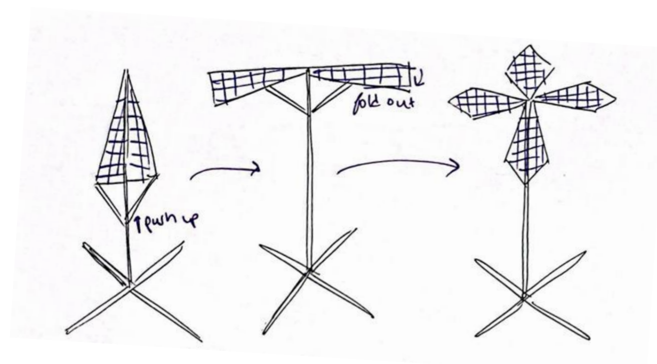
</td><td colspan="2">Umbrella
</td></tr>
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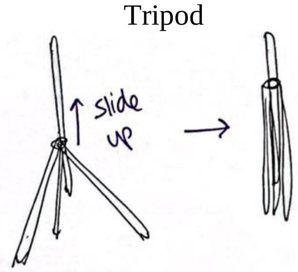
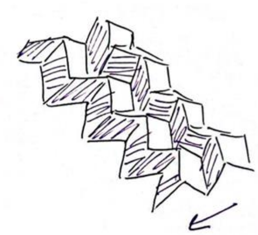
</td><td>Miura Ori
</td></tr>
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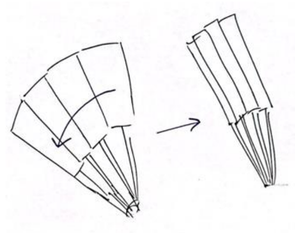
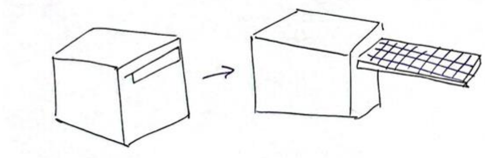
</td><td colspan="2">Drawer Slides
</td></tr>
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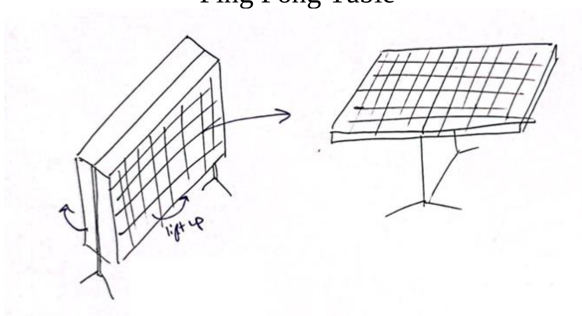
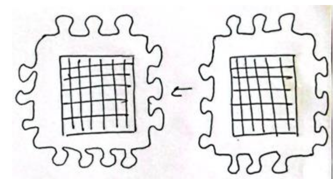
</td><td>Puzzle Pieces
</td></tr>
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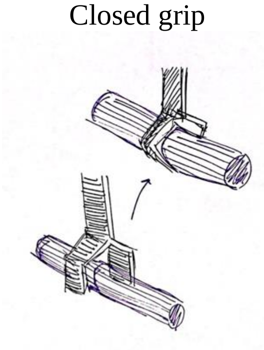
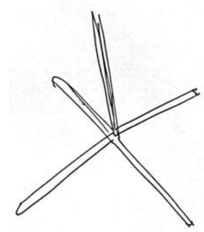
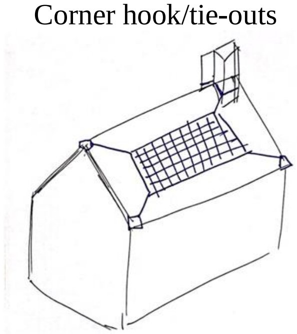
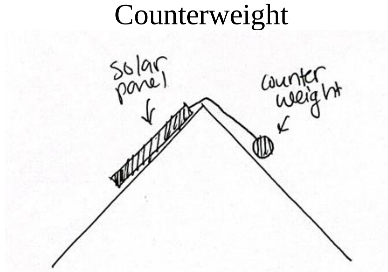
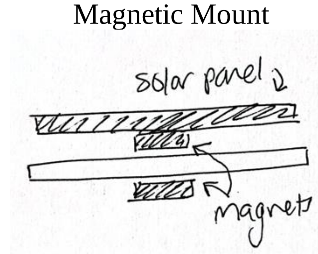
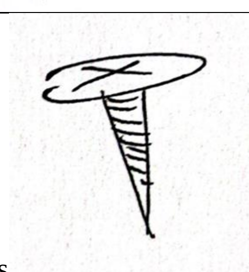
</td><td>Large/Heavy base
</td><td>Spike(s)
</td></tr>
<tr><td>Corner hook/tie-outs
</td><td>Counterweight
</td><td>Magnetic Mount
</td></tr>
<tr><td>
Screws</td><td></td><td></td></tr>
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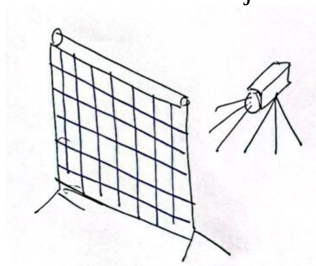
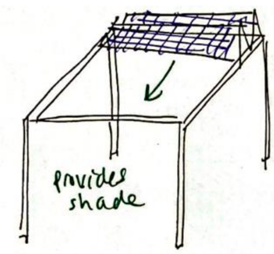
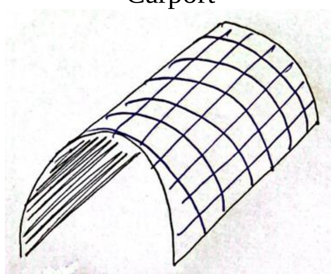
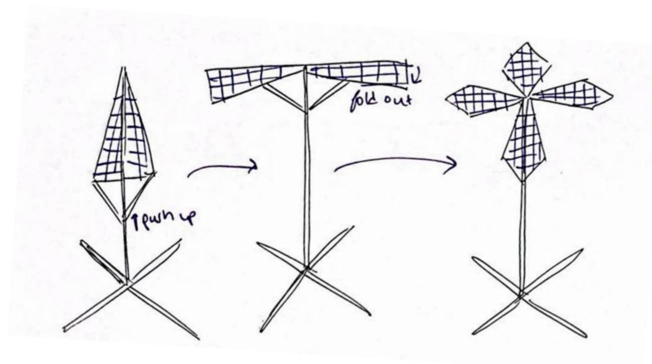
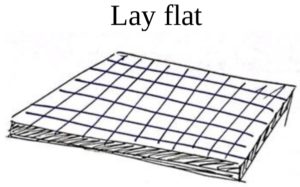
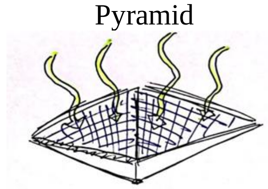
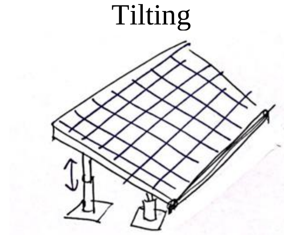
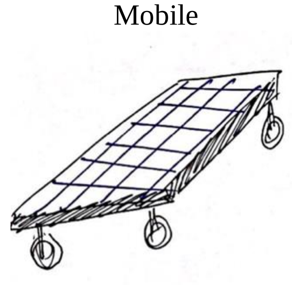
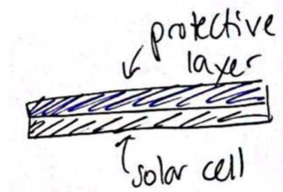
Function	Potential Solutions		
Adapt to Home Landscape	Outdoor Movie Projector 	Low Profile 	Tent/Gazebo 
	Carport 	Umbrella/Patio Shade 	
Accept Sunlight	Lay flat 	Pyramid 	Tilting 
	Mobile 		
Generate Power	Thin Solar Cell	Monocrystalline Solar Cell	Polycrystalline Solar Cell
Store Power	Battery	Supercapacitor	Grid
Deliver Power	Grid connection	Detachable battery	House hook-up
	Extension cable	DC to AC Convertor	
Resist weather events	Lid	Fan/fold in	Glass/Plastic covering 

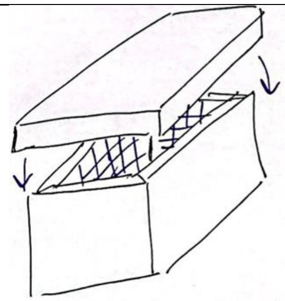
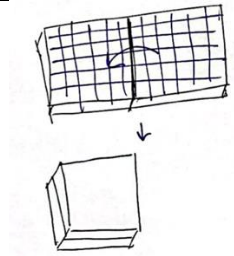
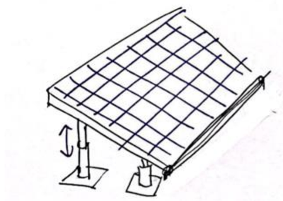
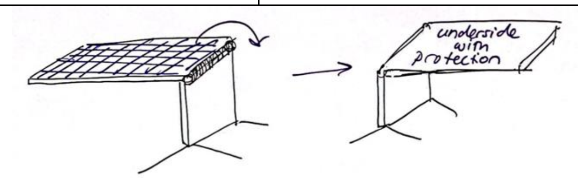
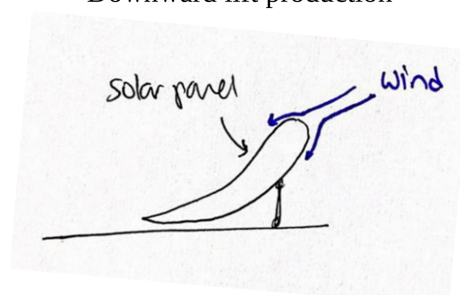
Function	Potential Solutions		
			
	Tilt 	Upside down 	
		Downward lift production 	

Figure 22: Morphological Chart

The product may be carried by adding handles to the final design, incorporating wheels or backpack straps. More creative solutions include an inflatable "lifter" that allows the panels to be placed on the ground and then raised to the appropriate height of the surface to be mounted on by inflating its base. Inspiration from furniture movers provides the solutions of appliance straps which allow the product to be lifted without bending over, and "moving men" allow the product to be slid across a variety of surfaces.

Another identified function is the need for the product to deploy and condense (either for portability/installation or shipping purposes). Some possible solutions include assembling the panels in a box formation and allow them to unfold using the edges of the box as pivot points. The panels may fold in an accordion or rolling style, and the base may fold up using a tripod design. The panels may also fold in an umbrella style where panels are pushed up on support rods and then unfolded once at peak height. Origami inspiration provides the Miura Ori as a possible folding solution as it allows for flat folding without deformation of individual panels. Lastly, the panels may deploy using a ping-pong table style folding mechanism where individual leaves fold upwards around a central pivot.

The product must be able to securely attach to any surface it is mounted to. A "closed grip" mount is optimal to attach to any smaller surface such as a railing, a pole, etc. This method uses actuated fingers to clamp around a surface. The product may use a large, heavy base as a non-permanent method of ensuring stability, or a screw-in spike which may be placed into a soft ground. Lastly, roof tie-outs could be used to ensure a low-profile, removable installation at a low cost. Perhaps most significantly, the final design must be capable of delivering power by accepting sunlight, generating power from this sunlight, storing power, and then delivering it. To accept sunlight the panels may lay in flat or pyramid solution and may optimize sunlight delivery through a tilting mechanism or by having a mobile base. Future solutions may incorporate methods of accepting sunlight by helping remove or clear shade-creating items. The product may generate power through the use of thin, monocrystalline, or polycrystalline solar cells. The cell outputs may be attached to a battery, a supercapacitor, or the main grid to store energy. Similarly, the product may disperse power through the grid, using a detachable battery, through a direct house hook-up or an extension cable. Lastly, the final design must be capable of resisting weather events. This may come in the form of a lid that is placed over the panels, a folding capability that places the solar-panel side of the device away from the sky, or a protective covering such as glass or plastic. A tilting mechanism that directs the panels away from the weather event or a hinge which flips the entire design upside down are additional possible solutions.

Using these individual function solutions, numerous integrated concepts can be created. A selection of these concepts is shown in Figures 23-30. In Figure 23, the idea uses the ping-pong table style folding mechanism with deployable monocrystalline solar cells to capture sunlight with a wheeled base for ease of maneuverability. Figure 24 shows the concept sketches for a "Solar Soldier" idea where a series of modular, rollable solar panels are connected and stored in a singular housing box with one motor to power sun tracking for all the panels. Multiple ideas (Figures 25-26) utilize the accordion/Miura-Ori folding pattern on a combination of bases to provide multi-functional use and ease of storage. These include a car-garage and grotto/tent style mounts that use the wide/heavy base mounting solution for stability. Several ideas also incorporate the tilting mechanism to best capture sunlight (Figure 27) in combination with folding panels. Ideas such as a solar panel garage door and window shade prioritize easy incorporation into the home ecosystem with thin solar cells but do not optimize sunlight capturing due to the mounting angles. Figure 28 shows a concept which allows for non-permanent roof installation (without screws) and attempts to optimize sunlight capturing through changing the angle between individual solar panels. The umbrella folding mechanism is used in combination with a wide base and monocrystalline cells to create multiple types of portable/foldable products (Figure 29). Designs which optimize capturing solar energy include a greenhouse-style magnifier as well as a mobile robot which "chases" the sun around the backyard and a complete solar tarp which could be easily moved at different times of the year to receive the best sunlight. Designs which best address weather resistance are a foldable generator with telescoping arms (Figure 30) which folds into a box with a lid to resist weather events and may be slid or rolled. These myriad of possible design solutions are subsequently evaluated based on the pre-determined engineering and customer specifications to ensure the creation of a product which is capable of completing all functions reliably while incorporating customer desires.

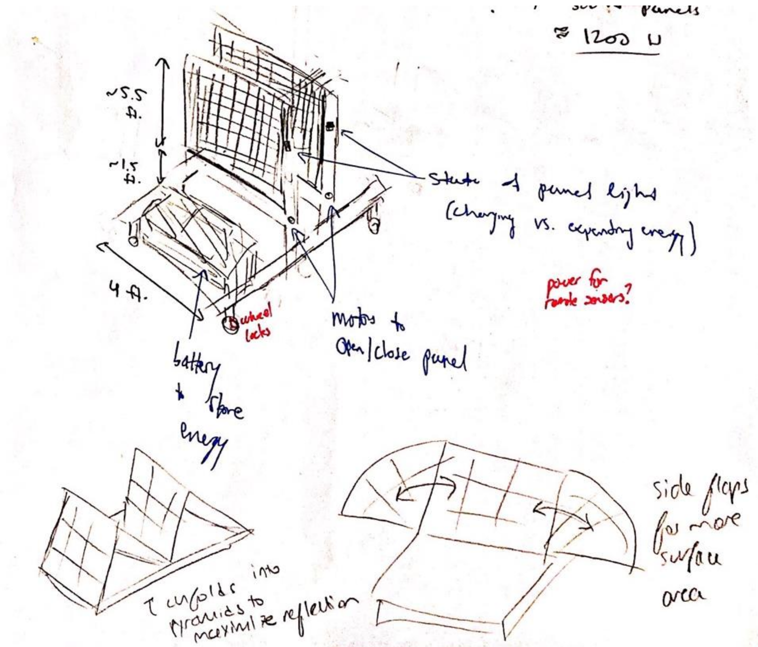


Figure 23: Initial idea for a ping-pong table style deployable solar panels

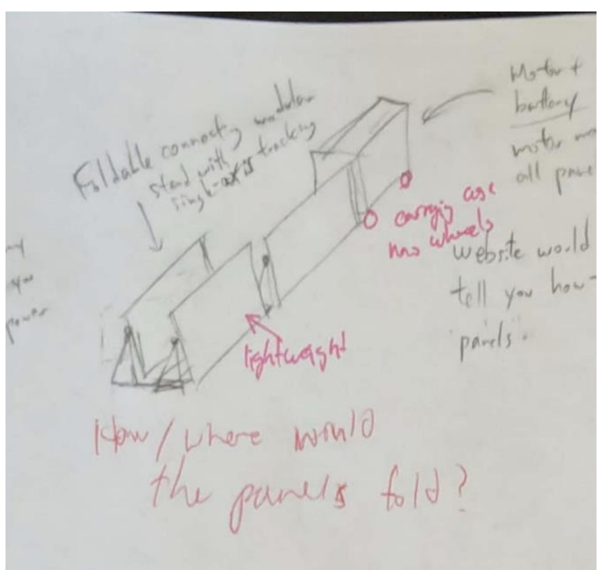


Figure 24: Initial idea for “Solar Soldiers”: a series of connected panels that condense into a portable box

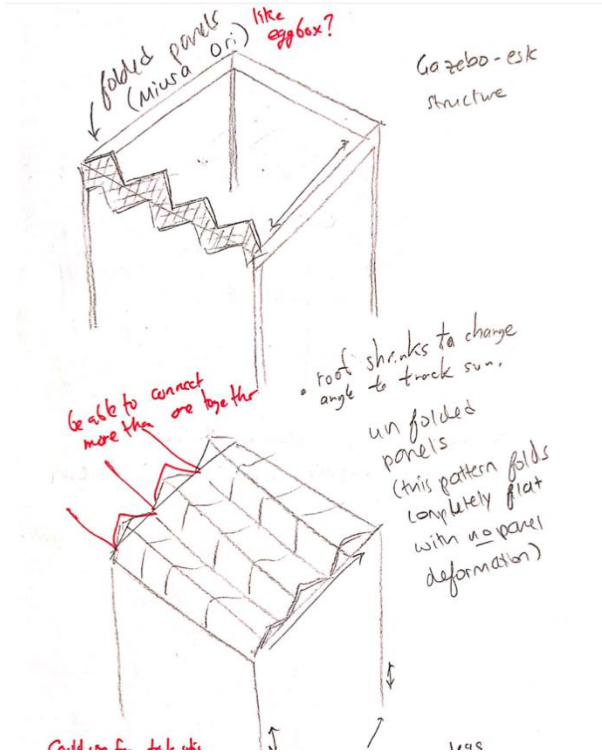


Figure 25: Initial idea for accordion/Miura-Ori folding grotto roof

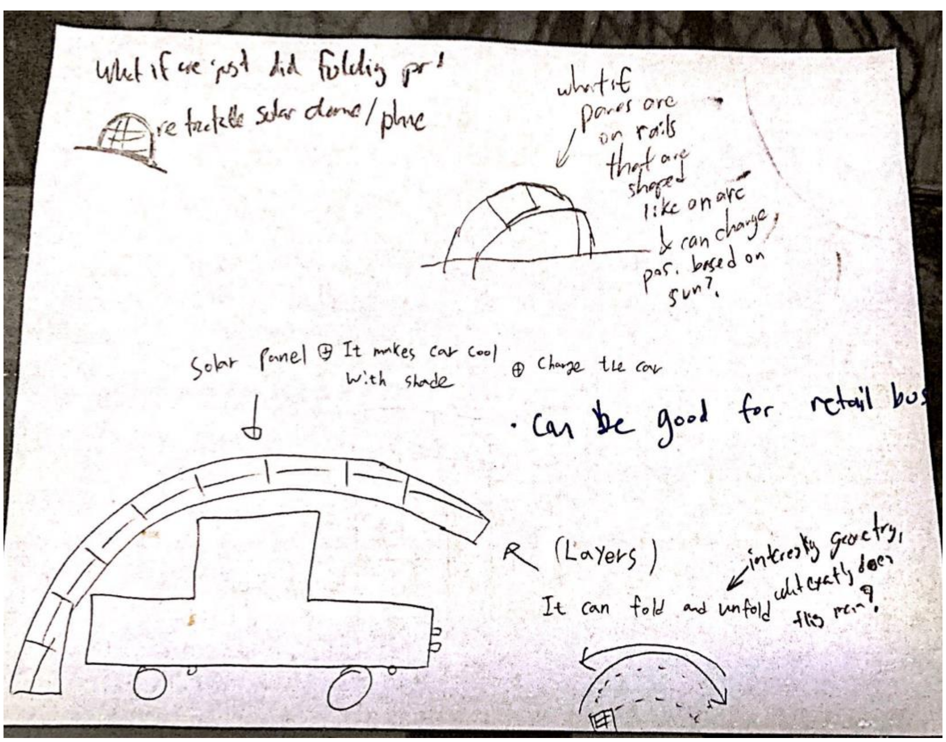


Figure 26: Initial idea for a car port using accordion folding panels

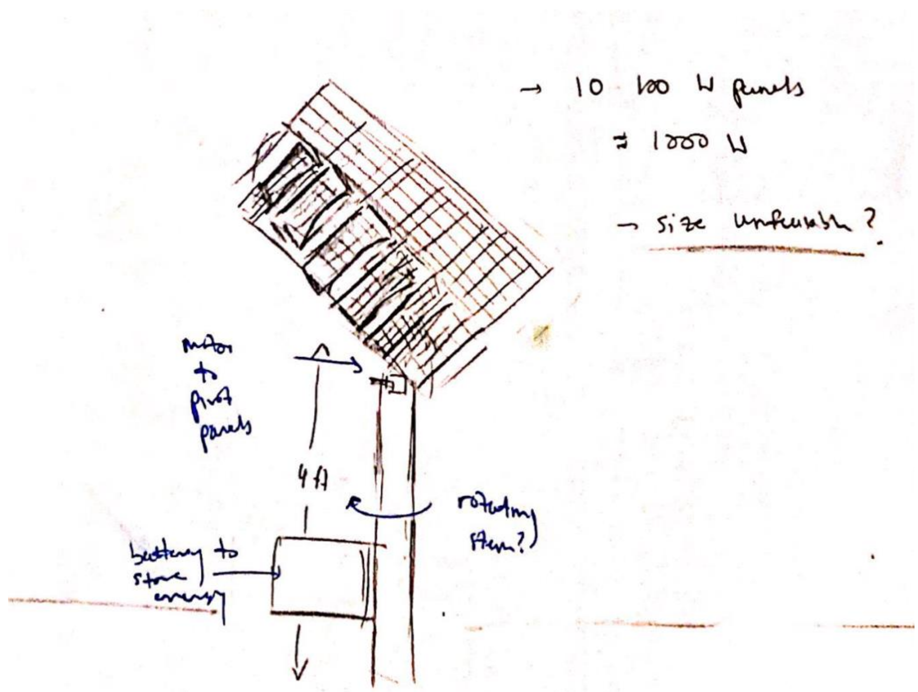


Figure 27: Initial idea for a “sunflower” tilting mechanism

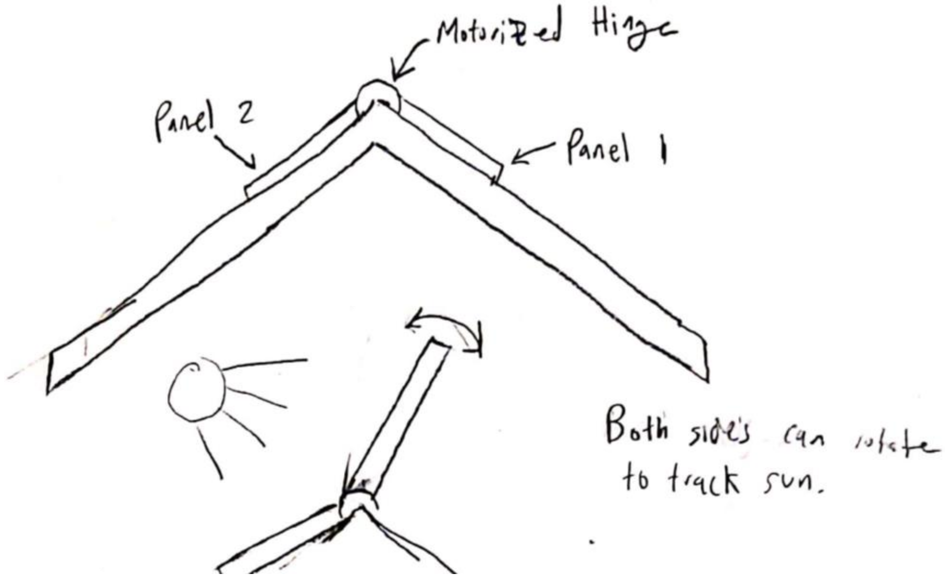


Figure 28: Initial concept sketches for a non-permanent roof-mounted device which follows the sun

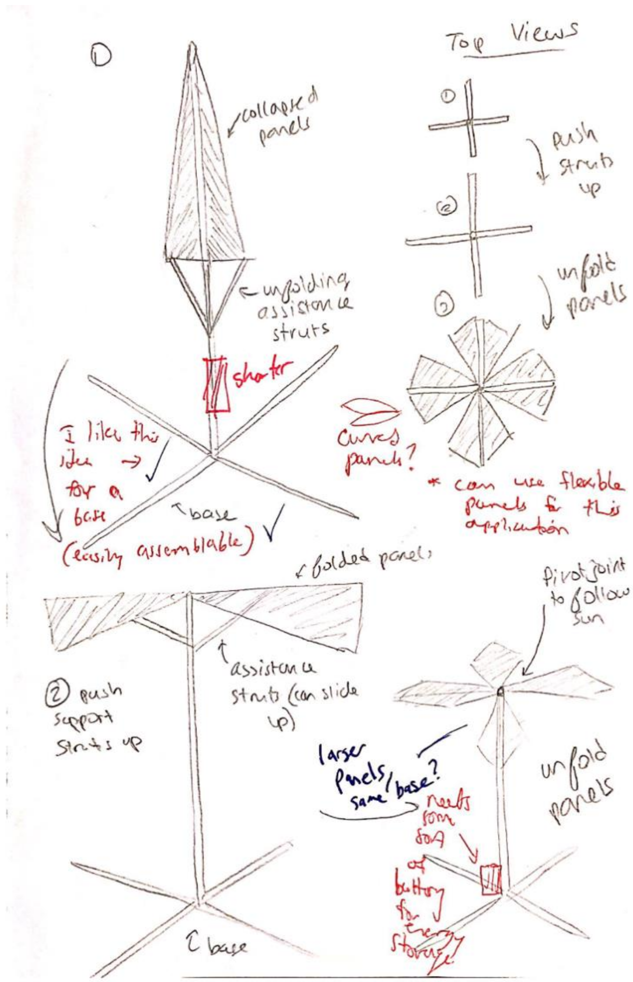


Figure 29: Initial concept sketches for an “umbrella” solar folding mechanism

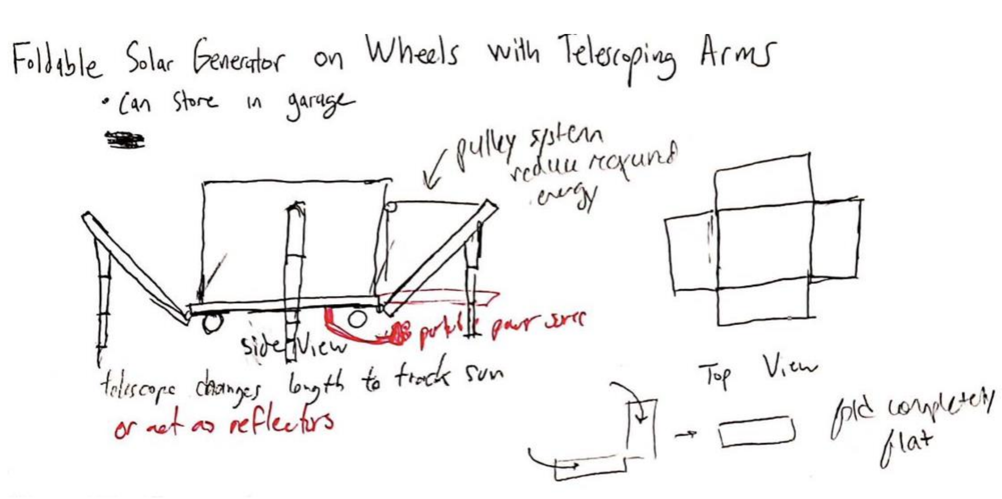


Figure 30: Initial concept sketches for unfolding solar box with telescoping arms

VII. Concept Selection and Justification

As seen in Table 1, a design evaluation matrix is used to select a preliminary design from four contenders. A design evaluation matrix quantitatively weighs each customer-centric criteria and rates each possible alternative in its effectiveness to meet design goals. The sum of each criteria score is divided by the total possible points to create an evaluation score. Designs 2, 3, and 4 did not meet the maximal criteria to be chosen for the final design. These designs included the Solar Cube (0.68 relative total) (Figure 29), the Solar Table (0.671 relative total) (Figure 23), and Solar Soldiers (0.654 relative total) (Figure 24). Notably, none of these design concepts were sufficient in their size (weight and dimensions), portability, nor their compatibility with general customers. As seen in Figure 31, the Solar Folder (Design 1), is selected as the preferred solution with a relative total of 0.757.

Table 2: Design Evaluation Matrix

Criteria	Importance	Design 1 (Solar Folder)	Weighted Total	Design 2 (Solar Cube)	Weighted Total	Design 3 (Solar Table)	Weighted Total	Design 4 (Solar Soldiers)	Weighted Total
Aesthetics	4	8	32	5	20	6	24	5	20
Ease of Installation	8	9	72	8	64	7	56	5	40
Low Maintenance	7	8	56	4	28	5	35	4	28
Functionality	10	10	100	8	80	8	80	9	90
Usable Life	8	7	56	7	56	7	56	7	56
Portability	2	7	14	10	20	9	18	8	16
Lightweight	5	4	20	5	25	4	20	6	30
Small	6	5	30	4	24	3	18	7	42
Safe to use	5	8	40	8	40	8	40	8	40
Durability (good over time)	9	7	63	7	63	7	63	7	63
Reliability (consistently good)	10	7	70	7	70	7	70	7	70
Efficiency	8	7	56	7	56	6	48	7	56
Sustainability	5	7	35	7	35	7	35	7	35
Quality	8	7	56	7	56	7	56	7	56
Compatibility with Environment	8	10	80	8	64	9	72	4	32
Total			780		701		691		674
Relative Total (divide by 1030)			**0.7572816**		**0.68058252**		**0.67087379**		**0.65436893**
Rank			**1**		**2**		**3**		**4**

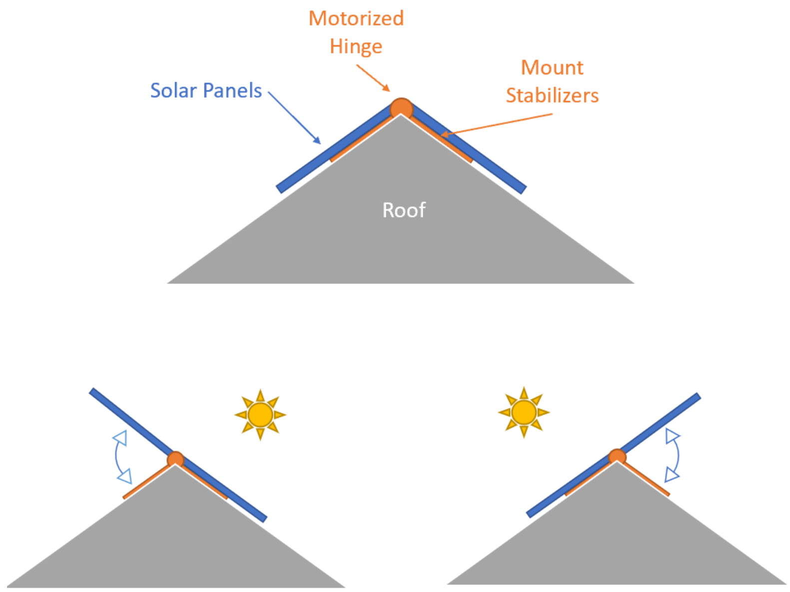


Figure 31: Solar Folder design concept

The Solar Folder is effective in that it addresses the shortcomings of other concept designs. Most notably, the Solar Folder is compatible with multiple mounting surfaces, as it has scored the highest score (10/10 evaluation rating) in the functionality category out of all four design concepts. The simple yet technically effective design of the Solar Folder allows consumers to choose whether the product is to be deployed on a residential roof, patio, or backyard. A motorized hinge between panels enables this flexibility, as the panels can easily form to match the shape of the surface that they are mounted to. In addition, each panel in series allows for the product to position itself in the direction of the maximal power output from the sun every day, while still being effectively mounted to the desired surface. The Solar Folder also allows for an ease of installation (9/10 evaluation rating) as the panels can be removed and reattached to the mount (Figure 32) and is highly compatible with any environment it is placed in (10/10 evaluation rating). Unlike other roof-compatible solar panels it does not require any permanent changes to be made to the roof (possible roof damage due to holes from screws being used in traditional solar panel systems). The mount is self-stabilizing using the forces of gravity and its own weight to counteract turbulent weather. The Solar Folder is currently rated to withstand winds up to 100 mph, which is the equivalent of a Category 2 hurricane, according to the Saffir-Simpson Hurricane Wind Scale detailed by the National Hurricane Center and Central Pacific Hurricane Center [14]. The overall solar folder design is shown in Figure 33.

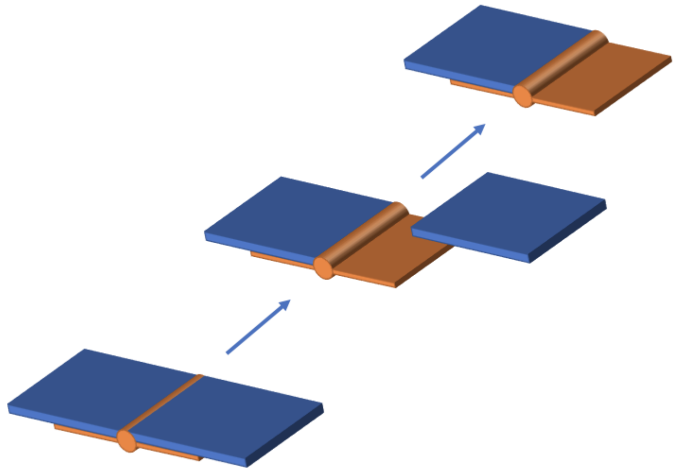


Figure 32: Solar panels on the Solar Folder design are modular and may be removed from the mount to allow for easy installation and removal as well as panel replacement

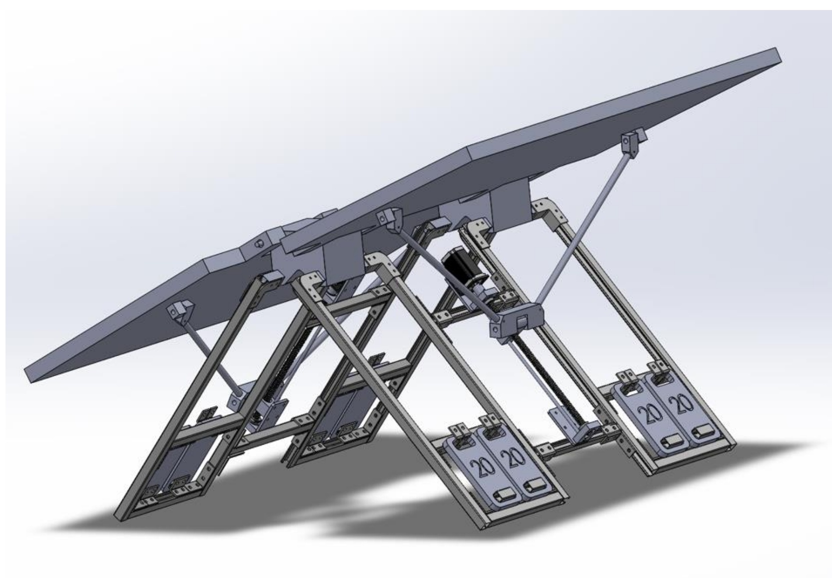


Figure 33: Fully Assembled Solar Folder Initial Design

Each Solar Folder system consists of two total ~350 W monocrystalline panels, with dimensions of approximately 39 x 65 x 1 in. (or 99 x 165 x 2.5 cm.). Both panels will be mounted individually to a stationary frame shown in Figure 34. A lead screw, as displayed in Figure 35 & 36, connected to each frame will allow the panels to move throughout the day, to ensure maximum solar efficiency. Each lead screw, and in result each panel, will be actuated by a high torque stepper motor. A specially designed hinge (Figure 37) will connect the two panels to each other and allow them to move synchronously when actuated.

Electrical components are divided into two categories: Circuity and programming. The role of the electrical circuit is to convert 120V AC from a standard wall outlet to up to 65V/5A DC. First, a power supply converts 120V AC to 36V DC. This will be connected to a motor driver, which controls whether the stepper motor receives power. The motor driver is controlled by the motor controller, which is implemented on a Raspberry Pi 4. The role of programming on the Raspberry Pi 4 is to control the motor driver. The software can be monitored and updated in real time by using SSH to access the Raspberry Pi. The electrical system diagram is shown in Figure 38.

The motor controller output signals on three GPIO pins connected to the motor driver, which took them as differential signals referenced to 3.3V. The "enable" pin controlled the ability of the motor to spin given the other inputs. The "direction" pin determined whether the motor turned clockwise or counterclockwise, thereby moving the panel either up or down. The "pulse" pin was a PWM output, whose frequency controlled the motor speed. To avoid damaging the motor when reaching higher speeds, the frequency on the PWM output was gradually ramped up and down until the desired motor speed was reached. All programming was done in Python using the gpiozero library to declare pins and control pin outputs. The code was stored locally on a Raspberry Pi and modified when the Raspberry Pi was connected to a laptop over SSH.

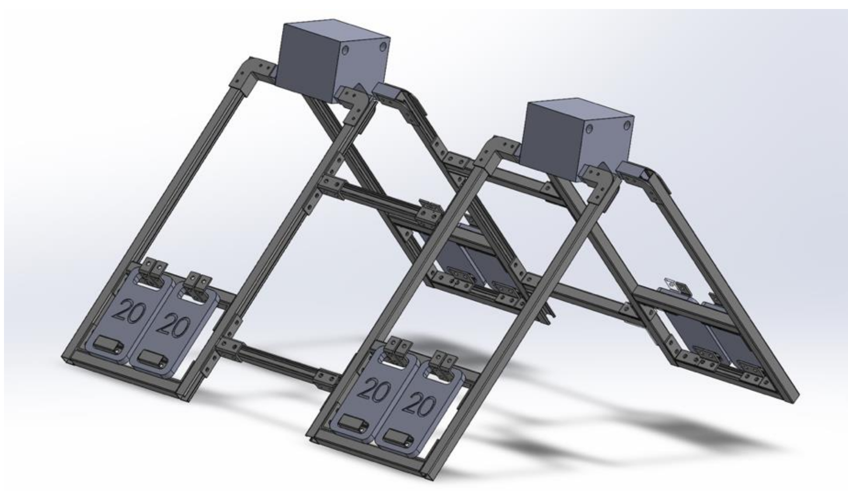


Figure 34: Stationary Mounting Frame Initial Design

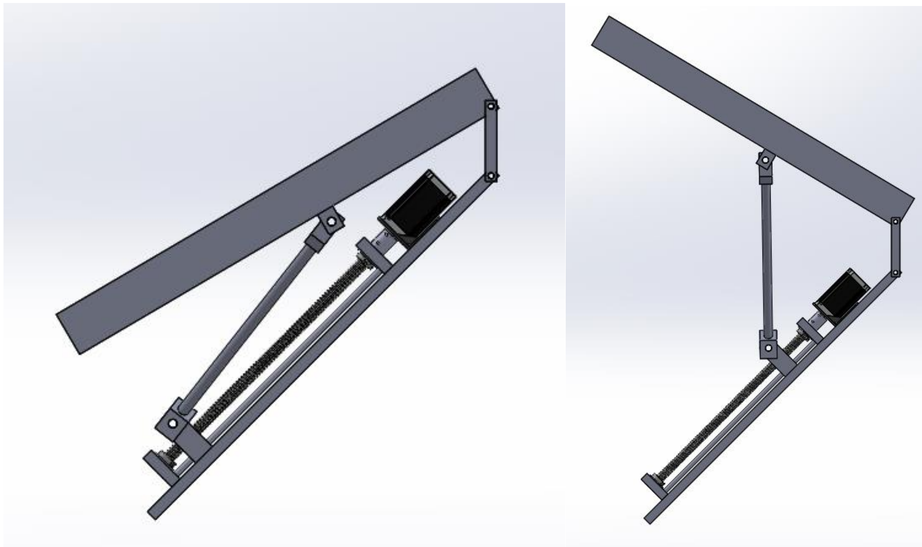


Figure 35: Lowered and Raised Solar Panel Side View

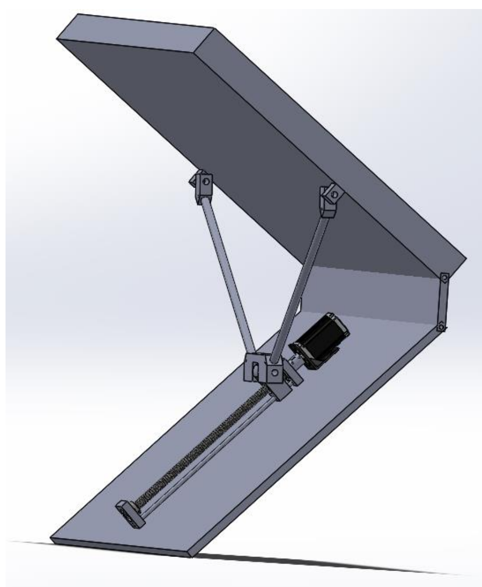


Figure 36: Isometric View

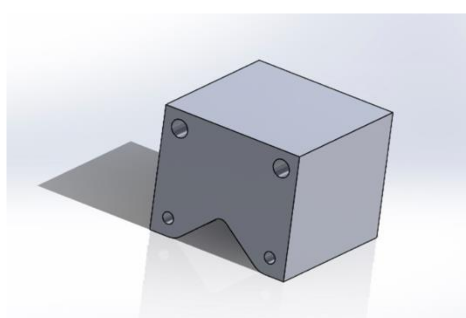


Figure 37: Specialty Hinge

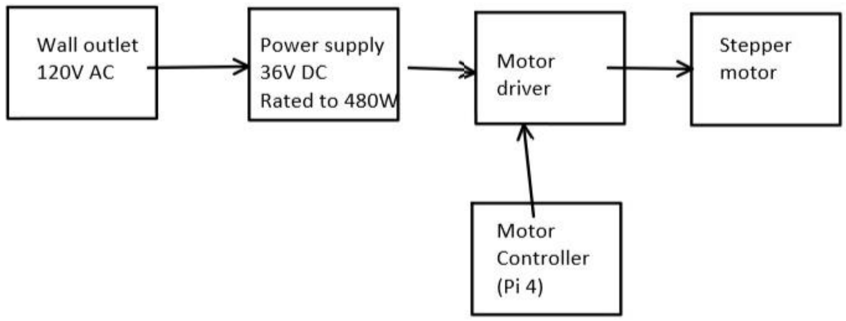


Figure 38: Electrical system diagram

The Solar Folder can be installed modularly and can be connected in series to other identical units to increase total power production. The product's variability in power output allows for consumers with multiple budgets and various desired applications. The Solar Folder can be used as a backup generator in case of inclement weather, continuous use for home appliances (such as lighting fixtures, microwave ovens, refrigerators), or even a cost-effective charging station for outdoor machinery (lawnmower, leaf-blower, chainsaw). The easily foldable design allows for high transportability during shipment and various customer applications. Due to its modular design, the Solar Folder can be easily transported between locations around the property or can be uninstalled for future use. The folding nature of the panels significantly decreases the system's surface area during transport and makes the system an ideal product for rural, suburban, and urban applications.

Upon prototyping, potential shortcomings of the selected design include the panels' inability to shield itself automatically from inclement weather. The magnitude of this shortcoming will depend on the surface cover ultimately selected which overlays the solar cells. Over an extended period of time this issue may decrease the system's functionality as damaged systems may produce lower power outputs.

VIII. Industrial Design

The overall design of the Solar Folder is made with the intention to increase ease of installation and use for the customer. As the goal of the product is to allow for non-professional installation, great consideration was taken to make sure no single piece of the product is too heavy for a single person to carry. Each component of the system is designed to weigh less than a solar panel (~50 lbs.). The design is also broken down into subassemblies which are self-stabilizing on the roof. This means that the customer may install a subassembly and leave it on the roof while bringing up another piece without having to worry about it sliding off the roof. Additionally, the entire design is modular and made for easy assembly and disassembly in order to allow for easy part replacement and installation. In particular, the mount of the system is divided into four panels which each weigh under 30 lbs. The mounts are equipped with handles for ease of carrying, and the final product will include a carrying case with which the user may easily transport the system.

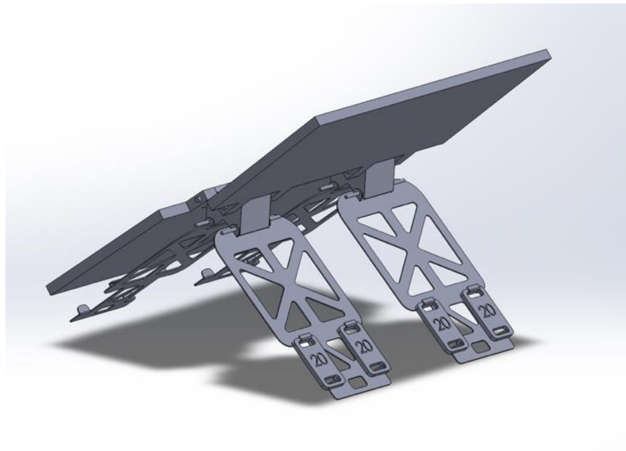


Figure 39: Galvanized Steel Mount Design

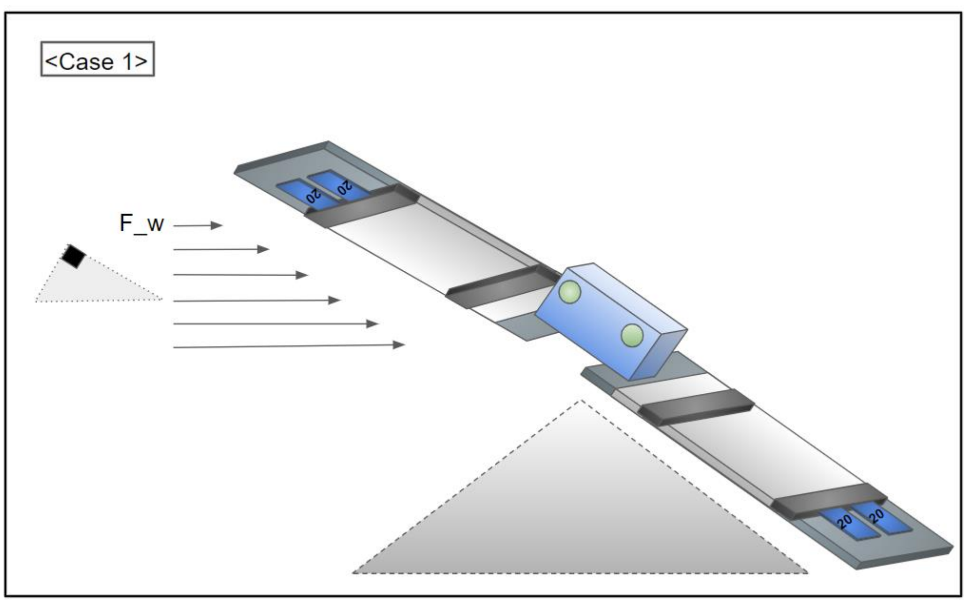
The final design will include a mount made of galvanized steel (Figure 39) whose surface finish and reflective nature resembles the individual cells of a solar panel and their changing color based on sun angle. The choice of this material plays into the overall message of the product as a clean and modern device and makes the product appear as a cohesive unit. Since customers who look into purchasing solar panels will be investing several hundred or thousand dollars, it is important that the product appears not only functional but also aesthetically appealing. A product in this price range should satisfy consumers not just with its functionality but also with its visual appeal, especially since it will be mounted on the outside of their home. Instead of trying to hide the panels, the chosen mounting structure highlights them and creates a modern appearance for the roof. Beyond the design of the product itself, the product will be branded and marketed as a clean and sleek device which provides functionality and modern energy practices without damaging the home. The device has zero need for contractor installation or for damaging mounting hardware. It will be marketed as a product with zero negative impact on the consumer's home, wallet, or daily habits. The logo associated with the product is shown in Figure 40 and reflects these goals through the use of the shape and word 'zero.' The product removes the research, cost, and installation hassle of other solar panel panels and introduces a zero-stress renewable energy home product. The shape and verbiage of the logo combined with its minimalistic shape conveys these messages.

Figure 40: Product Logo

IX. Engineering Analyses, Experimentation and Design Performance Prediction

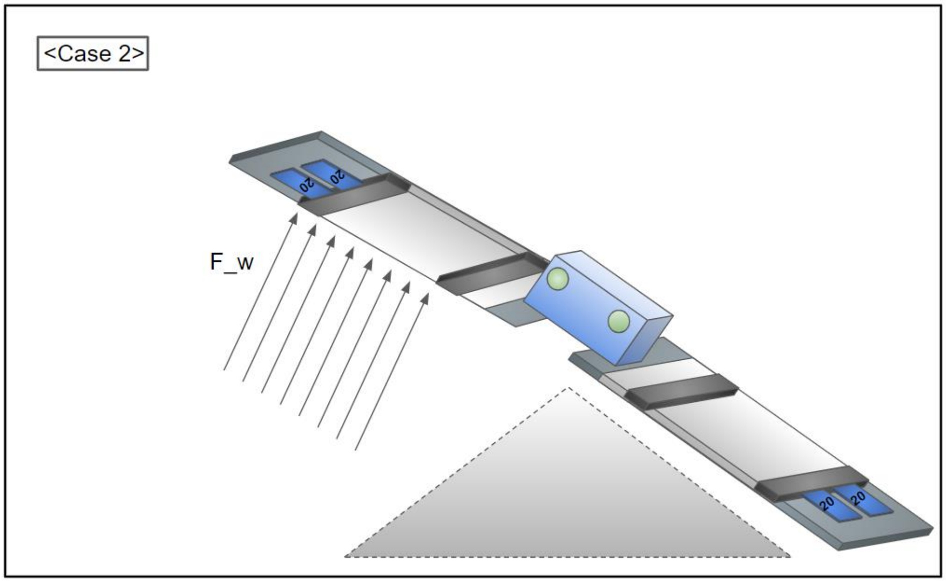
The analysis is split into three main sub-systems: the mount, the actuation, and the hinge. Initial calculations are performed using free body diagrams and machine design. Finite element analysis is then used to confirm initial calculations and machine design.

In order to safely secure the mount with panel to the roof, it is necessary to calculate the appropriate length of the mount and the weight sufficient to secure the mount. To do so, the influence of wind acting on the outside must be considered. There are two main cases to consider. As shown in Figure 41, there are simple horizontal winds, and wind acting perpendicular to the solar panel as shown in Figure 42.



$$F_w = Wind\ Force$$

Figure 41: Showing the first case of wind direction (horizontal)



$$F_w = Wind\ Force$$

Figure 42: Showing the second case of wind direction (vertical to the panel)

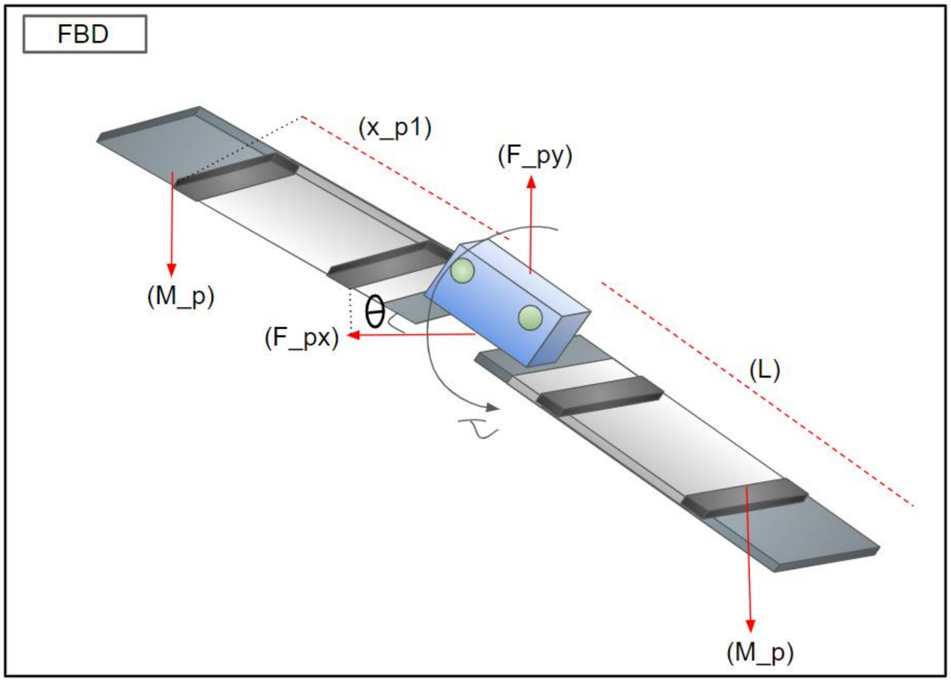
In each case, the wind properties were calculated above the normal level to ensure stability. Furthermore, the angle of the roof was also calculated by setting it to 45 degrees, which is the maximum roof slope angle on the average home. To determine the appropriate mount length and weight, equations for the X-axis, Y-axis, and moment values are found using the Free Body Diagrams (Figures 43-44). Each of the equations can be shown as defined below.

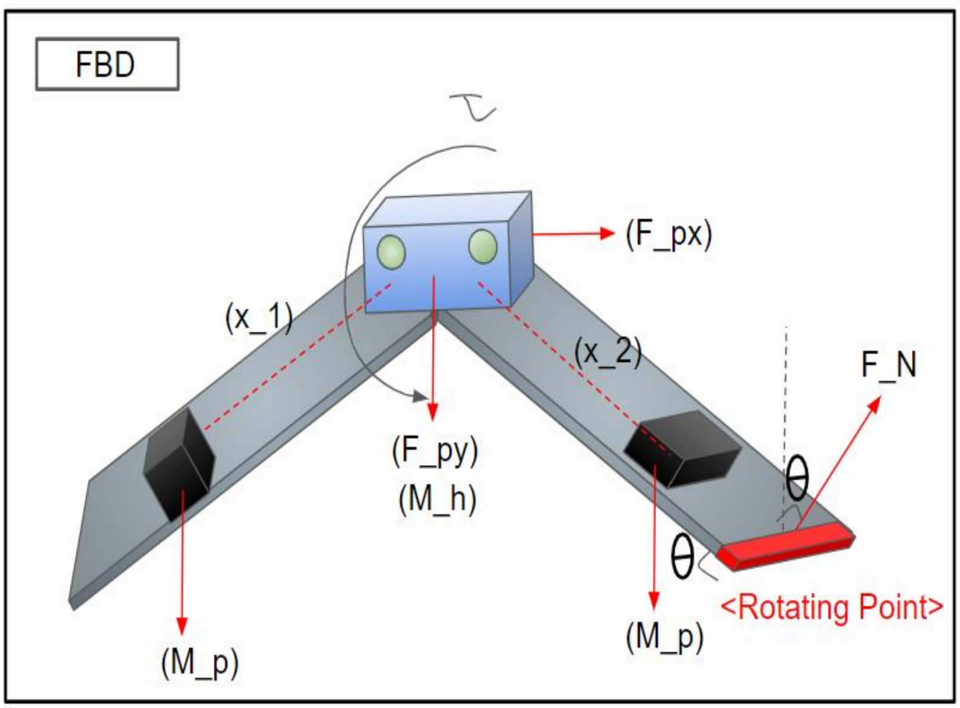
$$\Sigma F_x: F_{px} - F_{pr} \times Cos\theta + F_N \times Sin\theta = 0$$

$$\Sigma F_y: -F_{py} - 2m_1 g + F_N \times Cos\theta + F_{pr} \times Sin\theta - m_h g = 0$$

$$\Sigma M_A: -\tau + m_1 g \times L \times Cos\theta + +m_2 g \times (x_1 \times Cos\theta + \mathrm{L} \times Cos\theta) + (F_{py} + m_h g)\, \mathrm{L} \times Cos\theta = 0$$

As mentioned above, by using 80 mph wind force on a roof angle of 45 degrees, the minimum appropriate mount length is found to be 1.2m for a mount weight of 10kg per mount panel.





$$M_h = Hinge\ Weight$$

$$M_p = \ Panel\ Weight$$

$$F_N = \ Normal\ Force$$

$$X_{12} = \ Length\ (between\ the\ hindge\ and\ weght)$$

$$L = \ Length\ of\ Mount$$

$$\theta = Angle\ of\ Solar\ Panel\ Mount$$

Figures 43-44: Free Body Diagram for the calculation of mount's specification

The actuation method to drive the panel tracking is accomplished through a power screw and linkage design. Figure 45 shows a labeled parts diagram of parts on the solar folder relevant to the actuation. These labeled names will be referred to in this actuation engineering analysis. The part deemed most likely to break and which defines the whole actuation system specification is the power screw, so analysis focused on the power screw. Other parts in the actuation design received calculation analysis that are excluded from this report as they did not drive the design.

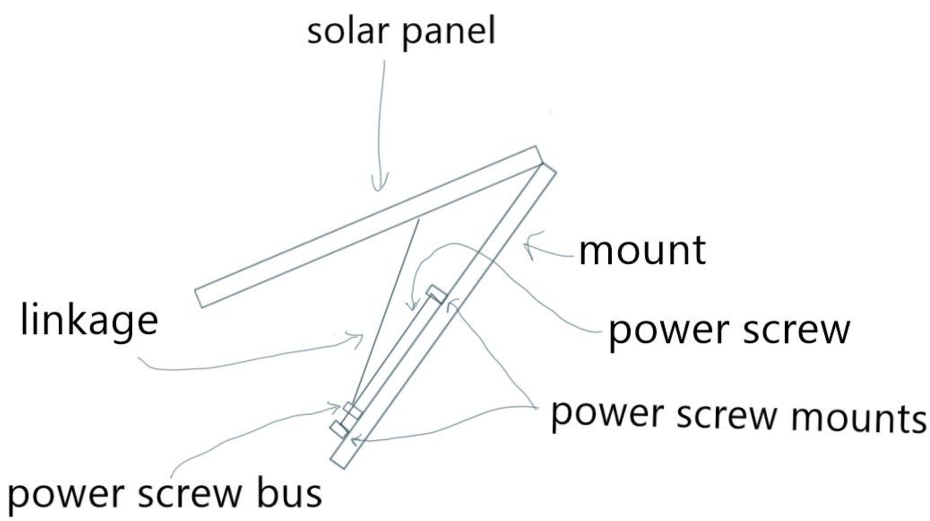
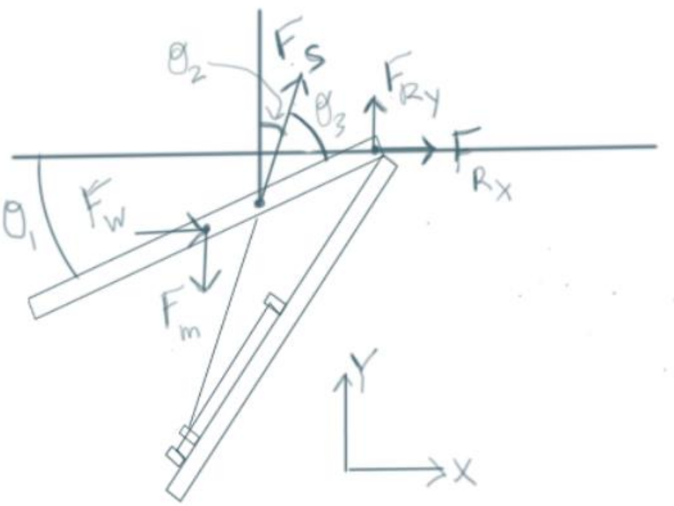


Figure 45: 2D Side View of the Solar Folder Actuation Geometry

The forces experienced by the Solar Folder change as the panel is tilted at different angles. Therefore, the system is designed around the worst-case scenario when loads are highest. A programming script was created to calculate the relevant actuation forces and machine design checks at any angle or setup the Solar Folder could be at, but only the worst case will be described in this report. Forces are maximized when the Solar Folder was in its lowest position at 35 degrees below horizontal and the solar panel is being raised in high wind speed conditions. Figure 46 displays a free body diagram of the worst-case scenario. The hinge contact point and the linkage attachment point to the solar panel are both approximated as pin supports. θ_1 is set to -35 degrees in this scenario. This analysis is 2D and assumes the forces in the third depth dimension to be uniform and therefore excludable in this static analysis. Forces that are important to identify are the wind force, weight of the solar panel, hinge reaction forces, and the linkage lifting force which originates from the power screw. Using a static balance of forces and moments, Eqn. 1, it can be shown that the linkage force (F_s) equals 2,112.7 N.



$$F_s = Linkage\ Force$$

$$F_w = Wind\ Force$$

$$F_m = Weight\ Force$$

$$F_R = Reaction\ Force\ from\ Hinge$$

$$\theta_1 = Angle\ of\ Solar\ Panel\ Relative\ to\ Horizontal$$

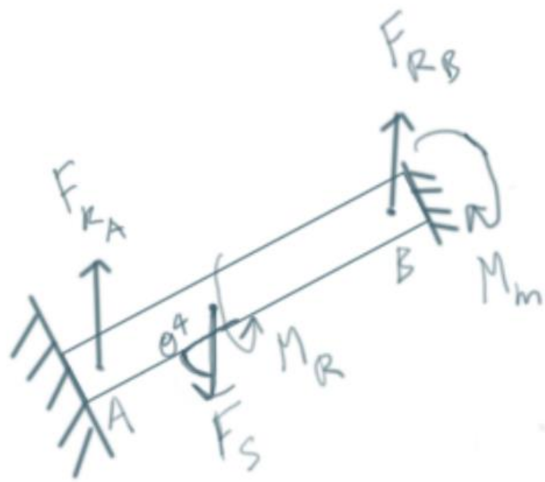
$$\theta_2 = Angle\ of\ Linkage\ Force\ Relative\ to\ Vertical$$

$$\theta_3 = Angle\ of\ Linkage\ Force\ Relative\ Solar\ Panel\ Surface$$

Figure 46: Free Body Diagram of the Solar Panel. F_s is the primary force of interest, as it determines the specifications of the power screw.

$$\sum F_x = 0, \sum F_y = 0, \sum M = 0 \text{ (Eqn. 1: Static Balance Eqn. System)}$$

Now that F_s is known, the power screw design can be solidified. Figure 47 shows a free body diagram of the power screw. Once again, this diagram is two dimensional, so forces in the third dimension are assumed to be uniform or cancel each other out in the third dimension. The forces impacting the free body diagram are the reaction forces from the power screw mounts, the force from the power screw bus/linkage/solar panel, the torque from the motor powering the screw, and the reaction torque of the power screw bus. Weight of the power screw is negligible compared to these other forces. Again, a force and moment balance (Eqn. 2) is performed to calculate internal linkage forces used in part machine design and to generate minimum motor specifications.



$$F_s = Force\ from\ linkage$$

$$F_R = Reaction\ Forces$$

$$M_m = Motor\ Torque\ Along\ Power\ Screw$$

$$M_R = Reaction\ Torque\ From\ Bus\ Along\ Power\ Screw$$

$$\theta_4 = Angle\ of\ Linkage\ Force\ Relative\ Power\ Screw\ Axis$$

Figure 47: Free Body Diagram of the Power Screw. Points A and B are quasi fixed supports. They are fixed in the 2D plane(as drawn), but the power screw is three dimensional and has freedom of rotation which is difficult to convey in the 2D free body diagram.

$$T_R = \frac{Fd_m}{2}\left(\frac{l + \pi f d_m \sec \alpha}{\pi d_m - fl \sec \alpha}\right)$$ (Eqn. 2: Raising Torque for ACME Screw)

$$f > \tan \lambda$$ (Eqn. 3: Power Screw Self-Locking Condition)

F_S can be broken down into component vector forces. Specifically, the force directed along the axis of the power screw is found to identify the force required to lift the power screw bus. This force was found to be 3,419.5N. To translate this force to the motor torque needed, Eqn. 2 is used. The torque to lower the screw bus is similarly calculated. It is found that the lifting torque required is 10.88 Nm and the lowering torque required is 7.98 Nm. This determined that a motor which can provide 11 Nm of torque should be chosen if no gearbox is desired. Additionally, a major factor in choosing a power screw as the actuation mechanism was that it can be self-locking. Eqn. 3 displays the conditions past which the power screw will self-lock without any motor actuation. The friction coefficient is found to be higher than the lead angle in this loading case, which means the system does self-lock. The power screw specification is initially assumed and then iteratively calculated to end with a 1-inch diameter with 10 threads/inch ACME screw.

Basic specifications were decided from this force analysis, and a machine design analysis was used to verify the power screw design. The screw is checked to find failure due to stress, deflection, and buckling. The stress check utilizes a 3D Von Mises Stress comparison, Eqns 4 & 5.

$$\sigma' = \frac{1}{\sqrt{2}}\sqrt{(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{xz}^2)}$$ (Eqn. 4: 3D Von Mises Stress)

$$\sigma' \leq S_y$$ (Eqn. 5: Von Mises Stress Check)

The normal and shear stresses required to calculate the 3D Von Mises come from a combination of bending, axial, and torsional stresses in the power screw. The worst Von Mises stress will be seen on the surface of the power screw where the power screw bus is located. The loading case of the power screw is described in Figure 47. Plugging in Eqns. 6, 7, and 8 into Eqn. 4, the 3D Von Mises Stress is calculated, and the 3D Von Mises stress is found to be less than the yield strength of the screw. Additionally, Eqn. 5 is satisfied meaning that the power screw will not fail due to stress.

$$\sigma_x = \frac{F}{A}$$ (Eqn. 6: Axial Normal Stress)

$$\sigma_x = -\frac{M_z y}{I_z}$$ (Eqn. 7: Bending Normal Stress)

$$\tau_{xy} = -\frac{Tr_{\max}}{J}$$ (Eqn. 8: Torsional Shear Stress)

The subsequent machine design check is to determine if the screw may fail due to deflection. The screw is in a fixed support intermediate loading scenario which means that its deflection can be calculated using Eqn. 9 where a and b define the position of the power screw bus by length to the power screw ends on either side. The deflection was found to be 0.013 in, which is negligible, so the beam does not fail due to deflection.

$$y = \frac{Fa^3b^3}{6EIl^3}$$ (Eqn. 9: Deflection for a fixed-fixed beam with intermediate load)

Lastly a buckling analysis is undertaken. The column is not a short column, and its slenderness ratio determines that the use of Eqn. 10 is recommended to calculate buckling failure. The fixed-fixed load case recommended 1.2 as the value for the End-Condition Constant C. The compressive load on the power screw is found to be less than P_{cr} so the power screw does not fail in buckling.

$$P_{cr} = \frac{C\pi^2 EI}{L^2}$$ (Eqn. 10: Buckling Limit)

Many modes of failure have been checked on the critical part of the actuation system and the specification of the power screw mechanism have been verified. These failure criteria and specifications have been determined iteratively to arrive at the final design values.

When calculating for the design of the pins used throughout the system, a double shear analysis was done (Figure 48). Given a maximum force of 1500N divided over two hinges, the pins for the hinge were required to be 2.58mm as shown in equation 11 below. This was determined to be far lower than any pins that were being used.

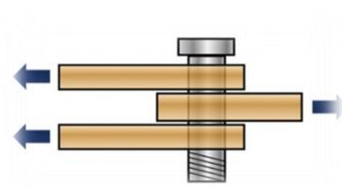


Figure 48: Double-Shear Joint

$$F_{total} = \frac{1500N}{2} = 750N$$

$$Safety\ Factor = 1.5 \qquad Yield = 215\ MPa$$

$$\tau_{allowable} = \frac{Yield}{Safety\ Factor}$$

$$V = \frac{F_{total}}{2} = 375N$$

$$D = \sqrt{\frac{4V}{\tau_{all}\pi}} = 2.5811mm$$

(Eqn 11 Double Shear Pin Diameter Formula)

The next concern for the design was the stress caused by contact between two concentric cylinders. In other words, the pins rubbing on the inside of the hinge cause a high amount of stress. Thus equation 12 was used to find the maximum pressure to be 103.96 MPa. The material properties used were those for steel.

$$b = \sqrt{\frac{2\cdot F}{\pi\cdot 1}\cdot\frac{\frac{\left(1-\nu 1^2\right)}{E1}+\frac{\left(1-\nu 2^2\right)}{E2}}{\frac{1}{d1}+\frac{1}{d2}}}$$

$$Pmax = \frac{2\cdot F}{\pi\cdot b\cdot 1}$$

Equation 12: Contact Stress for Concentric Cylinders

Finally, the thickness of the hinges were verified to withstand the combined wind force and weight of the panels. The main concern for a thin hinge would be buckling. Thus firstly hand calculations to find the critical load were conducted as seen below.

$$L = 150\ mm$$

$$C = 1.2$$

$$I = 2167.87\ mm^4$$

$$P_{critical} = \frac{SF(C\pi^2 EI)}{L^2} = 2.1681e+05\ N$$

Equation 13: Buckling Load for Hinge

Then this calculation was verified using Siemens NX Finite Element Analysis software using a mesh sized 7mm overall, 0.5mm around holes, with pinned constraints, and 400N bearing loads the part appears as seen in figure 49.

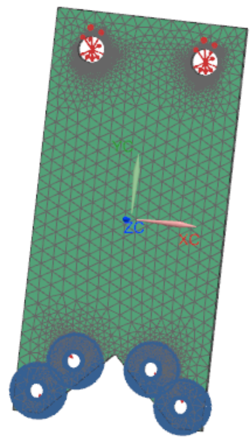


Figure 49: Hinge Mesh

Then a linear buckling analysis was performed which found the maximum displacement under this load would be 0.00129mm at the hinge pin holes (Figure 50). The maximum von misses stress would be just 7.689 MPa (Figure 51). Lastly, the first buckling mode occurs at 51 times the given load. The following two buckling modes were included for future analysis if higher forces are to be endured (Figure 52).

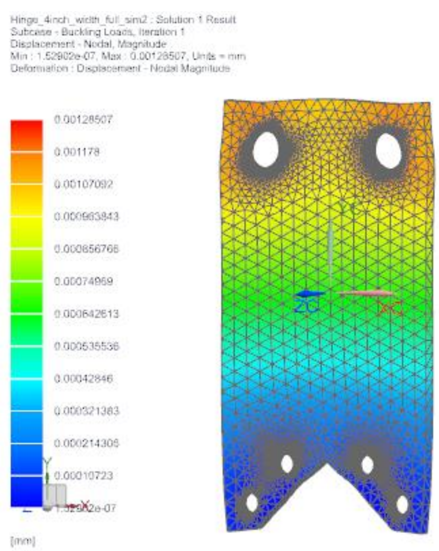


Figure 50: Maximum Hinge Displacement

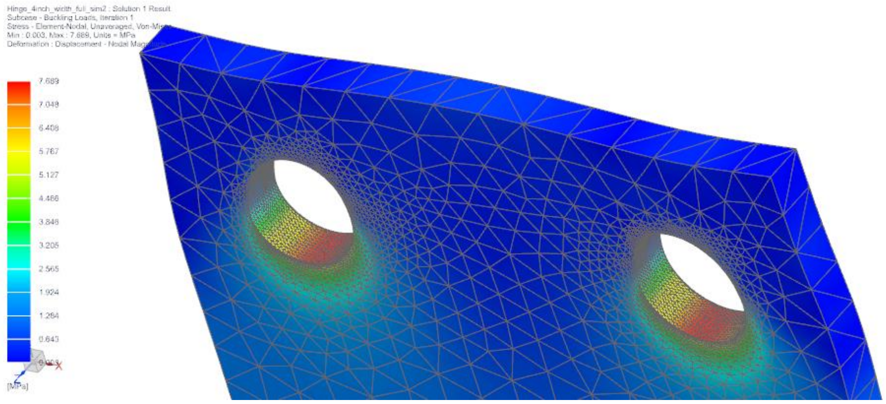


Figure 51: Maximum Hinge Von Misses Stress

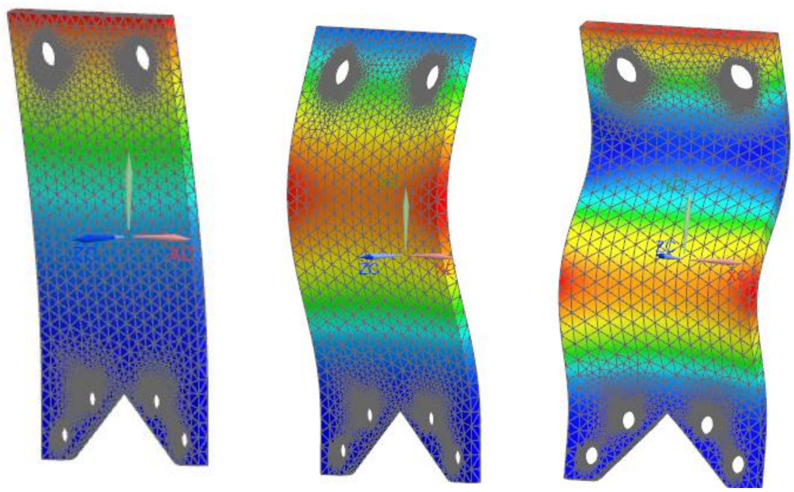


Figure 52: Hinge Buckling Modes

In addition, a linear analysis was performed on the actuating linkage arm (Figure 53). This part is of high importance as it bears the weight of the panel and allows it to rotate to track the sun. This analysis assumes a situation in which the dampers are not connected, the wind is pulling the system into tension, and the arm is pinned on both ends (Figures 54 and 55). This part experiences a maximum von misses stress of 101.74 MPa (Figure 56). The deflection is only 0.0229mm at this time (Figure 57).

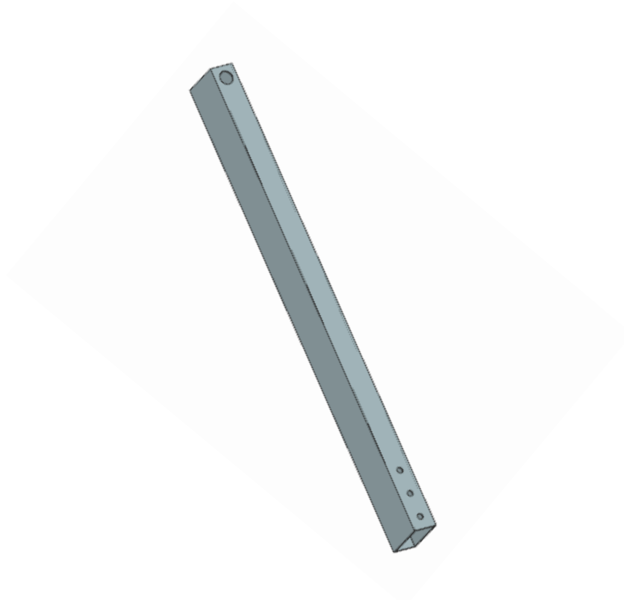


Figure 53: Actuating Linkage Arm Model

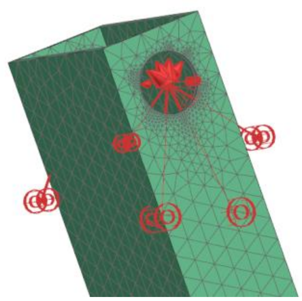


Figure 54: Actuating Linkage Arm Bearing Load

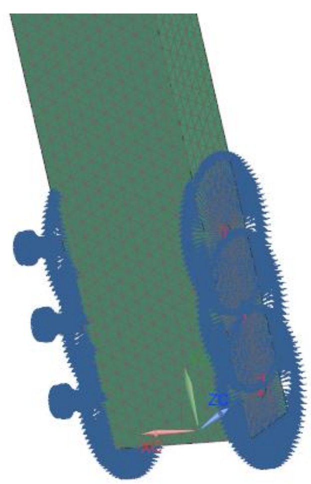


Figure 55: Actuating Linkage Arm Pinned Constraints

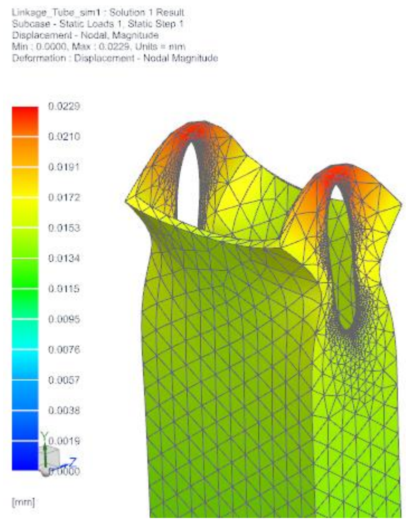


Figure 56: Actuating Linkage Arm Displacement

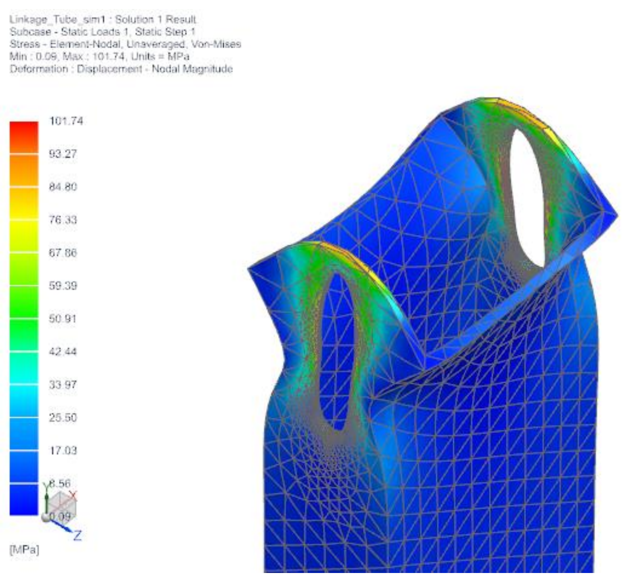


Figure 57: Actuating Linkage Arm Von Misses Stress

X. Final Design, Mockup and Prototype

The final design for the Solar Folder is shown in Figures 58, 59, and 60. It is comprised of four main sub system: actuation, mount, top panel, and hinge. The use cases of the final design on a mid-class suburban American customer's home is dislayed in Figure 61. The use cases include the Solar Folder sitting on the roof, additional modular units attachted to each other, and sitting on a flat area of the homeowner's property. Figure 62 suggests the view that pedestrians would see of the Solar Folder in use.

Figure 58: Solar Folder Full Render

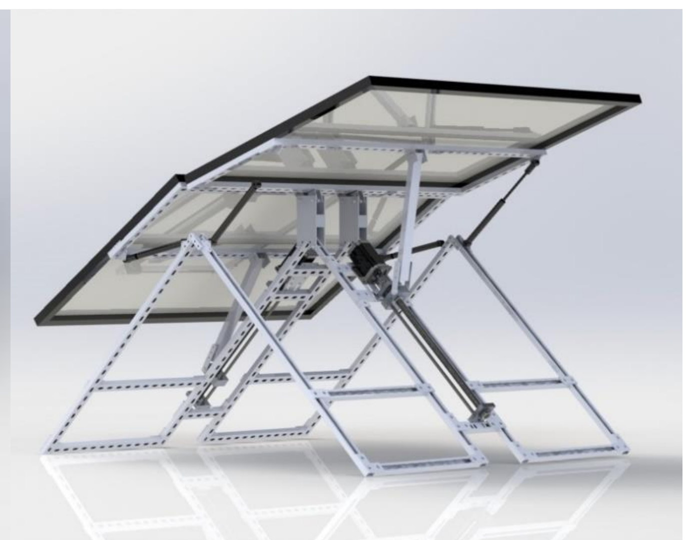


Figure 59: Solar Folder Top View

Figure 60: Solar Folder Bottom Side View Render

Figure 61: Solar Folder Use Cases Render

Figure 62: Solar Folder Street View Render

The goal for this capstone project was to show an actuating Solar Folder mount that could sit on a faux roof . The combination of the Solar Folder structure and actuation that enable ease of customer use and affordability per kWh is the innovation in this product, so showing this was the criteria for project success. Due to budget limitations sitting around $1000, only half of the prototype was actuated. Figure 63, 64, and 65 show various views of the final actuating prototype sitting on a mock roof. Figure 66 displays the electronics modified to actuate the solar tracking system. The system was able to tilt the solar panel faster than the actual angular speed of the sun relative to any single point on earth. The mount, top panel, and hinge sub systems supported the panel weight along with the actuation forces with ease. The magnitude of force that an 80 MPH wind would exert on the system was impossible to simulate, as a system to apply thousands of Newtons of force would have to be created. This wind force test was beyond the feasible budget of this capstone project. The full Bill of Materials for the assembled prototype is shown in the Budget Appendix.

Figure 63: Solar Folder Prototype

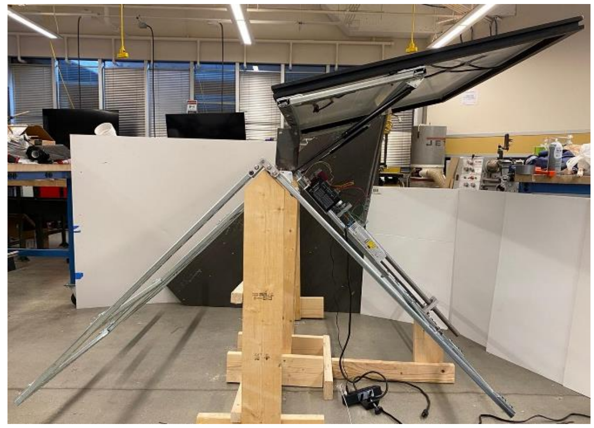



Figure 64 & 65: Solar Folder Prototype Various Views

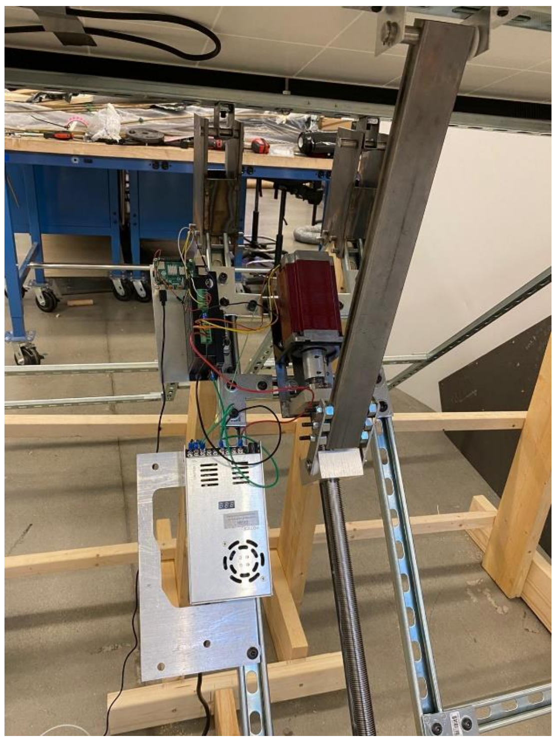


Figure 66: Electronics System for Solar Tracking Actuation

The actuation system final design is labeled in Figure 67. The designed system changes the panel angle using a single linkage lead screw mechanism. Figure 68 shows how this mechanism works. The stepper motor shaft is couples to the lead screw. When the lead screw rotates a nut that is fixed to the bottom end of the linkage moves linearly along the lead screw length. As the bottom end of the linkage moves away from the stepper motor, the top end of the linkage decreases in vertical height which moves the solar panel down. The top end of the linkage is in a fixed position at the bottom of the top panel/solar panel. The lead screw system worked as designed in the engineering analysis section and held the linkage stationary when the stepper motor was not actuated. The lead screw that was chosen from the analysis was a low carbon steel of 1in. diameter, and no deflection to the eye occurred under the load greater than the weight of the solar panel. This allows the panel to stay in a fixed position without consuming large amounts of energy. The final part of the actuation system implemented was the gas springs. These gas springs provided force to offset the weight of the solar panel in addition to acting as dampers. The gas springs provided 60lbs of force to offset the 45 lbs weight of the panel along with the weights of the top panel. The gas springs helped to offset any quick uneven forces applied to the solar panel along its width. High speed winds would apply such a force. The gas springs helped to reduce the moment experienced by the linkage. While precise amount of force that the system would experience under 80MPH winds could not be reproduce, about 50lbs of force were applied to each edge of the panel quickly to test this damping effect.

The range of the actuation system was a little different from the intended design due to manufacturing imprecision. It was designed to be rise to 30 degrees and lower down to -45 degrees relative to horizontal. However, the system created only rose to 28 degrees and lowered down to -45 degrees. Figure 69 displays the range. This does not exactly match the specifications desired, but it is very close by being under the target by 2 degrees. This imprecision can be excused by prototype conditions being in place but achieving a 30-degree angle for a final product is feasible given what the prototype has shown to be possible.

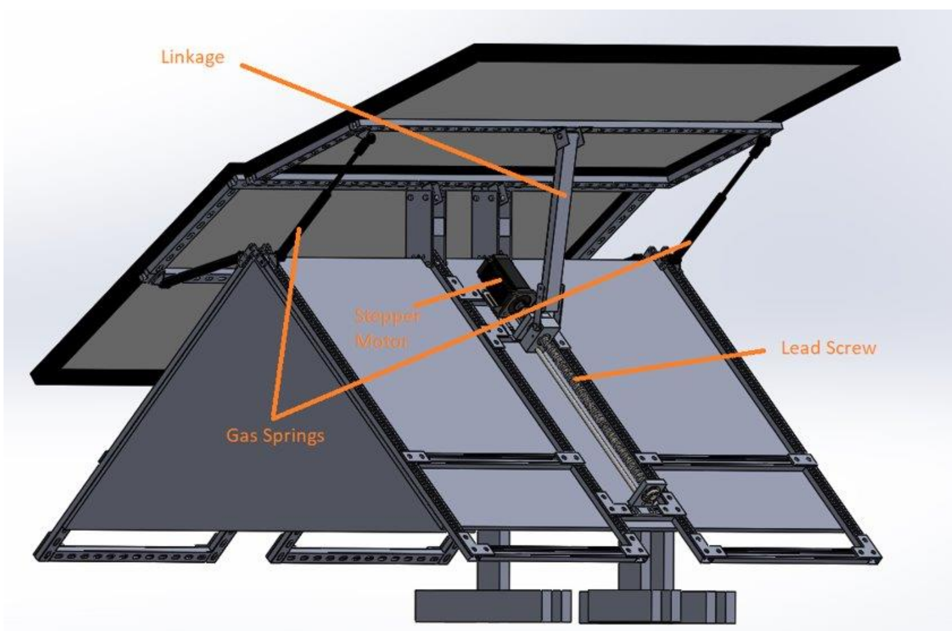


Figure 67: Labeled Actuation System Design

Figure 68: Single Linkage Lead Screw Actuation

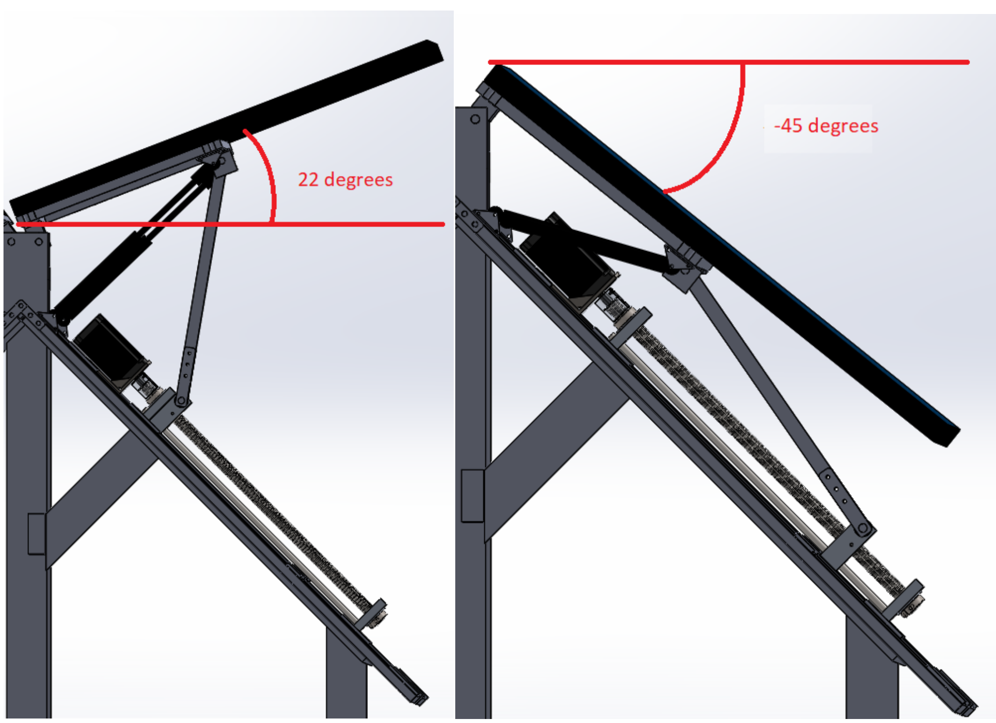


Figure 69: Maximum and Minimum Range of Solar Panel Tilt

The prototype mount assembly is shown in Figure 70 and consists of four individual mounting blocks which are attached together via connecting struts. Each of the mounting blocks weigh approximately 6.5 kg and are 4 ft by 2.25 ft in size. The prototype mount is constructed using purchased "super-strut" that is made of plain steel and is bolted together with corner brackets. This material was chosen due to its availability and low cost, but the final mount (Figure 71) design uses galvanized steel as this is much more resistant to the elements. The mounting system works by counterbalancing the weights of the solar panels in combination with weights added to the base of the mount to prevent the system from tipping over, whether on the roof or on the ground. As mentioned previously, 80 mph wind loading was not feasible in the given time limit and budget, but the prototype mount did succeed in supporting the panel on a faux roof during repeated actuated. The actuation system is attached to the mount via the connecting struts, and dampers are attached to the outer edges of each mounting block to resist lateral movement of the panel. The hinge is attached to the mount via two holes that pins are slotted into at the upper edges of the mounts. These pins may be adjusted to accommodate any mounting angle from 0 to 45 degrees.

The prototype version is designed for ease of assembly and disassembly but involves a high number of fasteners and steps. The final design (Figure 71) requires no customer assembly of the individual mounting blocks and allows for more streamlined installation. The same weight attachment points are included to allow for customization of overall mount block weights depending on local average wind speeds and mounting angle. The design also includes a handle at the bottom to allow customers to more easily maneuver the mount blocks. This final design was not used for the prototype due to additional complexity in manufacturing as well as upfront cost for the sheet metal and shipping.

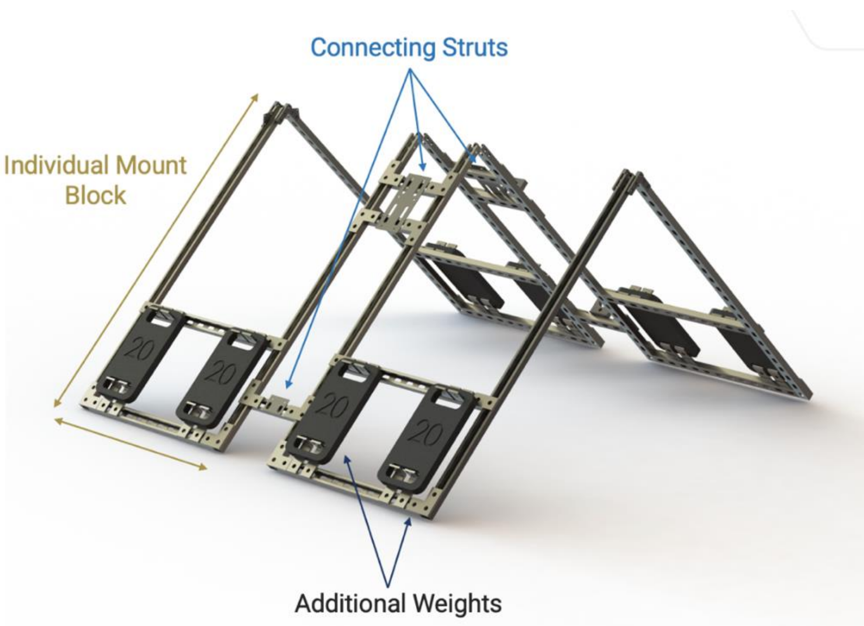


Figure 70: Full Prototype Mount System Assembly

Figure 71: Bent Metal Final Design Mount Block

This product is meant to be compatible with most 350 watt solar panels. In order to achieve this goal, the team created a quick attach panel strut subassembly which screws into commercial solar panels. This subassembly is comprised of two 65 inch and two 15.75 inch Super-Strut steel bars (figure 72). These bars are compatible with the varied bolts configurations of the many panel manufacturers.

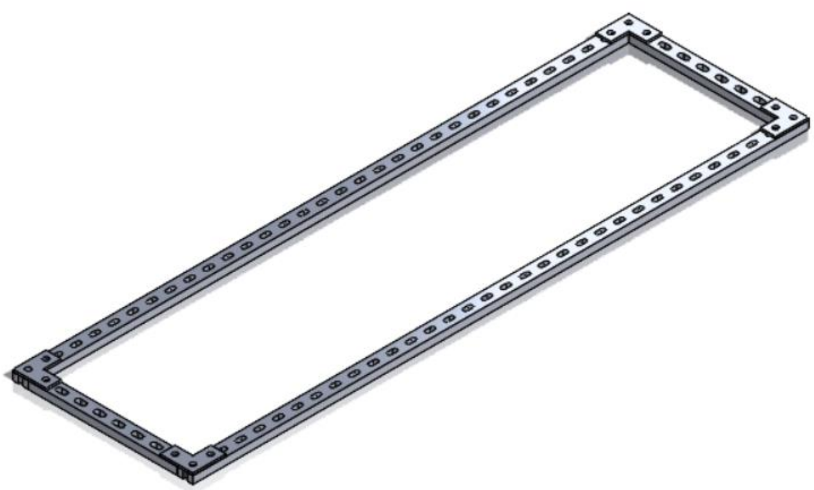


Figure 72: Panel Strut Subassembly

The hinge was custom designed to allow for the product to operate on any pitch of roof. The prototype can only be locked into the maximum 45 degree pitch roof, but a final product design would include multiple pin locking locations to adapt to various roof angles. This is where the "folder" in "solar folder" is envisioned. There are two large pin holes on top for the twin panels to rotate and 4 pin holes on the bottom for the panel mounts to attach (Figure 73). Four hinge cutouts are created and four spacers are placed between them to allow clearance for the mount subassembly and panel strut assemblies to attach (Figure 74). Finally, four U-shaped connectors are manufactured to attach the panel strut subassembly to the hinge subassembly (Figure 75).

Figure 73: Hinge Panel

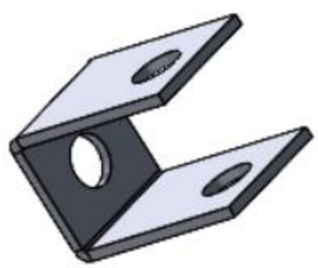


Figure 74: Hinge and Strut Assemblies U- Connector

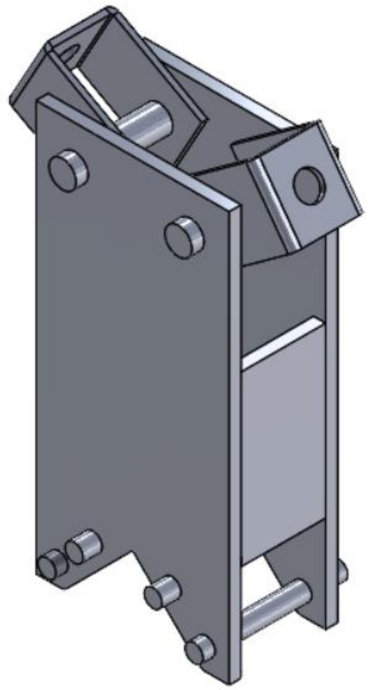


Figure 75: Hinge Subassembly

XI. Manufacturing

The Solar Folder is manufactured by utilizing a multitude of machining and tooling methods, as each subsection consists of at least one custom designed and manufactured part. The actuation system features the most complex custom designed parts. Most notably, the motor coupler (Figure 76) which connects the stepper motor shaft to the 1” diameter lead screw is a technically challenging prototype part. The coupler is manufactured using a manual lathe and a vertical mill. The lathe is used to cut the concentric hole for the shaft of the stepper motor and the lead screw. The vertical mill is used to cut and thread the holes normal to the coupler, which allow for the set screws to lock onto each shaft. In addition, a high-speed bandsaw is used to cut the shaft relief and the set screw relief that allows for the tightening of the coupler. At a larger scale, this manufacturing process may need to be shortened in time due to the potential of high labor costs to manufacture. A CNC machine may be a more economical option, as the time to mass produce this custom motor coupler can drastically decrease.

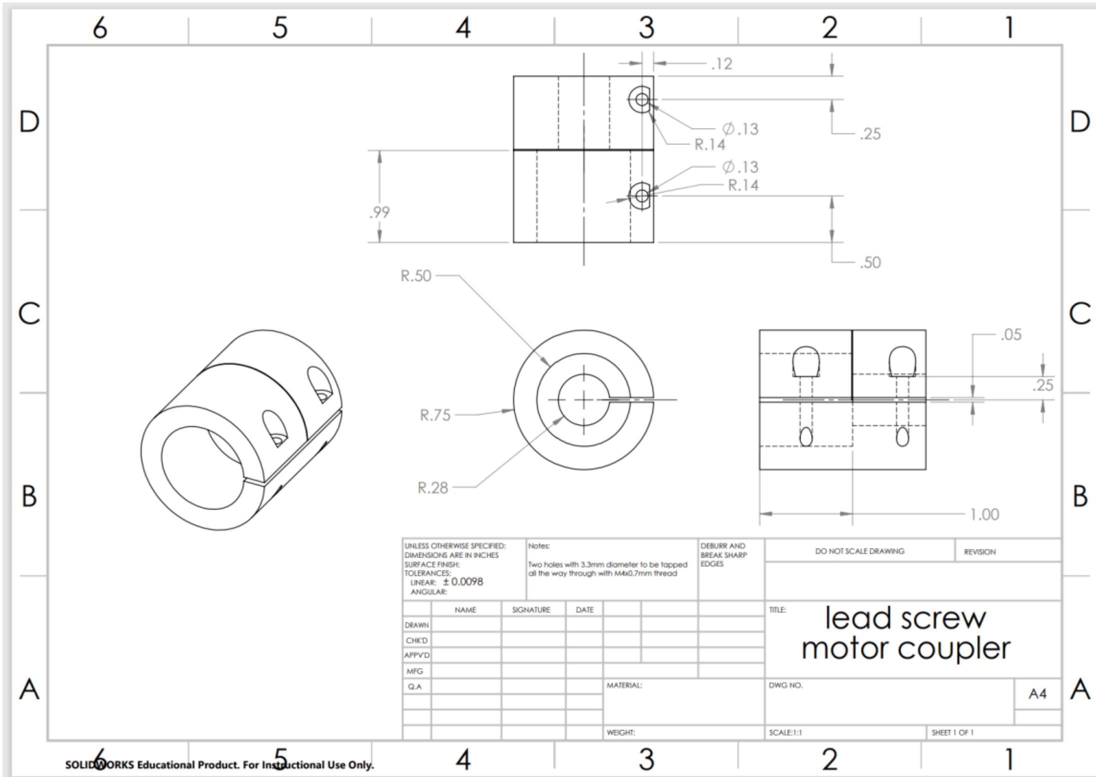


Figure 76: Lead screw motor coupler drawing

Other custom machined parts include the top actuation shaft (Figure 77), screw bus shaft (Figure 78), lead screw bus, (Figure 79), lead screw rail (Figure 80), lead screw nut (Figure 81), and 2 lead screw mounts (Figure 82). Since these parts are relatively easily machined using a both manual lathe and vertical mill, for large scale production, labor costs may be low enough to save capital costs for a CNC mill. The most challenging aspect from these parts are the depth of the cuts, which can be either extremely miniscule or considerable. This should not cause issue though, as machinists are trained with and use extreme precision manufacturing parts. Aside from custom machining, other manufacturing processes used include welding, water jetting, metal cutting, and metal drilling. Each hinge is formed by welding two steel plates using a connection piece. For mass production this manufacturing step may need to be automated in order to increase production speed. CNC machining may be a more cost-effective and reliable method moving forward.

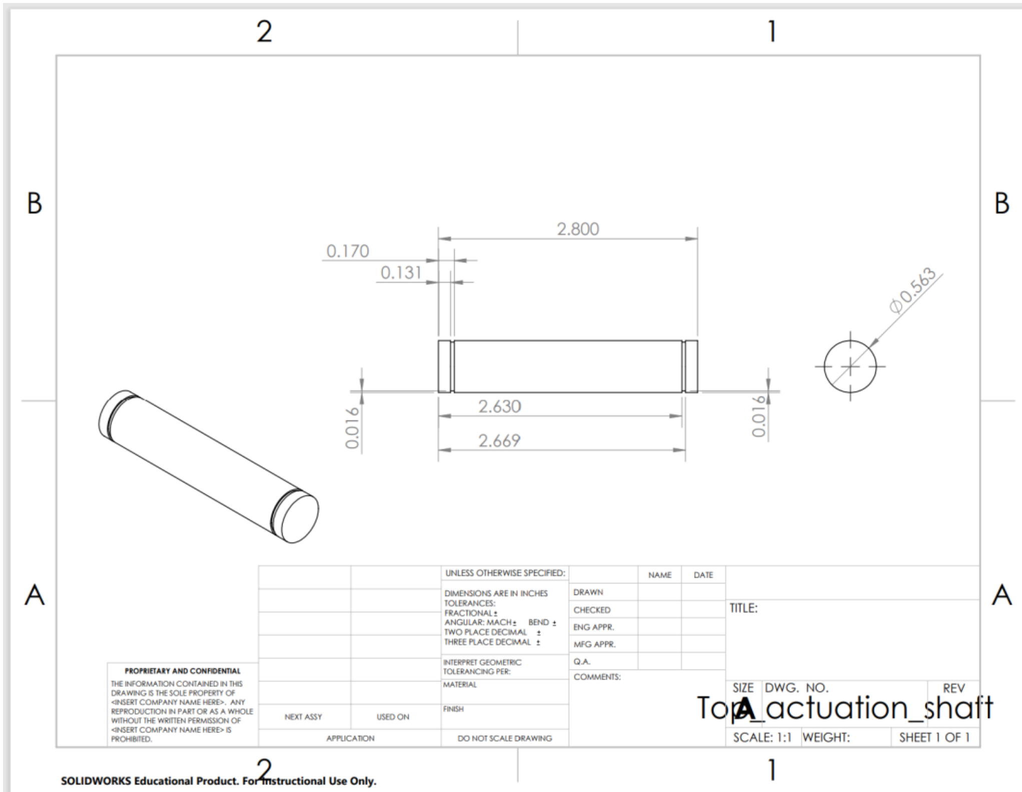


Figure 77: Actuation shaft drawing

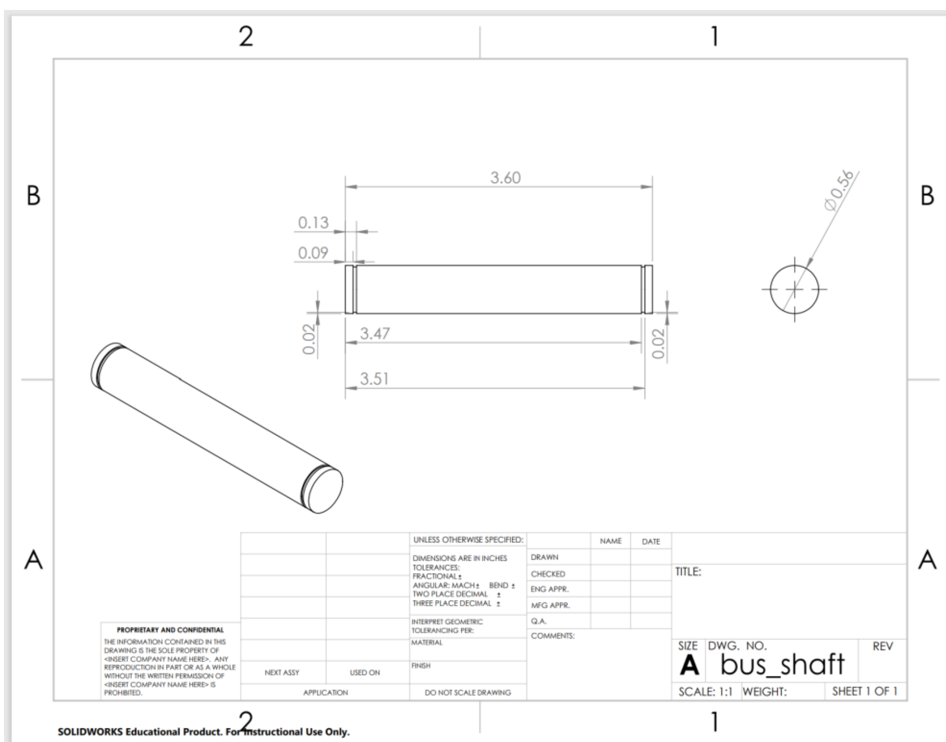


Figure 78: Screw bus shaft drawing

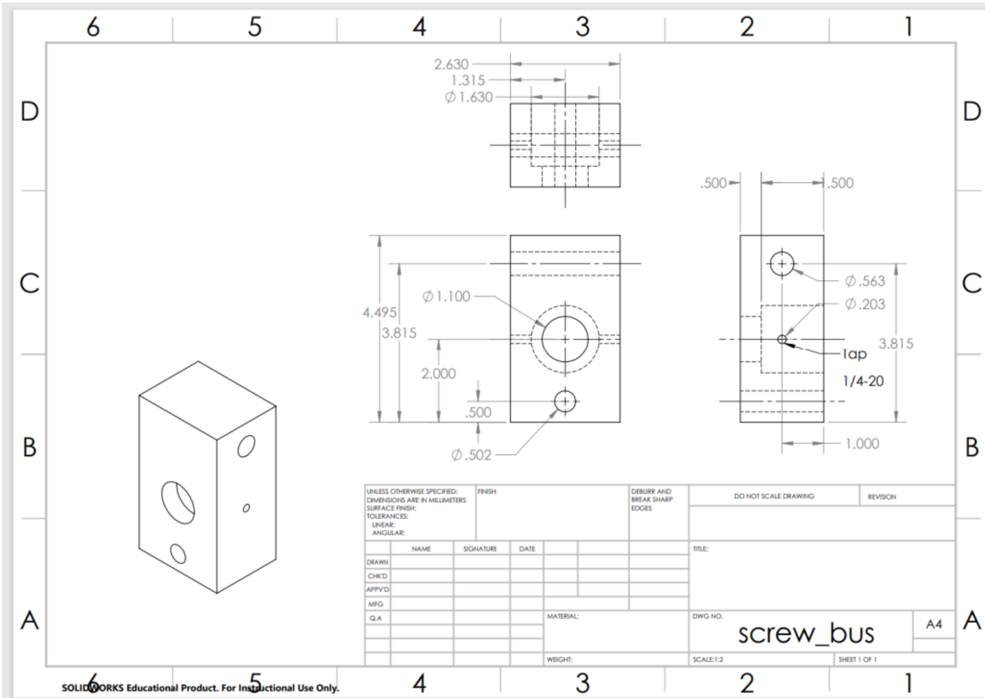


Figure 79: Lead screw bus drawing

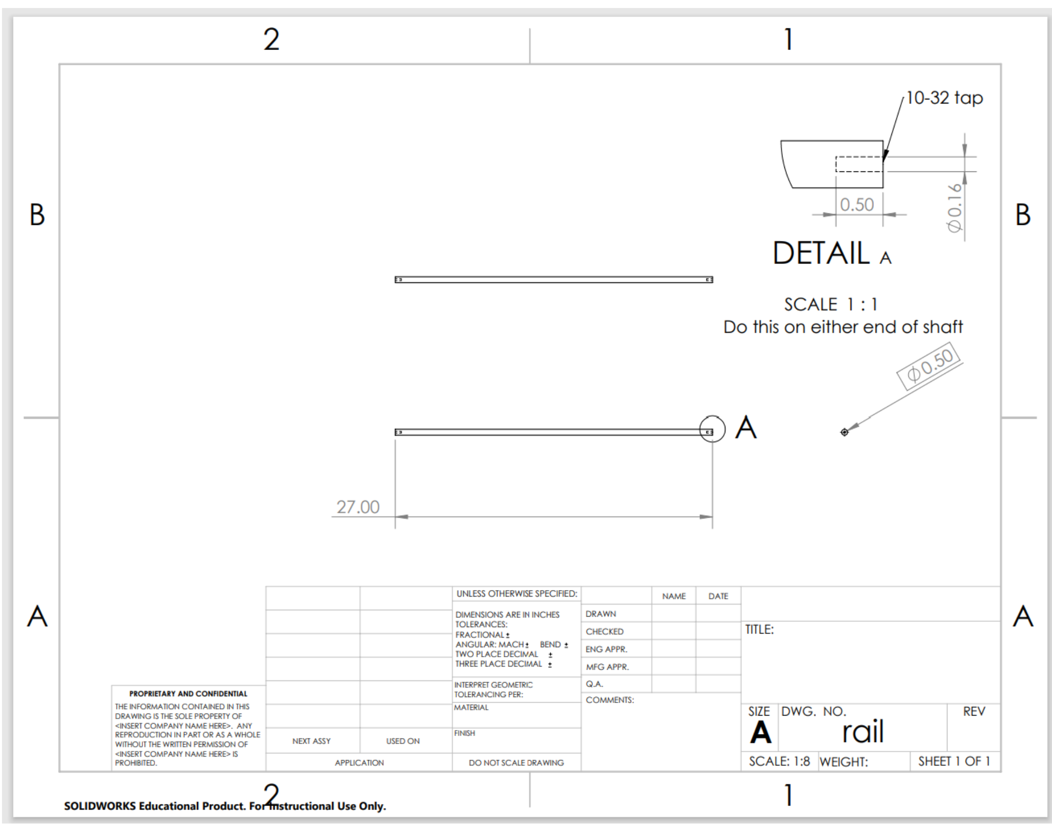


Figure 80: Lead screw rail drawing

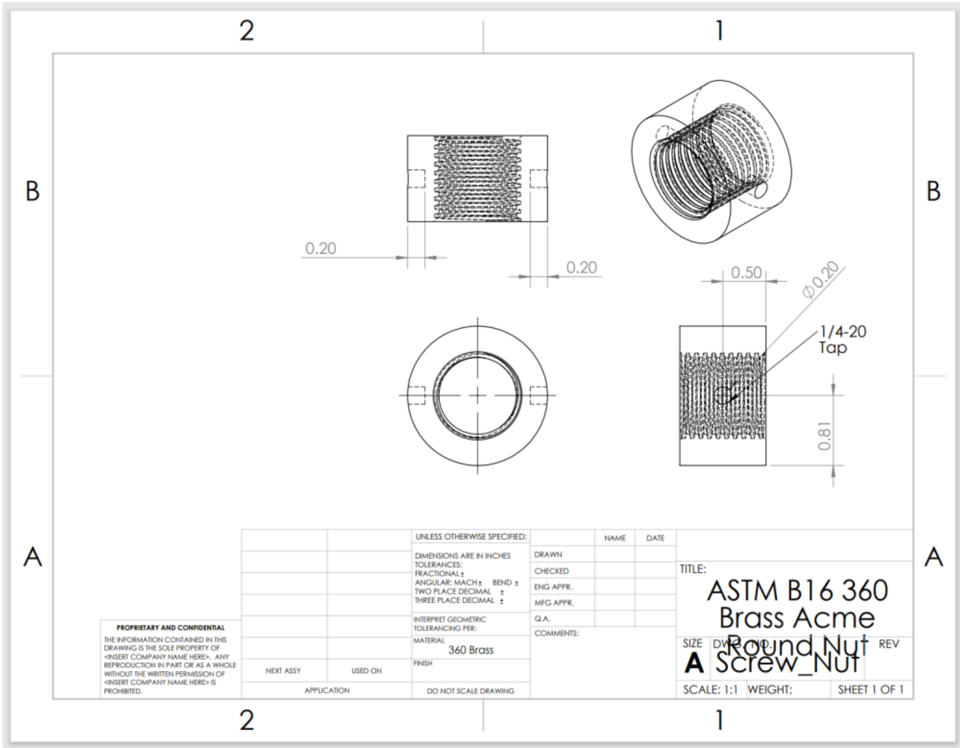


Figure 81: Lead screw nut drawing

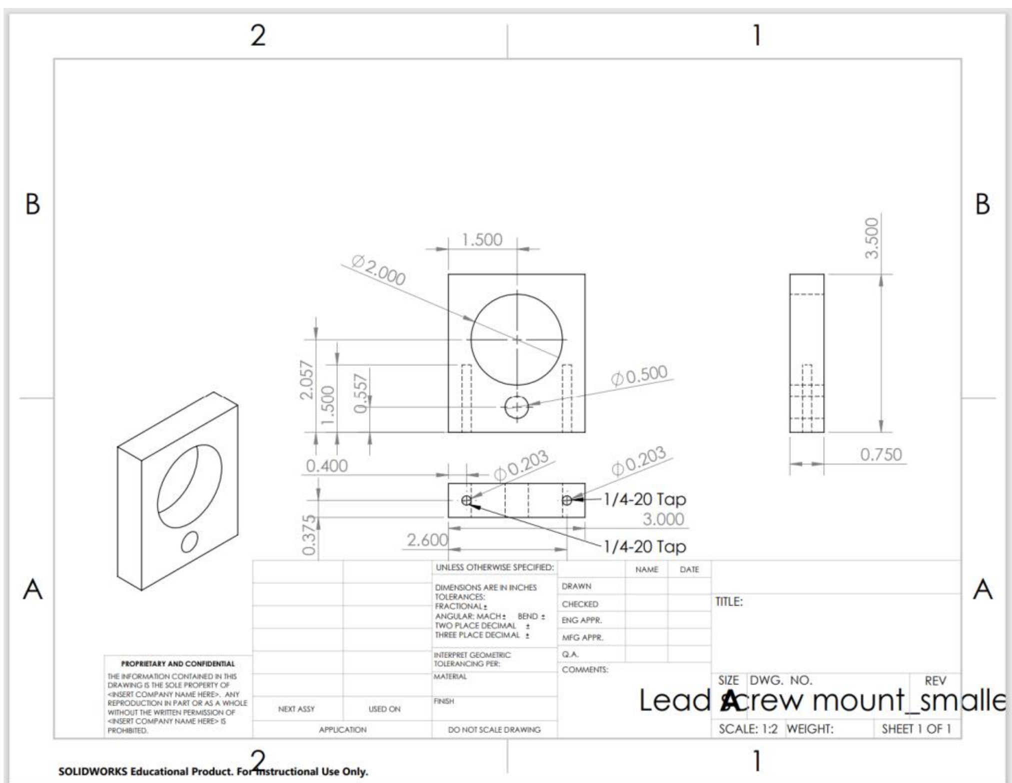


Figure 82: Lead screw mount drawing

Material selection is essential in manufacturing a successful solar folder. Due to large forces on each solar panel (~ 46 lbs.), the stepper mount and electrical system (~ 15 lbs.), and each hinge (~10 lbs.), material with a high tensile strength and ultimate tensile strength must be chosen. For the initial prototype, *Superstrut* Electro-Galvanized Strut Channels is used to construct the mount. Although *Superstrut* succeeded in bearing the various loads on the Solar Folder, a more easily manufacturable and reliable material (6061 aluminum) should be used for large production. Each part of the actuation subassembly which is weight-bearing (lead screw mounts, screw bus, and motor coupler), is machined from 6061-T6 aluminum, which is both high-to-moderate strength and corrosion resistant.

Special production methods that are necessary to design and construct the Solar Folder including waterjetting, use of the manual lathe and the vertical mill. These machines are strictly only allowed to be used by certified individuals. Team members of the design team are required to pass the training course for each respective machine in order to be able to use it. Machined parts that require precise tolerancing include each shaft that requires retaining rings. The retaining rings the team has selected are 0.03" in width, so machining of the retaining ring grooves requires extreme accuracy. In addition, a press fit must be achieved to exactly place the lead screw bearings inside the lead screw mounts, cuts must be made ± 0.05" to the required hole diameter. Although having both large parts and involving complicated machining processes, the Solar Folder is a system that can be easily assembled using tools found in household toolkits (i.e. screwdriver, wrench, drill, hammer) once the required parts are machined. Each assembled Solar Folder mount occupies ~ 36 square feet, in result ample assembly and storage space is required, as well as special shipping methods of oversized parts.

The total production cost estimate for the Solar Folder is $2816.23, including raw material and parts costs and labor costs. The raw material and parts cost for the Solar Folder is $1073.98, a price breakdown is found in Table 3. As highlighted by the table, the mount subsystem and the actuation system are the most expensive in terms of raw material and parts, this estimate may be substantially lowered during mass production, as large quantities of material tend to come in discount bulk prices. Due to custom machining and assembly involving the subsystems of the Solar Folder, about 75 labor hours are necessary for the design team before the product is ready for shipping. In the state of Georgia, using the average hourly wage for an entry-level machinist ($23.23 [15]), the total labor cost for the Solar Folder before shipment is $1742.25. The total production cost of the Solar Folder can be optimized for mass manufacture as several iterations of the prototype will feature a sleeker design and use cheaper materials, in addition to the team having the access to a streamlined supply chain network.

Table 3: Raw material and parts price breakdown

Subsystem	Cost	
Actuation Hardware:	$	282.13
Electronics:	$	84.97
Hinge:	$	97.46
Top Panel:	$	35.63
Mount:	$	467.79
Solar Panel:	$	100.00
General Materials:	$	6.00
Total Cost	$	1,073.98

XII. Societal, Environmental, and Sustainability Considerations

The Solar Folder is a product that increases the accessibility of renewable energy, and more specifically solar energy, to the general consumer market. A social impact assessment has been completed prior to manufacture to ensure that societal, environmental and sustainability considerations have been considered during the product's lifecycle. Table 4 determines the goal and scope of this assessment, and Table 5 includes an inventory analysis of social life cycle analysis using The Methodological Sheets for Sub-Categories in Social Life Cycle Assessment (S-LCA) [16].

Table 4: S-LCA Goal and Scope Summary

Objective of Assessment	**Design Function**	**Functional Unit**	**Lifecycle Stages Considered**	**Associated Activities**
Assess social impact of Solar Folder	Easily installable system that can maximize solar efficiency with sun-tracking capabilities	Solar mount	Processing	Manufacturing
				Assembly
			Use	Customer use
				Maintenance

Table 5: S-LCA Inventory Analysis Summary

Product Lifecycle Stage	Stakeholder Group	Social Impact Category	Impact Indicators
Processing	Worker	Working Time	Number of effective hours worked per employee
			Number of holidays effectively used by employees (at each level of employment)
		Fair Salary	Living Wages in the US by state, county, community
			Minimum wage in the US by state
Use	Consumer	Health and Safety	Quality of labels of health and safety requirements
			Percentage of injuries due to self-assembly and maintenance
		End-of-Life Responsibility	Do internal management systems ensure that clear information is provided to consumers on end-of-life options?
	Local Community	Community Engagement	Organizational support for community initiatives (Town hall meetings)
			Number and quality of meetings with community stakeholders (HOA meetings)

The Solar Folder is a product that is ultimately designed to introduce new customers into the renewable energy market, whose expansion is greatly necessary for the sustainability and wellbeing of both planet Earth and human life in the future. The design addresses the lack of optimized solar efficiency and ease of installation in typical residential solar panel systems that are widely used throughout the world today. This product will positively impact the well-being of planet Earth, as its widespread adoption will combat greenhouse gas emissions and reduce the world’s collective dependence on fossil fuels [17]. As a result, human well-being will be enhanced through decreases in air pollution and long-term deceleration of global climate change.

Despite the variety of benefits of a renewable energy source such as solar, at the processing product lifecycle stage there are possible negative social impacts to how panels are produced and sourced from foreign countries. As reported by the New York Times, solar technology companies that produce panels in China may be exploiting forced laborers of minority populations for cheap solar manufacturing [18]. In order to minimize the negative societal impact of the Solar Folder, the design will not include panels sourced from companies that are known to exploit workers. In addition, large-scale production of the Solar Folder will be manufactured by workers that are paid a fair wage and given ample vacation time to be used as necessary. These social impact categories can be measured by indicators such as number of effective hours worked per employee and living wages in corresponding manufacturing regions, as highlighted in Table 4.

After manufacturing, the Solar Folder will have societal impacts that will affect both consumers and the local community. As the system is designed to be installed by the average homeowner, health and safety is a potential concern. If the homeowner chooses to mount the Solar Folder on the apex of their roof, they are putting themselves in potential danger. Labels including health and safety requirements will be included with the product, and percentage of injuries due to self-assembly and maintenance can be tracked as an impact indicator. In addition, end-of-life responsibility information will be provided to the owner so that the system can be recycled responsibly if the owner wishes to dispose it. The local community will also be impacted, as the increase in the popularity of Solar Folder systems may increase organizational support for renewable energy initiatives. Homeowners' associations (HOA) that previously banned solar panels in communities due to aesthetics may recall these regulations, so more homeowners are able to utilize solar power in their homes.

XIII. Risk Assessment, Safety and Liability

To reach 100 percent of the original efficiency of this design, management of the panel is required, just as it is with an original solar panel. There is a lot of pollen and dust, especially in the spring and fall, so customers should wipe up the panel and take care of it. Users should use caution when using the panel on the roof, since injuries may be possible during installation, maintenance and removal. Furthermore, unlike original panel mounts, the motion of the mount is created by the motor, so dust should be avoided because dust in the heated motor can catch fire and cause a fire. Customers should also be cautious of possible injuries when cleaning owing to the nature of the design installed in high places.

XIV. Patent Claims and Commercialization

The prototype assembled shows promise for commercialization as there is an established consumer base along with a working prototype. However, the design team has decided to pursue other initiatives, and, therefore, the product will not be commercialized by the current team. Further work such as cost reduction, weight reduction, implementation of a battery system, and customer UI/UX would be required to create a consumer ready product. Consequently, no patent claims are considered at this stage in the product development.

XV. Conclusions, Future Work / Project Deliverables

The problem space, specifications, and solutions concerning home-mounted solar panels have been investigated. The problem has been defined as filling a price-performance-ease gap in consumer solar for the average American homeowner. The project has evaluated many possible designs and a single design direction, the Solar Folder, was chosen. The final design is a durable device that delivers energy at a reasonable price and follows many customer preferences for ease of installation. Further work is required to see the product arrive at a market ready stage. The power system was not designed or created due to limited power electronics expertise and budget constraints. Aesthetics need to be modified to fit typical middle class US homeowner expectations. Weight reduction modifications are needed to improve ease of installation. Additional design analysis is required to finalize ground mount capabilities of the product. The prototype meets most requirements detailed in the specification sheet, but weight, aesthetics, and ease of installations require further market feedback to confirm whether the created prototype is sufficient. The project team has created an initial prototype that show cases the successful preliminary design of the product.

XVI. Team Member Contributions

Madeline Holda: Worked on electrical design and programming, including loading the operating system and setting up SSH access to a Raspberry Pi 4. Obtained a working Raspberry Pi 4 and two stepper motors from the ECE Senior Design Lab. Also designed the electrical system and identified components for purchase. Edited and reviewed several sections of the report. Wrote the Prior Art & Patents section.

Sangjin Lee: Assisted in ideation process. Looked into overall size difference needed for same wattage for flexible and standard solar panels. Calculated amounts of wattage needed for the project. Wrote introduction and background section of report. Assisted the calculation about the mount and panel's specification. Wrote Engineering Analyses and Experiments.

Vishva Patel: Assisted ideation and preliminary design concept selection and justification. Created House of Quality in order to find relationships between engineering and customer requirements. Created Design Evaluation Matrix in order to select most favorable preliminary design for production. Justified all designs analyzed and product design chosen (Solar Folder). Conducted Social Impact Assessment (SIA) and research regarding sustainable sourcing of materials and manufacturing.

Michael Goldstein: Created customer survey for primary market research. Researched existing products and brands. Consulted patent engineer regarding design. Assisted in ideation process. Designed hinge, pins, and panel struts in Solidworks. Got trained in Montgomery machining mall. Waterjetted hinges, cut pins and panel struts, and welded hinge assemblies. Assembled final product. Performed hand calculations to verify design. Recreated full model in Siemens NX in order to perform Finite Element Analysis on the parts.

Olivia Plumb: Researched types of solar panels and methods of solar cell DIY panel. Created specification table and assisted in House of Quality. Brainstormed initial ideas and created function tree and morphological chart. Created Solar Folder graphics and wrote design concept ideation portion of report. Performed static analysis on fundamental mount designs to determine feasibility of designs. Created three iterations of mount designs, including CAD models, part lists, and manufacturing plan. Integrated CAD subsystems into final assembly. Assembled fabrication package. Assembled prototype mount.

Bill Huang: Conducted secondary research in EIA data on wattage and market price. Researched Zoning and HOA Code restrictions on solution implementation. Assisted in finding products on the market. Assisted in ideation process. CADed, designed, and performed analysis calculations for the actuation system of the Solar Folder. Helped assemble and manufacture the prototype. Wrote codes, the actuation system section of the Engineering Analysis subsection, created BOM, created actuation subsection of fabrication package, and conclusion section.

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Global Issues Appendix

The implementation of the proposed Solar Folder solution into the francophone world will require additional consideration of the local culture, market status, pricing and product availability, and government regulations. The following analysis will consider specifically the French market, but further investigation is required to address other francophone countries.

The current state of the solar market in France contributes to the viability of the Solar Folder. Firstly, the French overall are committed to significantly increasing the prevalence of solar energy in the country. Specifically, Macron aims for roughly increasing solar energy production in France by tenfold by 2050 [19]. The state offers grants for solar panel installation to further this goal; consumers are eligible for a 390 euro grant per kW of solar panels installed [20]. Additionally, installations of less than 3kW are subject to a reduced VAT (Value-Added Tax) of only 10% as opposed to the normal 20% [21]. The effects of these measures can be seen in the percentage of French households with solar panels; 13% of households have panels as opposed to the meager 4% in the United States [22] [23]. This shows that the French are receptive to solar panel opportunities. However, one potential pitfall is that there are increased competitor products in the French market. For example, Ikea has partnered with Voltalia in France to provide solar panels at around 15% cheaper than its competitors [22]. While this does provide easier access to solar panel installation, the Solar Folder remains unique in its actuated design and non-invasive mounting technique. Furthermore, the significant cost difference between a single Solar Folder unit and a full roof installation (even if 15% cheaper than competitors) means the product is still a viable alternative for those looking to try solar panels, but who do not have the available capital to purchase a full system.

While the cost of electricity in France makes solar power attractive, the regulations around installing solar may create a higher barrier to entry than in the US. Electricity is more expensive per KilaWatt hour in France than in the US, coming in at $0.193 per kWh as opposed to $0.159 per kWh in the US as of September 2021 [24]. This provides more of an economic incentive for people to make the initial investment in solar. However, a prior declaration of work submitted to the government is required to install any roof-mounted panels in France due to change in appearance. Additionally, any ground-mounted panels higher than 1.8m must apply for city planning authorization if in a protected area.

The French market is investing more and more in solar energy. The high cost of electricity in combination with government-provided grants and lower tax rates make the Solar Folder attractive to French consumers. However, increased competition and government regulations present roadblocks to the implementation of the Solar Folder in France.

Budget Appendix

Part Name	Part Number	Quantity	Cost Per	Sum Cost	Sub System
1018 Carbon Steel Precision Acme Lead Screw, Right Hand, 1"-10 Thread Size, 3 Feet Long	99030A033	1	$ 41.79	$ 41.79	Actuation
ASTM B16 360 Brass Acme Round Nut, Right Hand, 1"-10 Thread Size	95100A123	1	$ 18.53	$ 18.53	Actuation
303 Stainless Steel Clamping Acme Lead Screw Collar Right Hand, 1"-10 Thread Size, 1-3/4" OD	2228N26	2	$ 37.25	$ 74.50	Actuation
Ball Bearing Shielded, Trade Number R16-2Z, for 1" Shaft Diameter	60355K605	2	$ 13.08	$ 26.16	Actuation
Nema 34 Stepper Motor Steel Mounting Bracket with Mounting Screws	Nema34-Mount	1	$ 9.99	$ 9.99	Actuation
Easy-to-Machine 1144 Carbon Steel Rod, High-Strength, 1/2" Diameter	6628K284	1	$ 11.80	$ 11.80	Actuation
Multipurpose 6061 Aluminum, 1-1/2" Diameter, 6in	8974K18	1	$ 16.00	$ 16.00	Actuation
Heat Custom Aluminum 6063 Angle, 2" x 2"x 8", 1/16" Width (Pack of 4)	AA2X2X8P4	1	$ 15.99	$ 15.99	Actuation
Ruihuang Energy SS250-60M(Black)	SS250-60M	1	$ 100.00	$ 100.00	Solar panel
Digital Stepper Motor Driver 2.4-7.2A 18-80VAC or 36-110VDC for Nema 34	DM860T	1	$ 48.99	$ 48.99	Electronics
DROK 48V Power Supply, AC 110V/220V to DC 0-48V 10A 480W	100	1	$ 35.98	$ 35.98	Electronics
Everbilt 1/4 in. x 4 in. x 12 in Plain Steel Plate	800497	4	$ 13.64	$ 54.56	Hinge
SuperMag3-Hole Flat Corner Strut Bracket - Gold Galvanized with Magnets	ZAB219M	6	$ 4.82	$ 28.92	Top panel
Superstrut 10ft 14-Gauge Silver Electro-Galvanized Strut Channel	ZB14HS10EG	7	$ 30.00	$ 210.00	Mount
Everbilt 8 in. x 24 in. 16-Gauge Plain Sheet Metal	800667	1	$ 17.21	$ 17.21	Mount
SuperMag 3-Hole Flat Corner Strut Bracket - Silver Galvanized with Magnets	ZAB219MEG	12	$ 4.82	$ 57.84	Mount

Supermag 2-Hole Flat Straight Bracket with Magnets - SilverGalv	ZAB206MEG	8	$ 4.73	$ 37.84	Mount
Everbilt 1/4 in.-20 x 1 in. Phillips Flat Head Zinc Plated Machine Screw (50-Pack)	800902	1	$ 6.90	$ 6.90	Mount
Superstrut 3/8 in. Strut Channel Spring Nut (5-Pack)	ZA1003/8EG-10	13	$ 6.58	$ 85.54	Mount
DuPont Teflon White Lithium Grease	D10106601	1	$ 6.00	$ 6.00	General
Medium-Strength Steel Nylon-Insert Locknut, Grade 5, Zinc-Plated, 1/4"-20 Thread Size, 100 per pack	95615A120	1	$ 6.31	$ 6.31	Actuation
Low-Carbon Steel Rectangular Tube 0.065" Wall Thickness, 1" x 2" Outside Size	6527K87	1	$ 15.85	$ 15.85	Actuation
Gas Struts 20 inch 60 lbs Prop Spring Shocks 20"	C16-08260	1	$ 24.00	$ 24.00	Actuation
10MM Ball Stud Mounting Bracket Angled L-type for Gas Struts Lift Supports Shocks Spring Prop Silver 4PCS ARANA	B07SFH58QR	1	$ 13.00	$ 13.00	Actuation
Delrin® Acetal Plastic Washer, Water- and Steam-Resistant, 9/16" Screw Size, 0.594" ID, 1.156" OD	95647A138	1	$ 8.21	$ 8.21	Actuation
Multipurpose 304/304L Stainless Steel Rod: 3/8" Diameter 1 ft Length	89535K87	1	$ 5.61	$ 5.61	Hinge
Multipurpose 304/304L Stainless Steel Rod: 9/16" Diameter 2 ft Length	89535K18	1	$ 16.66	$ 16.66	Hinge, Actuation
3-Hole Flat Corner Strut Bracket - Silver Galvanized (Case of 10)	ZAB219EG-10	1	$ 35.63	$ 35.63	Mount, Top panel
External Retaining Ring for 9/16" OD, Zinc Yellow-Chromate-Plated Spring Steel	98410A124	1	$ 9.71	$ 9.71	Hinge, Actuation
External Retaining Ring for 3/8" OD, Black-Phosphate 1060-1090 Spring Steel	97633A170	1	$ 10.92	$ 10.92	Hinge, Actuation
1/4 in. Strut Channel Spring Nut (5-Pack)	ZA1001/4EG-10	5	$ 6.36	$ 31.80	Mount
Everbilt 1/4 in.-20 x 1 in. Zinc Plated Hex Bolt	800596	35	$ 0.18	$ 6.30	Mount
Everbilt 25-Piece 5/16 in. Zinc-Plated Flat Washer	802314	2	$ 3.85	$ 7.70	Mount

Everbilt 1/4 in. Zinc-Plated Flat Washer (25-Piece per Bag)	802304	2	$ 3.33	$ 6.66	Mount
			Total Cost	$ 1102.90	

Part Number	Part Link
99030A033	https://www.mcmaster.com/99030a033/
95100A123	https://www.mcmaster.com/95100A123/
2228N26	https://www.mcmaster.com/2228N26/
60355K605	https://www.mcmaster.com/60355K605/
Nema34-Mount	https://www.amazon.com/Stepper-Motor-Mounting-Bracket-Screws/dp/B079R8W1BH/ref=sr_1_3?crid=2KGE01Q8FRXHJ&keywords=nema+34+stepper+mount&qid=1647295548&sprefix=nema%252034%2520stepper%2520moun%2Caps%2C125&sr=8-3
6628K284	https://www.mcmaster.com/6628K284-6628K283/
8974K18	https://www.mcmaster.com/1610T13-1610T107/
AA2X2X8P4	https://www.amazon.com/dp/B09L6CXKJG/?coliid=I3RLMVZ22R7D2S&colid=KCYQ0Y5L62KW&psc=1&ref_=lv_ov_lig_dp_it
SS250-60M	FB Marketplace Vishva Patel's account, Product link https://energypal.com/best-solar-panels-for-homes/ruihuang-energy/ss250-60m-black
DM860T	https://www.amazon.com/STEPPERONLINE-Digital-2-4-7-2A-18-80VAC-36-110VDC/dp/B06Y68Q8ND/ref=sr_1_3?crid=3TOHWA8QWK1ZQ&keywords=stepper+motor+driver+nema+34&qid=1647448325&sprefix=stepper+motor+driver+nema+34%2Caps%2C76&sr=8-3
100	https://www.amazon.com/DROK-110V-220V-Converter-Adjustable-Transformer/dp/B08GFQZFC1/ref=sxin_14_pa_sp_search_thematic_sspa?crid=DPHIGHHZG5SK&cv_ct_cx=boost%2Bconverter%2B65V&keywords=boost%2Bconverter%2B65V&pd_rd_i=B08GFQZFC1&pd_rd_r=8e386a3f-644c-4196-a2b0-2cff258e24f8&pd_rd_w=Y3gqZ&pd_rd_wg=NRm4I&pf_rd_p=e2fbde06-fdfe-405b-9a4a-aa3a1757321c&pf_rd_r=P1V3Z6HD7MY2KRG1N69X&qid=1647564156&sprefix=boost%2Bconverter%2B65v%2Caps%2C84&sr=1-4-a73d1c8c-2fd2-4f19-aa41-2df022bcb241-spons&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEzREhPS0RBQjROWkE2JmVuY3J5cHRlZElkPUEwMjMxODEwMVlaWVM5SjI4NVNORiZlbmNyeXB0ZWRBZElkPUEwMTQyMTY3MVZIMjJOUDZHNDhUQiZ3aWRnZXROYW1lPXNwX3NlYXJjaF90aGVtYXRpYyZhY3Rpb249Y2xpY2tSZWRpcmVjdCZkb05vdExvZ0NsaWNrPXRydWU&th=1
800497	https://www.homedepot.com/p/Everbilt-1-4-in-x-4-in-x-12-in-Plain-Steel-Plate-800497/204325592
ZAB219M	https://www.homedepot.com/p/SuperMag-3-Hole-Flat-Corner-Strut-Bracket-Gold-Galvanized-with-Magnets-ZAB219M/305573913
ZB14HS10EG	https://www.homedepot.com/p/Superstrut-10-ft-14-Gauge-Silver-Electro-Galvanized-Strut-Channel-ZB14HS10EG/202714280
800667	https://www.homedepot.com/p/Everbilt-8-in-x-24-in-16-Gauge-Plain-Sheet-Metal-800667/204325596
ZAB219MEG	https://www.homedepot.com/p/SuperMag-3-Hole-Flat-Corner-Strut-Bracket-Silver-Galvanized-with-Magnets-ZAB219MEG/305645479

ZAB206MEG	https://www.homedepot.com/p/Supermag-2-Hole-Flat-Straight-Bracket-with-Magnets-SilverGalv-ZAB206MEG/312233760
800902	https://www.homedepot.com/p/Everbilt-1-4-in-20-x-1-in-Phillips-Flat-Head-Zinc-Plated-Machine-Screw-50-Pack-800902/204596469
ZA1003/8EG-10	https://www.homedepot.com/p/Superstrut-3-8-in-Strut-Channel-Spring-Nut-5-Pack-ZA1003-8EG-10/100179881
D10106601	https://www.amazon.com/DuPont-Teflon-Lithium-Grease-Aerosol/dp/B000GKTZIW/ref=sr_1_5?crid=203ZHAN4BI5BZ&keywords=lithium%2Bgrease&qid=1649427453&sprefix=lithium%2Bgrease%2Caps%2C100&sr=8-5&th=1
95615A120	https://www.mcmaster.com/95615A120/
6527K87	https://www.mcmaster.com/6527K87-6527K872/
C16-08260	https://www.amazon.com/C16-17566-Heavy-duty-Tonneau-Outdoor-Suitable/dp/B07C7RYJRJ/ref=sr_1_4?crid=RCNMM1TWYFG&keywords=gas%2Bsprings&qid=1648659925&sprefix=gas%2Bspring%2Caps%2C148&sr=8-4&th=1
B07SFH58QR	https://www.amazon.com/Bracket-Ball-Stud-Supports-Gas-Shocks-ARANA/dp/B07SFH58QR/ref=sr_1_1?crid=TM80F3N1JWMY&keywords=B07SFH58QR&qid=1649432450&sprefix=b07sfh58qr%2Caps%2C66&sr=8-1
95647A138	https://www.mcmaster.com/95647A138/
89535K87	https://www.mcmaster.com/89535K87/
89535K18	https://www.mcmaster.com/rods/metal/multipurpose-304-stainless-steel-6/
ZAB219EG-10	https://www.homedepot.com/p/Superstrut-3-Hole-Flat-Corner-Strut-Bracket-Silver-Galvanized-Case-of-10-ZAB219EG-10/202221752
98410A124	https://www.mcmaster.com/98410A124/
97633A170	https://www.mcmaster.com/97633A170/
ZA1001/4EG-10	https://www.homedepot.com/p/Superstrut-1-4-in-Strut-Channel-Spring-Nut-5-Pack-ZA1001-4EG-10/100115936
800596	https://www.homedepot.com/p/Everbilt-1-4-in-20-x-1-in-Zinc-Plated-Hex-Bolt-800596/204633241
802314	https://www.homedepot.com/p/Everbilt-25-Piece-5-16-in-Zinc-Plated-Flat-Washer-802314/204276370
802304	https://www.homedepot.com/p/Everbilt-1-4-in-Zinc-Plated-Flat-Washer-25-Piece-per-Bag-802304/204276388?MERCH=REC-_-pipsem-_-204276370-_-204276388-_-N&