SOLAR BATTERY PROJECT PORTFOLIO

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I. Executive Summary

With the rising usage of cell phones and mobile devices, there has been a rising demand for energy, specifically portable energy. Modern devices do not always have the battery capacity to meet the demand of many consumers, and battery consumption will continue to go up as the reliance on cell phones and mobile devices goes up.

Each member of the team has experienced issues regarding their phone battery life not being sufficient to fulfill their needs. The team also knows dozens of people who experience the same or similar problems frequently. Whether it's a daily occurrence or a weekly occurrence, each member of the team has deemed it necessary to find a solution to ease the burden that the demand for energy is putting on the device's battery life.

The focus of the project is to bridge the gap between energy demand and energy supply, especially on the go. Currently, the energy demand exceeds the supply, which is causing people to have issues with their battery life not being insufficient. As a result, consumers may be put in dilemmas or be forced to make sacrifices due to the lack of adequate battery life.

Through research, the team found that current market solutions only provide a temporary fix to this problem in the form of portable chargers. These portable chargers solve the problem by providing a longer battery life rather than solving the problem of demand. The question still remains: what if the portable charger also runs out of battery? Many of these solutions do not address this question, rather, they just provide charge to ease consumer concerns. There are a few portable chargers on the market that do answer this question by implementing renewable energy harvesters, but they do not nearly provide adequate results. Oftentimes, recharging via the renewable energy harvester becomes secondary to recharging from a wall outlet simply because of the harvester's ineffectiveness.

The team initially considered using piezoelectricity to create a self-reliant portable charger that could convert mechanical vibrations into electrical energy. However, after doing research, the team concluded that piezoelectric materials were insufficient to meet modern energy demands. As a result, the team looked through other sources of renewable energy and decided that solar power was the way to go. Solar power is the most efficient passive renewable energy source; that is, it does not require constant input by consumers to generate electrical energy. In addition, solar power has proven to work in the past; all that is needed is some .fine-tuning

The goal of this project is to design a product that implements renewable energy more effectively than the other competitors on the market. The new device will function not only as a portable charger but also as a viable alternative to outlet charging. This report will go over the process of designing this more effective renewable energy portable charger, from the problem identification to market analysis, decision making, research, and calculations. By the end, the team will have designed a product that fits the demand for energy using renewable energy.

II. Market Analysis

II.1 General Need for Product

Products are created based on demand for the solution they offer. As the world increasingly relies on technology, more mobile devices will be used, and thus, more energy will be required. Additionally, with the waning supply of fossil fuels, demand for renewable energy will increase. When talking about renewable energy, few ever think about the renewable energy everyday citizens can produce, lightening the load that big industries have on producing enough renewable energy. Giving everyday consumers the ability to make renewable energy for themselves may also create many conveniences, most notably in mobile device charging.

II.1.1 Widespread Use of Mobile Devices

An estimate published by Federica Larricchia in 2024 estimated that the number of smartphones being used worldwide can be as high as 6.7 billion, with roughly 69% of the total population owning a smartphone. This number has risen from 65% in 2016 and is expected to keep growing in the future. In places like North America or Europe, it is estimated up to 86% of people own a smartphone, nearly the entire population.

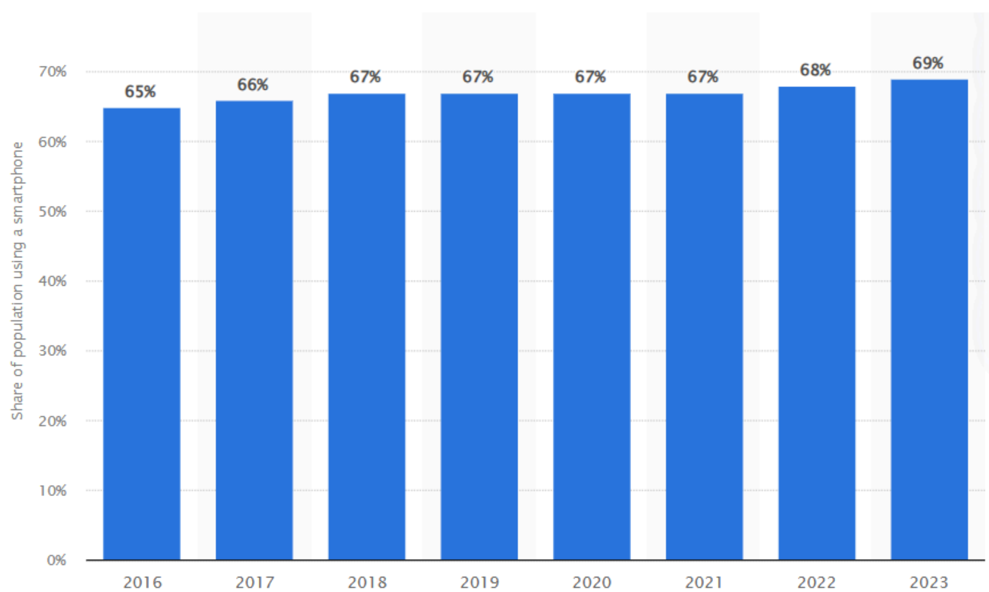


Figure II.1.1 shows the increasing usage of smartphones around the world in the past 10 years.

II.1.2 The Rise of Battery Issues

With such high usage of phones, battery life issues may become a daily occurrence for some people. A study conducted by Anker, a leader in mobile power, found that 47% of people report that their phone dies at least once a week, with 66% of those people experiencing their phones dying daily. However, issues may arise even before a phone is completely dead. A survey conducted by LG found that 9 out of 10 people had a condition coined "Low Battery Anxiety," which is when people are fearful because their devices have low battery. Although not an actual medical disorder, this issue has noticeable consequences. When presented with a battery below 20%, people have found to change behaviors in their everyday lives to accommodate for their low battery. These changes to people's decision-making can have consequences: people have been reported to miss important parts of their life simply because of a low battery. Low Battery Anxiety may also affect relationships: LG reported that 60% of people have turned down calls from loved ones or significant others because of a dead or dying phone battery, which can be easily misinterpreted as ignoring, or "ghosting."

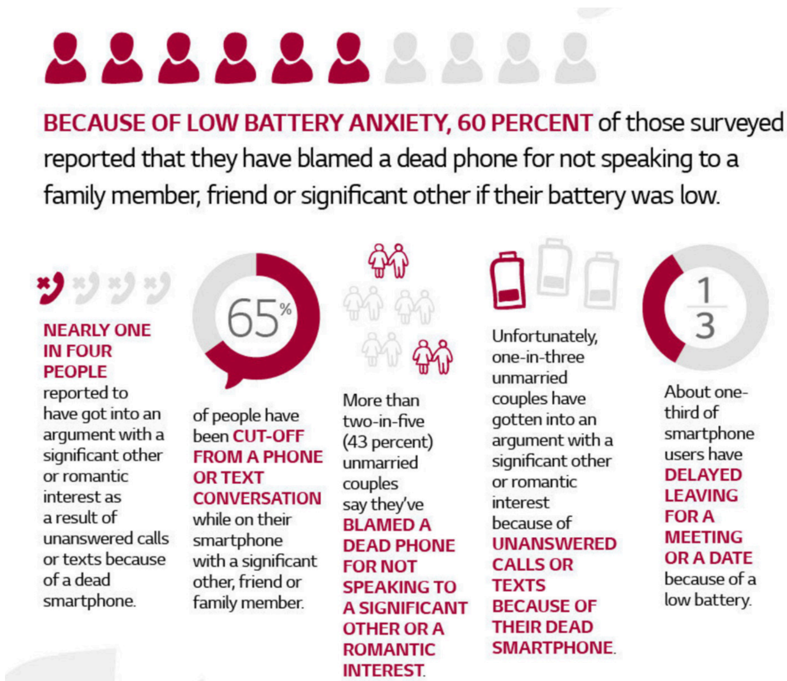


Figure II.1.2 shows some additional statistics collected by LG's survey on Low Battery Anxiety.

In response to low battery problems, people have turned to portable chargers as a way to counter it. Allied Market Research estimates the market size of portable chargers to reach $17.3 billion by 2031, a 2.5 times increase from the 2021 market size of $6.8 billion. These devices have seen increasing demand because of their distinct characteristic that allows consumers to have a fast charger within their pockets. Additionally, its multiple outlets and low cost provide a convenient solution on the go. With the rise of 4G networks, power consumption has gone up, causing battery life to go down. Paired with the increasing reliance on the internet, these reasons drive up the demand for portable chargers.

However, portable chargers themselves have shortcomings as well. Portable chargers have a battery life, too, and they must be constantly charged to maintain the power. If not, usage and battery leaks can quickly drain the battery. Battery leaks happen naturally but can be amplified by improper use, extreme temperatures, or just wear and tear. All of these contribute to the battery's waning battery life, which creates the need to recharge it constantly. One solution to this workaround is designing a battery that is capable of charging itself.

There are not many sources of energy that can be incorporated into portable chargers that are sufficient to meet the energy demands of consumers. Recently, the team did research into piezoelectricity as a potential solution to harvest energy for portable chargers, but the numbers came out to be too small to create a meaningful solution. Other types of energy harvesters, like mechanical harvesters using motors, prove to create an inconvenience to the consumer. The only viable solution was to incorporate solar-powered panels as an energy harvester for the portable charger. There are already successful portable chargers with solar panels on the market, but many of them have one big flaw: the charge time. Many solar-powered batteries require several days to become fully charged using the solar panels, with the most effective ones requiring up to 5 hours of sunlight to collect enough energy to charge a phone.

II.1.3 Data Collected at the School

A survey conducted at Centennial High School by the team found that 69% of participants used their phones for more than 3 hours a day. 95% of participants reported carrying a phone whenever they go out. 61% of participants reported having battery problems frequently with 22% of these participants reporting having battery problems every day. About 42% of participants reported using some portable power source throughout the day, with 56% of these participants reporting using portable chargers to charge their phones.

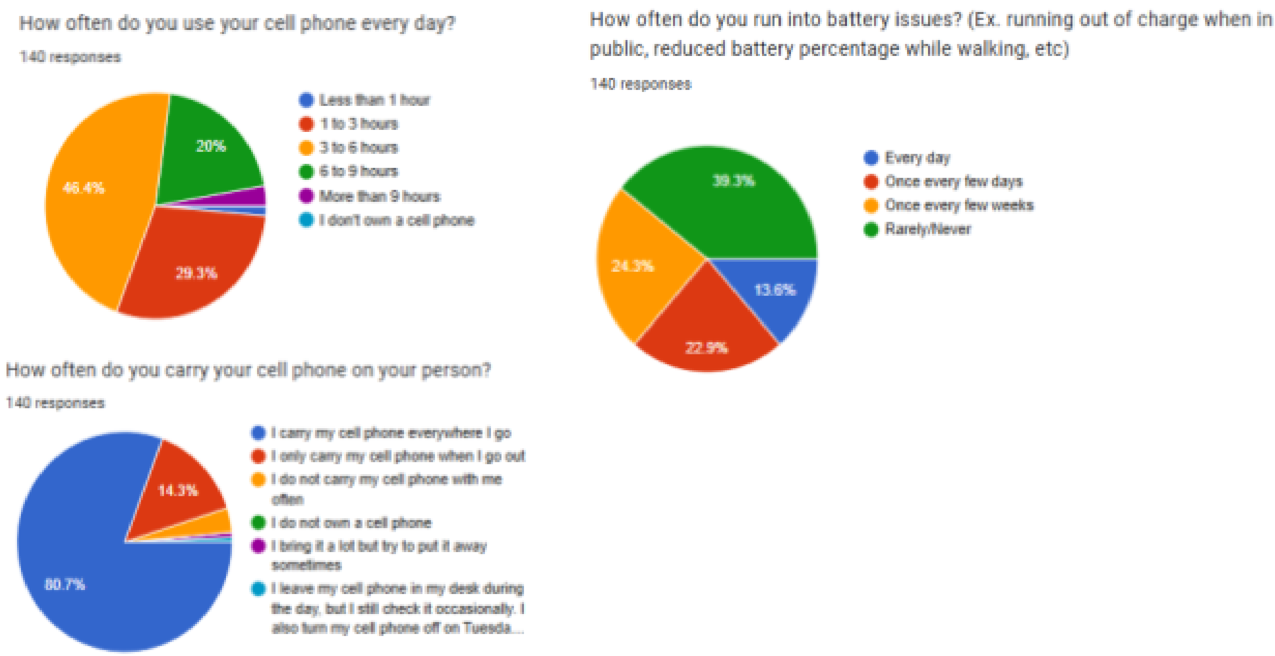


Figure II.1.3 shows data the team collected at Centennial High School over a 2-week period.

With the data matching up with the research, it is clear there is a high demand for mobile energy for portable devices. Current products may provide solutions, but it is clear these solutions are insufficient to meet the demands. Based on the data, there is still a need for more powerful sources of portable energy. Key stakeholders—consumers that use their mobile devices plentifully—will continue to demand for more energy solutions, especially as the reliance on said mobile devices increases. There is a clear demand for a product that can fulfill the energy needs of everyday consumers, both in terms of power capacity and power harvesting.

II.2 Comparing Similar Products

II.2.1 Similar Solutions Matrix

Five other similar portable power sources were compared to establish the need for the new battery. Each similar solution was judged based on seven factors: power capacity, charging speed (Wattage), size and shape, weight, price, recharging time, whether it can be charged on the go, and extra perks. The different types of power sources compared are shown in Figures II.2.1 to II.2.5 below:

Figure II.2.1: A portable charger that is charged from wall outlets (Competitor 1). The specific product chosen to be compared is the Ekrist Portable Charger Power Bank.

Figure II.2.2: A portable charger that can be charged from wall outlets or through solar panels (Competitor 2). These competitors compete directly with the product being developed. The specific product chosen to be compared is the JNEESYAN Portable Solar Phone Charger.

Figure II.2.3: A portable charger that turns stored power in conventional batteries into a power bank for mobile devices (Competitor 3). The specific product chosen to be compared is the Success4Sport Portable AA Battery Travel Charger.

Figure II.2.4: Although a laptop is not a direct competitor, laptops have portable charging capabilities that compete with our product, which also provides portable charging capabilities (Competitor 4).

Figure II.2.5: Although a car is not a direct competitor, cars have portable charging capabilities when they are on, which competes with our product's focal point of providing portable charging capabilities (Competitor 5).

Each competing product was evaluated by reviewing the design specifications of the products pictured. Although different products from different companies may have different specifications, one specific "Goldilocks" model was chosen to be evaluated. Competitors 4 and 5 were not designed specifically for portable power storage, so no specific model was chosen; instead, estimates were made for each specification for these products.

a. Quantitative Data

Many factors being assessed can be done so in a quantitative fashion. For example, factors like price, weight, power capacity, charging speed (Wattage), and recharge time can all be measured numerically, providing a more objective comparison between products. Competitors 4 and 5 were treated differently when comparing properties like price and weight as these products were not solely designed to act as a portable power source. For example, the weight of a car was not recorded as cars were not designed to be carried around by a person. The weight of a laptop, however, was recorded as a laptop designed to be carried on a person, albeit not to the degree of many mobile power banks. Nevertheless, this factor may affect the product's practicality as a portable power source.

Some of the specifications compared are not always provided in product descriptions, meaning they would need to be calculated. For example, the wattage, used to measure charging speed, is not always listed in product specifications. Therefore, the wattage of a battery would need to be calculated using:

$$W = V \times A \qquad \textbf{Equation II.2.1}$$

where W is the wattage, in Watts, of the battery, V is the voltage, in Volts, of the battery, and A is the current released by the battery, in amperes.

Similarly, the recharge time of each battery needed to be calculated as it was not listed in many product specifications. The recharge time, in hours, can be calculated using:

$$t = \frac{E}{P} \qquad \textbf{Equation II.2.2}$$

where t is the recharge time, in hours, E is the battery capacity, in watt-hours, and P is the power of the charger, in watts. The value of P may change depending on how well the battery receives the charge. P can be calculated using Equation II.2.1, replacing W, if the specifications are given. If not, a standard value for USB or USB-C charging power, depending on which port the device uses, will be used instead. The battery capacity, E, also depends on the battery, specifically the power capacity and voltage of the battery, and can be calculated using:

$$E = \frac{V \times Q}{1000} \qquad \textbf{Equation II.2.3}$$

where Q is the power capacity of the battery in milliampere-hours. Putting together Equations II.2.2 and II.2.3 gives:

$$t = \frac{V \times Q}{1000P} \qquad \textbf{Equation II.2.4}$$

which can calculate the total amount of time it takes to recharge a battery. Putting all the quantitative data in Table II.2.1 allows comparisons to be made between different prior solutions and competitors.

Table II.2.1	Competitor 1	Competitor 2	Competitor 3	Competitor 4	Competitor 5
Weight (oz.)	8	10.93	2.7	64	N/A
Price (USD)	$25.95	$20.98	$16.99	N/A	N/A
Power capacity (mAh)	25,800	20,000	11,200	5,000	60,000
Wattage (W)	15	10.5	12	100	90

Recharge time (h)	8.6	6	N/A	0.74	N/A

Table II.2.1 shows the quantitative properties of each of the chosen competitors. For competitors 4 and 5, an average estimate was made to determine the values. N/A was put if the value is not applicable.

The following table, Table II.2.2, shows the rankings of each factor on a scale of one to five, where five is the highest ranking and one is the lowest ranking. The rankings are determined by how well the specification can solve the problem or by how well the specification can mitigate additional problems. For example, the battery with the highest power capacity got the highest score in that category because a higher-capacity battery allows for more power to be stored. On the other hand, the battery with the lowest weight got the highest score in that category because a lighter battery causes fewer issues than a heavier battery. A heavier battery may be more inconvenient to carry, more likely to fall out of a pocket, and more likely to swing around while in a pocket. A lighter battery, although not immune to these issues, is less likely to run into these issues and these issues are less drastic compared to that of heavy batteries. The results of the rankings are shown in Table II.2.2 below.

Table II.2.2	Competitor 1	Competitor 2	Competitor 3	Competitor 4	Competitor 5
Weight	4	3	5	2	1
Price	3	4	5	2	1
Power capacity	4	3	1	2	5
Wattage	3	1	2	5	4
Recharge time	2	3	1	4	5

Table II.2.2 shows the rankings of the quantitative properties on a scale from one to five, where five is the highest score and one is the lowest score. The properties marked with N/A in Table II.2.1 are ranked in this table since they still affect the product's practicality.

b. Qualitative Data

Not all of the factors being assessed could be done quantitatively. Factors like the size and shape, extra perks, or whether it could be charged on the go cannot be expressed with numbers.

Rather, they would need to be assessed based on a line of reasoning. The results of the assessment are shown below in Tables II.2.3 to II.2.6.

Table II.2.3	Dimensions	Shape description
Competitor 1	5.91" x 2.95" x 0.6"	Rectangular prism with rounded corners
Competitor 2	5.31" x 2.95" x 0.6"	Rectangular prism with tapered corners
Competitor 3	3.8" x 2.9" x 0.31"	Rectangular prism with tapered corners
Competitor 4	9” x 14” x 0.75”	Rectangular prism

Table II.2.3 compares the dimensions, shapes, and sizes of each chosen competitor. Competitor 5 was not included as it is not designed to be carried by a person.

Table II.2.4	Ranking	Explanation
Competitor 1	3	This competing product, although much larger than some other products, has a very slim profile, which is very practical for when it is carried on the go.
Competitor 2	4	This competing product also has a very slim profile but is slightly smaller than competitor 1.
Competitor 3	5	This competing product by far has the smallest dimensions as well as the slimmest profile
Competitor 4	2	This competing product has the largest volume compared to all the other products ranked above it. Since this product is not solely designed as a portable power source, its use as a portable power source may be limited.
Competitor 5	1	This competing product is not designed to be carried by a person, severely limiting the practicality of this product as it can only be used under certain circumstances.

Table II.2.4 ranks each chosen competitor in **Table II.2.3** on a scale of one to five, where five is the highest score, and provides explanations as to why each ranking was given out.

Table II.2.5	Ranking	Explanation
Competitor 1	2	Although this power source has no additional perks aside from the charger, it does have 2 different USB ports for 2 different charging speeds, putting it above competitor 3, which only has 1 USB port.
Competitor 2	3	In addition to storing power and its multiple ports, it may also act as a flashlight, placing this above all the other competitors that lack perks. The battery's portable rechargeability was not considered in this evaluation.
Competitor 3	1	Although this power source has a convenient LED built-in, its lack of multiple charging ports limits its overall usability as a portable charger compared to the other products

Table II.2.5 ranks the extra perks of each portable power source. Competitors 4 and 5 were not judged because they are not designed solely to be a power source, meaning they have more uses than just a battery.

Table II.2.6	Ranking	Explanation
Competitor 1	1	This competitor cannot be recharged on the go; it requires to be plugged into a wall to recharge.
Competitor 2	5	This product is the only product that can be charged on the go. Even though the power harvesting capacity of this battery is slow, it is still able to harvest renewable energy indefinitely.
Competitor 3	1	This competitor cannot be recharged on the go; it requires extra AA batteries to recharge.
Competitor 4	1	This competitor cannot be recharged on the go; it requires to be plugged into a wall to recharge.
Competitor 5	2	Although most car batteries are not rechargeable, they often have enough power to not require a recharge. Although this quality doesn't fully address the issue involving renewable energy, the car battery will rarely run out of power as a portable charger.

Table II.2.6 ranks the rechargeability of each portable power source. Accommodations were made for power sources that could not harvest energy on the go but had qualities that may affect a consumer's decision-making process when choosing portable power sources.

c. Summary

Weight: The weight of the product should weigh around the same as many other portable chargers similar to Competitors 1 and 2. Ideally, the weight should not deviate too much from the weight of these other chargers on the market. The weight should have no relation to the weights of Competitors 4 and 5.

Price: The price of the product should be around the price of other competitors. Since the battery is designed to be more efficient, and hence may need more cost put into it, it should not exceed the price of current models too much to not dissuade customers from purchasing.

Power Capacity: The power capacity of this product should match many competitors currently in the market. Since this is going to be a portable charger, its main purpose is to be a power source, meaning the power capacity of the product must be on par with the other competitors on the market.

Wattage: The wattage of this product should match current competitors in the market, as consumers who are charging on the go may not always have the time to charge their devices for long periods. The speed of charging is an important factor in the product and must meet standards set by the market.

Recharge time: The recharge time of the product must match the recharge time of current competitors on the market. Although the recharge time is not as important as other factors like wattage or power capacity, it is still important when deciding which products consumers would purchase. The recharge time, both via solar panels and USB cable, should be maximized and meet, if not exceed, the competitors on the market.

Dimensions and shape: The shape of the product should be a rectangular prism because rectangular prisms may have very slim profiles while maintaining a sizable area. Many products on the market are rectangular prisms for this reason: they use up space most efficiently. Dimensions of the product must not exceed the competitors on the market much, as they are already tailored for everyday use for humans. Lastly, all the corners and edges on the product must be tapered or filleted to make the product less dangerous. Sharp corners or edges may be sharp and pose a poking hazard if not properly treated.

Extra perks: Although not all competitors had extra perks, nearly all the portable chargers with solar panels also came with an LED light, meaning this product will likely benefit from incorporating a light; however, that would be secondary to developing a more efficient solar-powered charger.

Rechargeability: Many of the competitors on the market didn't have portable rechargeability, meaning they could not be charged on the go. The only other competitor that had portable rechargeability was the other solar-powered portable charger. On the market, these chargers have limited recharge current from the solar panels, with the highest current found by the team being 960 mA. This product will need to have a recharge current higher than 960 mA to be more efficient than current competitors on the market.

II.2.2 Prior Patents

To gather information regarding the prior development, designs, and applications of both piezoelectric and solar-powered devices, several patents were researched and evaluated based on performance and size. This information was used to determine if the device in question was viable for use to charge phone batteries.

a. Piezoelectric harvesters

The first piezoelectric harvester patent the team researched was US20100084947A1, which is a piezoelectric energy harvester that can effectively turn ambient vibrations into electrical energy. Its design is for use in sensors that otherwise would prove costly to provide energy to by electrical wires. Therefore, this harvester was designed to be the source of the power so costly wires would not have to be set up for these sensors. This is especially useful since piezoelectric components are location-independent: unlike wires, there is an unlimited range the piezoelectric harvester can go.

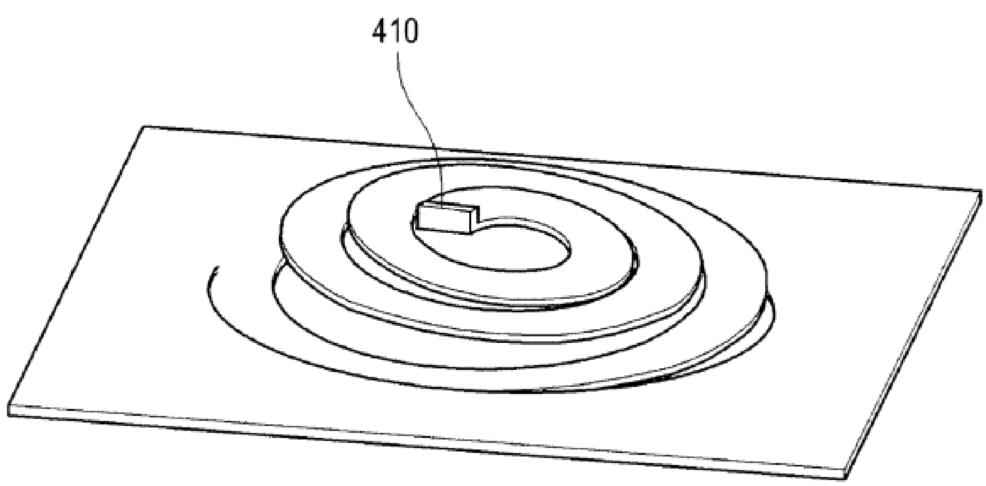


Figure II.2.6 shows the piezoelectric harvester US20100084947A1. The design is a spiral spring-like structure that harvests vibrational energy and uses it to generate a voltage difference, which induces a current and creates electrical energy.

The purpose of this generator is identical to what the team hopes to create: a power source that isn't limited by the range of a cable. However, this device itself is not designed to harvest energy through human movement and it is not designed to have the capacity to charge modern-day cell phones. The device is meant to handle mechanical vibrations with much higher frequencies than everyday motions, requiring over 200Hz, or else the "element may not resonate with the ambient vibration source through frequency tuning." The team deemed this device was unfit for the applications of modern-day mobile device charging as it requires such high frequencies, and thus, also likely lacks the power needed to fully charge a modern phone.

The second piezoelectric harvester patent the team looked at is US7948153B1, which, like the first patent, is designed as a replacement for conventional power sources used in sensors. This time, this energy harvester is also designed to double as a battery for the sensors it powers, making it a better fit than the first patent. However, this patent contains the same shortcomings as the first patent does.

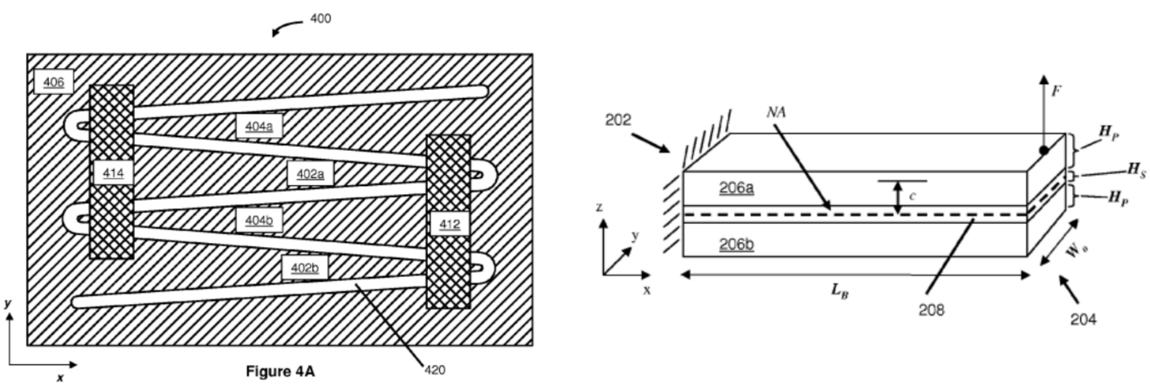


Figure II.2.7 shows the piezoelectric harvester US7948153B1. These are the diagrams for one cell of this harvester. Ideally, multiple cells are assembled together and connected in parallel to create the best power output.

The patent listed some specifications, which proved to be too ineffective to charge phone batteries. One cell takes up an area of about 12.5 x 3.67 mm^2 and each cell can produce 0.43 mW of power. This means to get the wattage to even 1 Watt, 2,326 cells will need to be connected in parallel, assuming the circuit is ideal. 1 Watt by itself is not enough to charge a portable charger or phone effectively, meaning this patent is simply not efficient enough for the phone.

While doing research in the design process, many piezoelectric products in the market ran into the same problem: not enough power. The piezoelectric effect, although revolutionary, is not enough to provide ample power to meet the demands of modern devices today, meaning an alternative renewable energy source must be chosen and evaluated before proceeding, which is why the team moved to solar energy.

b. Solar-powered harvesters

After switching over to solar energy, the team looked at current solar-powered portable chargers to justify the viability of solar panels as a power source and prove the ability to improve the charging speed of solar-powered portable chargers. In the process, some patents were researched and evaluated to get a solid foundation of the abilities of solar power.

The first solar-powered patent the team looked at was CN201813324U, which is a portable solar panel array. These panels come in a box and can be quickly set up for military-grade usage. They can deliver 200W of power to devices and come equipped with lithium batteries, a control panel, power sockets, and many more gadgets for controlling power output.

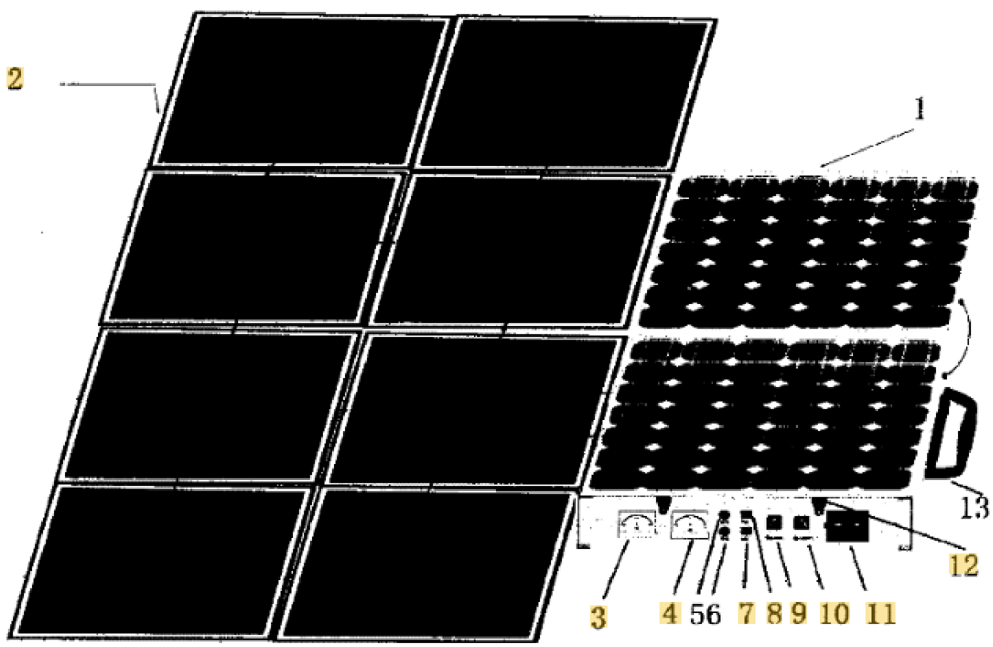


Figure II.2.8 shows the solar panel setup CN201813324U. This product has enough power to fulfill the needs of everyday mobile devices or phone usage, but the size makes it impractical to be carried around every day.

Although this patent does a great job of fulfilling energy needs, it is very large for a portable charger that is designed to be carried around by a person. This product was not designed for everyday use: rather, it was designed for more stationary events that needed a source of electricity. Hence, the dimensions of this product are way too big to be a product someone can carry around with, meaning it doesn't solve the immediate problem at hand.

The last patent the team looked into was CN203707851U, which is a solar-powered portable energy harvester. This product is in the shape of a suitcase that opens up and contains 2 surfaces with solar panels on the inside. This product has an output voltage of 12V and has multiple 5V USB outputs to charge devices from. It also has a stand that may allow it to be angled for maximum efficiency.

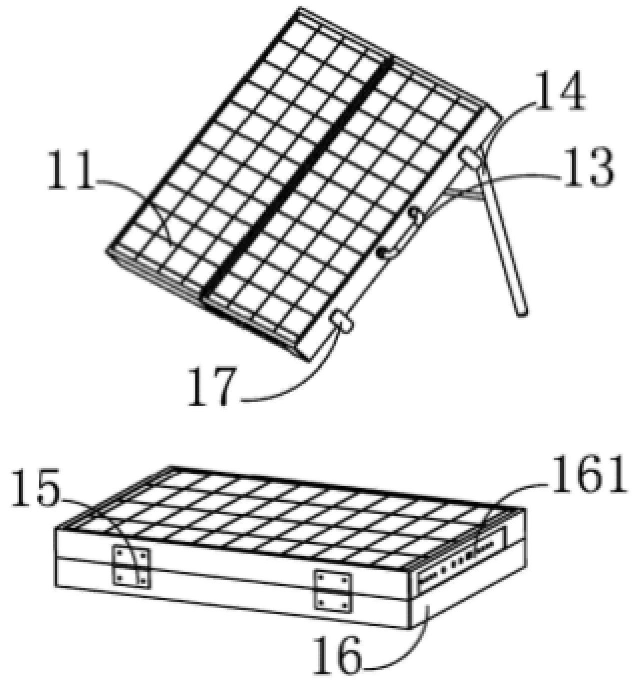


Figure II.2.9 shows the solar panel setup CN203707851U. This product is built like a suitcase with an openable hatch and a stand (see 14) to angle the solar panel for the most efficiency. It also has multiple charging ports (see 161).

The size of the patent does create issues with its portability. Although the size is not explicitly mentioned, with the handle seen in **Figure II.2.9**, one can infer the size of the panel is approximately the size of a suitcase. With its design and shape, it is unlikely the handle is used for any different purpose other than being a handle, which means it is likely to be the size of a standard handle. Compared with the size of the entire product, the handle is relatively small, meaning it is very likely the product is too large to be comfortably carried around on a person all day.

II.2.3 Opportunities for Competitive Advantage

Comparing patents to similar solutions, there are two major differences: size and power capacity. Many of the products outlined by patents have very high power and charge rates but are much larger than most convenient portable items. Many products on the market are very small, making them much more convenient to carry around, but lack in terms of power capacity and charge time. There is a direct relationship between charging capacity and size: as the size becomes larger, charging capacity goes up; as size goes down, charging capacity goes down. If a product were to have a small size, it would have a small charging capacity, meaning it would be less efficient.

However, size isn’t everything; how the product uses its size also matters. The team has recognized how size, more specifically surface area, could be improved upon without adding too much to the product size. By maximizing this, the team will be able to create a product that is the same or similar size to current pocket portable chargers while having higher charging speeds than current pocket portable chargers.

III. Problem Statement

As the use of phones and mobile devices increases around the world, the demand for portable energy increases at a critical rate. Although many products on the market offer solutions to the demand for energy, many solutions either only offer temporary solutions or offer products that are too large to be practical for everyday portable use. Even solutions that implement energy harvesters fail to meet the demands of consumers. These products do solve the problem at its roots, but their ineffectiveness leads consumers to ignore these solutions in favor of other solutions that only offer temporary, but more effective solutions.

The need for continued innovation and improvement of current designs is evident. The potential of current solutions has not been fully realized, which is shown by current solutions being inadequate. Critically, these solutions lack the charging speed necessary to keep up with the demands of everyday consumers. This newly-designed solution’ aim is to bridge the gap between demand and current solutions by creating a charger that can better minimize the charging time.

IV. Design Requirements

IV.1 Stakeholder Analysis

The primary stakeholders will be individuals who heavily depend on portable energy solutions to power their devices throughout the day. This includes travelers who often find themselves away from reliable power sources, outdoor enthusiasts engaging in activities such as camping or hiking in remote areas, and professionals whose work requires long hours on the go without access to fixed power outlets. These groups represent a diverse range of users who share a common need for convenient, durable, and efficient portable energy solutions to stay connected and productive in various environments.

IV.2 Design Requirements

Through a combination of frequent in-person interviews, email exchanges, and telephone surveys with a diverse group of mobile device users, the team gained insights into the challenges and needs that are connected with portable energy solutions. In addition, extensive market research on existing portable battery products, including reviews, comparisons, and user feedback, allowed the team to identify key strengths and weaknesses in current solutions. This approach let the team establish a well-informed baseline of requirements, ensuring that our design addresses the most critical demands of modern consumers. (See **Section II.2.1** for more details)

Using these insights, finalized specifications for the design were determined. Below is a list of the specifications that the team came up with

Power Capacity
The battery must provide a power capacity of 20,000–40,000 mAh to meet industry standards. This ensures sufficient energy storage to support multiple charging cycles for a variety of devices, enabling users to stay connected and powered for extended periods.

Price Range
The product must retail within the competitive range of $30–$60, striking a balance between affordability and high performance. This ensures accessibility to a broad range of consumers without compromising quality.

Shape and Form Factor
The product's design must feature a sleek, modern rectangular prism with tapered or filleted corners. This ergonomic and aesthetically appealing shape ensures easy handling and visual appeal while maintaining functionality.

Portability
To maximize convenience, the battery must maintain a slim profile of 3 cm or less, allowing it to fit seamlessly into pockets, purses, or small bags. This compact design ensures that users can carry it comfortably during daily activities or travel.

Durability
The product must withstand common wear and tear, including:

- Accidental drops from a typical hand height of 3 feet.
- Exposure to minor environmental conditions such as light rain, dust, or splashes, ensuring reliability in diverse scenarios.

Solar Efficiency

The integrated solar panel must be highly efficient, capable of recharging the battery under direct sunlight. This feature is essential for users in remote locations or outdoor settings without access to power outlets.

User Reliance

Designed to address the growing demand for portable energy solutions, the product targets a critical issue: in 2024, 47% of individuals reported experiencing weekly battery problems. This highlights the pressing need for reliable, innovative energy storage options.

Lightweight

The product must weigh no more than 500g, ensuring effortless portability and minimizing user fatigue during extended use, whether during travel or outdoor activities.

Compatibility

The battery must be universally compatible with a wide range of devices, including smartphones, tablets, and USB-powered accessories, providing versatility and utility for diverse user needs.

Eco-Friendly Materials

To align with modern sustainability values, the product must utilize recyclable and eco-friendly materials wherever possible, minimizing environmental impact and appealing to eco-conscious consumers.

Safety Features

Integrated safety mechanisms are essential, including protections against overcharging, overcurrent, and short circuits. These features ensure safe operation, preventing potential damage to devices and ensuring user peace of mind.

Additional Features

The product design should include user-friendly extras, such as:

- An LED indicator to display the current battery charge level.
- A built-in flashlight to provide added utility in low-light or emergency situations.

V. Decision Matrix

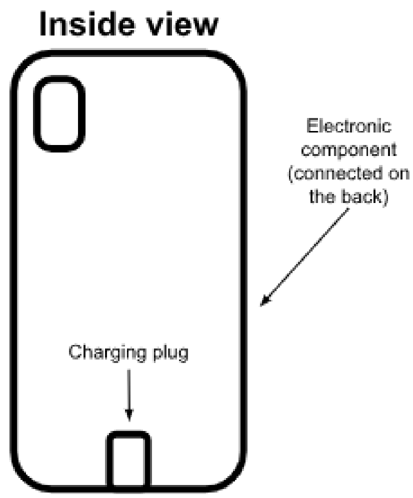
V.1 Initial Piezoelectric Designs

Before switching to designing a solar-powered portable battery, the team drafted some rough drafts for initial piezoelectric phone case designs. Although this decision matrix didn't direct the path the team went down, it still decided many factors when designing the newly proposed product. When designing the phone case, the team considered many of the design requirements and categorized them into three categories: fixed criteria, variable criteria, and constraints. Fixed criteria and constraints are requirements that remain the same regardless of the design, while variable criteria may change depending on the development of the project. The fixed criteria were identified to be safety durability of the charger, cross-charger compatibility, and area for the battery. The constraints were identified to be profile, and cost, and the variable criterion is recharge speed. Although there are many more factors that dictate the criteria and constraints of the design, these factors are either the same between designs or cannot be determined at the decision matrix.

The design specifications, constraints, and parameters for the piezoelectric phone case were shaped by balancing power efficiency, size, durability, and cost. Key stakeholders—users, retailers, and manufacturers—provided input through surveys and consultations, helping prioritize design goals.

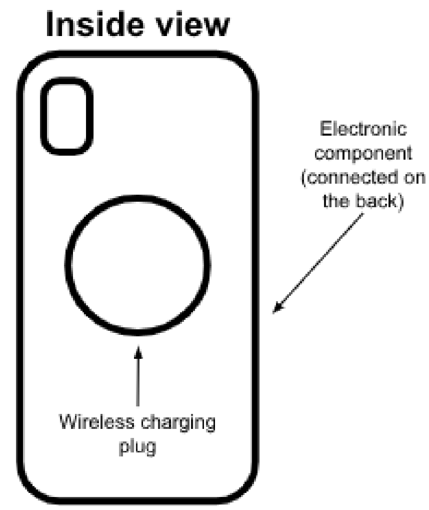
- Safety (weighted 10)
  - What threats may this design potentially pose and how big are these threats?
- Cost (5)
  - How much will the technology cost to produce?
- Durability of charger (8)
  - How well can the charger hold up to wear and tear or brunt force?
- Area for battery (5)
  - How much area will the battery be able to take up?
- Cross-charger compatibility (3)
  - Is this compatible with other chargers? How easy would cross-compatibility be?
- Profile (3)
  - How bulky is the design? Is it going to flop around in pockets?

Three main concepts were proposed: the first concept involved embedding a charging port at the bottom of the phone case that connected to a piezoelectric generator at the back of the phone case; the second concept involved a wireless charger that was connected to the piezoelectric generator at the back of the phone case; the third concept involved adding a wire at the back of the phone case connected to the piezoelectric generator at one end and a charging port at the other end. All three of these concepts have their advantages and flaws, but in the end the third concept scored the highest and was chosen as the best fit for the project. The process of making this decision is shown in the matrix below.



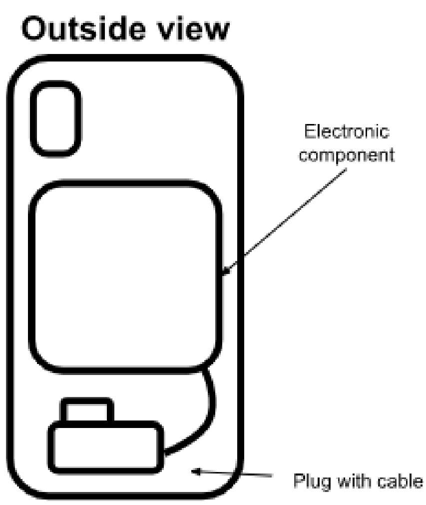
Concept 1: the phone case has the charger embedded into the button on the inside with the battery component at the back

Signed: *Eric Ma*



Concept 2: the phone case has a wireless charger embedded into the back on the inside with the battery system at the back

Signed: *Eric Ma*



Concept 3: the phone case has a wired charger connected to the battery at the back. The wire allows the phone to be changed when the consumer wants it

Signed: *Eric Ma*

Figure V.1.1 shows rough sketches for three different proposed designs with more detailed descriptions of the three designs.

Concept	Safety	Cost	Durability	Area	Compatibility	Profile	Total	Total (weighted)
Concept 1	2	3	1	3	1	1	11	64
Concept 2	1	1	3	3	1	1	10	60

Concept 3	2	2	2	2	3	2	13	71

Table V.1.1 shows the relative ratings of each design for each criterion or constraint. The weighted total was found by finding the product of each rating by their respective weights, then taking the sum of all the weighted ratings.

V.2 New Solar Powered Battery Design

When the team switched to designing a solar powered battery, a new decision matrix was needed to decide the path the team was going to take with the new ideas. The first step was to choose a reliable solar panel that could be a good fit for the project. This solar panel would need to fit in the small profile of the battery while providing enough voltage to charge the battery and enough current to do it quickly. After some research, the team came up with 4 different panels that fit many of the project's criteria and constraints.

Figure V.2.1 shows the 4 mail solar panels chosen for the decision matrix. The panels are numbered 1-4 from left to right, with the very left one being1 and the very right one being 4.

The team took information from the data sheets of each solar panel and put them in a table to compare. In addition, the team chose a different approach to weighting that allows for a better reflection of the actual desired value. The new approach, rating each category on a scale of 1-10, allows for a better rating of qualities relative to each other. In the end, solar panel 4 was chosen as the final solar panel.

Category	Panel 1	Panel 2	Panel 3	Panel 4
Price ($)	5.50	5.50	6.00	9.00
Size (mm x mm)	32.5 x 94	52 x 52	52 x 52	66 x 66
Mass (g)	12	8.2	8.0	14.4
Max voltage (V)	2.97	2.43	6.07	6.07

Max current (mA)	170	130	60	110

Table V.2.1 displays the quantitative data found from the data sheets of the respective solar panel.

Category (weight)	Panel 1	Panel 2	Panel 3	Panel 4
Price (2)	10	10	9	8
Size (3)	10	10	10	10
Mass (2)	9	10	10	8
Max voltage (10)	1	1	10	10
Max current (8)	10	10	2	9
Total	158	160	184	234

Table V.2.2 shows the ratings of each panel in each category as well as the weighting for each category. After adding up all the weighted ratings, it was decided that solar panel 4 would be used.

Next, the team decided what path they will take with the form factor of the battery. Some ideas from the winner of the initial decision matrix, like incorporating USB compatibility and using external wires to connect the battery to devices, were incorporated into the design. After some research, the team decided on adding flaps on the battery to maximize the surface area for the solar panels to sit. The team had to decide on the number of solar panels to implement and sketched designs for a battery with three, four, and five straps. Each flap would include 2 solar panels connected in parallel. A wire would run by the hinges to connect the panels together. In addition, the location of the flaps and how they would close were also decided. After the decision matrix, the design with 5 flaps was chosen.

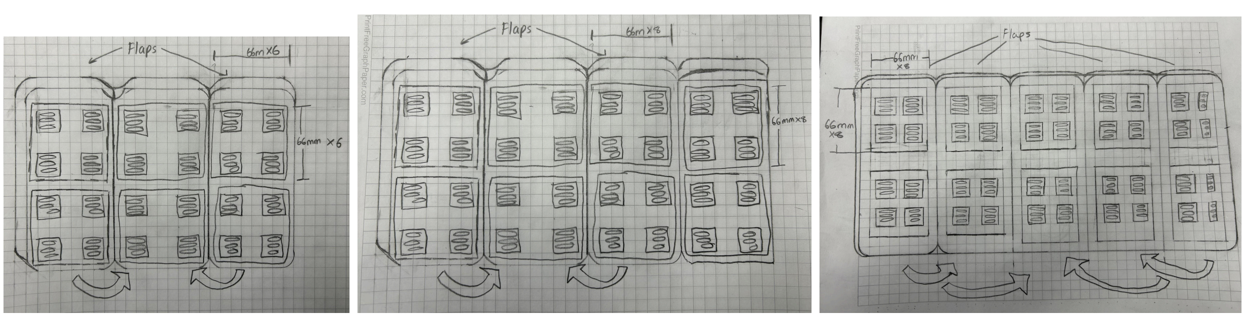


Figure V.2.2 shows the three different concepts with different numbers of flaps. The arrows indicate how the flaps will fold in. The concepts are numbered from left to right with the left concept being concept 1 and the right concept being concept 3.

Concept (weight)	Safety (0.5)	Energy Capacity (0.5)	Cost (2)	Estimated weight (2)	Charging Speed (3)	Potential Issues (3)	Total (weighted)
Concept 1	10	7	8	8	3	6	61.5
Concept 2	10	7	7	7	6	7	68.5
Concept 3	10	7	6	6	9	5	69.0

Table V.2.3 shows the process of deciding which concept was chosen. The totals came out to favor concept 3, or the concept with 5 flaps.

VI. Application of STEM Principles

VI.1 Research

Although all team members have experience in engineering and a foundation in electricity and magnetism, additional research was required. This project relies heavily on applications of physics and mathematics, even requiring some calculus knowledge to complete.

VI.1.1 Piezoelectricity

The team's first idea was to implement piezoelectricity as a renewable energy source into a portable battery. Since the team had no prior experience with piezoelectricity, research was required to understand the concept better. Below are the results of our research:

Piezoelectricity, also dubbed the Piezoelectric Effect, is a property materials, specifically those with crystalline structures, may possess that allows them to convert mechanical stress experienced by that material into electrical energy. This happens because a voltage difference is generated with the force applied, which gives way to an electric field and a current. This current will be proportional to the force exerted: the higher the force, the larger the current.

The team realized creating a piezoelectric harvester from scratch was unfeasible with the time, funds, and experience currently. Due to the microscopic nature of these materials, creating these generators will be impossible without the specialized equipment to do so. The team decided on purchasing premade generators and putting them together in a prototype to prove effectiveness before considering the potential of developing one.

However, during this research, the team decided piezoelectricity was not the correct pathway to take (see **Section VI.2.1**) and decided to switch to other methods of renewable energy that could produce a better output.

VI.1.2 Researching Batteries

In addition to research on piezoelectricity, the team did research on the inner workings of batteries. Since the project is to create a battery that is capable of self-charging fast enough to meet consumer demands, an understanding of how batteries work will be needed to effectively create the product. The summary of the research is below:

Batteries work by putting two different metals with different activity levels into a casing. When connected to a circuit, these two metals undergo a redox reaction, where one metal receives electrons and the other gives electrons, creating a current. Paired with the battery's internal resistance, the battery is able to create a voltage difference, and thus, run any electric circuit. A rechargeable battery works the same way a standard battery would but with one major difference: the redox reaction in the rechargeable battery is reversible. By running a voltage greater than that of the battery, the current can be reversed, returning the electrons from the receiving metal to the giving metal. Once recharged, the battery would be in a state where it can pump out more electrons and create a current.

From this, the team learned that the renewable energy source would need to output a high electric potential difference so it could adequately charge the battery. Without this high potential difference, the energy harvester will be unable to reverse the redox reaction inside of the battery.

VI.2 Calculations

VI.2.1 Proving Viability

Before the switch to solar panels, the team looked at various piezoelectric energy harvesters on the market and found many of them are very costly. However, the team was lucky to find one piezoelectric energy harvester that was both viable for the project in terms of dimensions and cost. However, charging capabilities, more specifically time, would need to be calculated by the team. The team decided to calculate the time it took to charge a cellphone battery as a benchmark for charge time, as many people are aware of the relative speeds of charging cell phones.

On the product specifications, it was stated the product could generate 0.7 mW of power with 6 V of potential difference under a load of 8 Gs. After doing some research and contacting a mentor, the team estimated that a footstep would put a 1G load on the sensors, meaning a total power of 0.0875 mW of power would be generated for every footstep. Using the definition of power in terms of voltage and current, the team got the equation

$$P = IV \qquad \textbf{Equation VI.2.1}$$

where P is the total power output, V is the voltage, or potential difference output, and I is the current output. Moving the variables around grants the equation

$$I = \frac{P}{V}$$ **Equation VI.2.2**

Plugging this expression in the equation for the definition of charge, or $Q = \int I\, dt$, yields

$$Q = \int \frac{P}{V}\, dt$$ **Equation VI.2.3**

where Q is the charge (battery charge capacity) and t is the total charge time. Since P and V are constants, they may be moved out of the integrand, yielding the equation

$$Q = \frac{P}{V} t$$ **Equation VI.2.4**

Rearranging the equation to solve for t yields

$$t = \frac{QV}{P}$$ **Equation VI.2.5**

However, this equation makes one fundamental assumption: the piezoelectric energy harvester is constantly harvesting energy, meaning the 1 G load put on the charger is constant. In reality, the load on the harvester is not constant: since humans walk on two legs, the load put on the harvester will only be a proportion of the time, meaning a coefficient μ would need to be added to account for the difference.

$$t = \frac{QV}{\mu P}$$ **Equation VI.2.6**

The difference in the load throughout the step was considered to be negligible.

With the completed equations, the next step would be to determine the two other constants. Since people take steps on two legs, the team decided to set μ to 0.5 as each foot would be experiencing a step for half of the duration of the walk. For the charge, the team decided to use the capacity of the iPhone 14 Pro Max as it is a good middle point: many phones have a lower battery capacity, but plenty of phones also have a high battery capacity. The iPhone 14 Pro Max has a battery capacity of 4323 mAh, or 15563 C. With these constants, the charge time can be calculated.

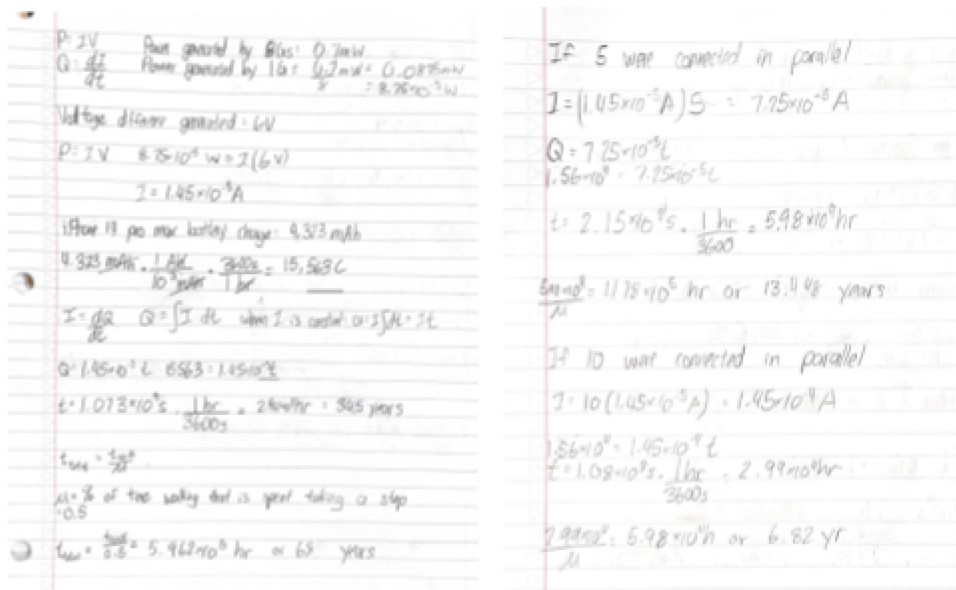


Figure VI.2.1 outlines the completed calculations of the charge time the piezoelectric energy harvesters require to fully charge an iPhone 14 Pro Max battery.

The calculations made it clear that piezoelectricity was too insufficient to be a viable solution. The numbers in **Figure VI.2.1** showed that even with 10 generators connected in parallel, it would still take up to 7 years to fully charge the battery of an iPhone 14 Pro Max. Additionally, the equations ignore any potential energy loss that would occur in the process of charging, which later will prove to be significant. The team decided to switch to a different solution.

The next solution the team looked into was solar energy, which had more promises. Before the team could make a decision matrix to justify the use of a specific solar panel, they would need to prove solar power's effectiveness first. The team chose one of the four candidates and plugged the specifications into the equations to prove effectiveness. The specification sheet claimed the solar panel could output a maximum of 0.3 W and 2V under direct sunlight. **Equation VI.2.5** was chosen over **Equation VI.2.6** to calculate the charge time since μ would be unnecessary with the solar panels.

Competitor 2 ($5.50 each) 52×52×1.6mm 8g
0.3W 2V
$t = 1.56 \times 10^4 \left(\frac{V}{P}\right) = 1.56 \times 10^4 \left(\frac{2}{0.3}\right) = 10400\,s$ or 29 hours of sunlight

3 connected in parallel
0.9W 2V

$t = 1.56 \times 10^4 \left(\frac{2}{0.9}\right) = 34667\,s$ or 9.6 hours of sunlight

4 connected in parallel
1.2W 2V

$t = 1.56 \times 10^4 \left(\frac{2}{1.2}\right) = 26000\,s$ or 7.22 hours of sunlight

6 connected in parallel
1.8W 2V

$t = 1.56 \times 10^4 \left(\frac{2}{1.8}\right) = 17333\,s$ or 4.8 hours of sunlight

10 connected in parallel
3W 2V

$t = 1.56 \times 10^4 \left(\frac{2}{3}\right) = 10,400\,s$ or 2.89 hours of sunlight

Figure VI.2.2 outlines the completed calculations of the charge time the solar panels require to fully charge an iPhone 14 Pro Max battery.

Although the time of 2.89 hours from **Figure VI.2.2** does not account for any energy loss inside the system, it is a good starting point to prove that solar panels are viable to create a portable charger that can meet consumer demands. Even if the loss of energy substantially affects the charge time, it is still much better than many solutions currently available.

VI.2.2 Calculating the power output of the final product

When deciding a path to go down, the team needed a more accurate formula to better predict charge time with more precision than the one presented in **Figure VI.2.2**. After consulting with the team's mentor, the team came up with an equation to calculate the ideal output of a solar panel.

$$P_s = k\eta A \qquad \textbf{Equation VI.2.7}$$

where k is the solar constant, adjusted at the surface of the earth, η is the solar panel efficiency, A is the solar panel surface area, and P_s is the power outputted by the solar panel. However, there are other inefficiencies that will reduce the power outputted by the solar panel. Most notably, the angle of the sun, θ, and the cloud coverage, a can affect the total power output. Put together, the equation yields

$$P_s = k\eta A\left(a \cos \theta\right) \qquad \textbf{Equation VI.2.8}$$

With the power output of the solar panel, the voltage output, V, of the panel can be found by looking at the power-voltage relationship graphs in the specification sheet of the solar panel.

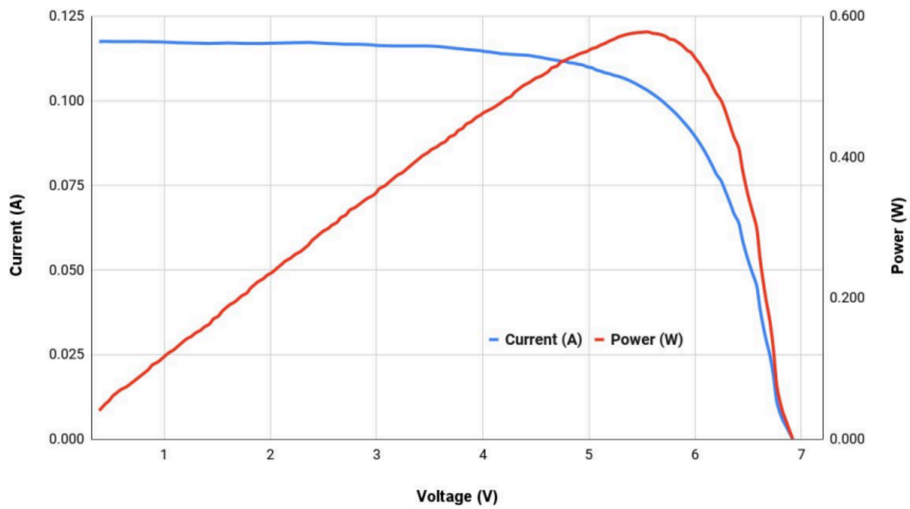


Figure VI.2.3 shows the relationships between power and voltage and current and voltage, as found on the specification sheet.

Lastly, one last coefficient was added to the calculation, that being the charge efficiency. Batteries can only store a fraction of the power inputted into the battery, which has a substantial effect on the charge time. The efficiency of the battery can be calculated with

$$b = \frac{P}{P_s} \qquad \textbf{Equation VI.2.9}$$

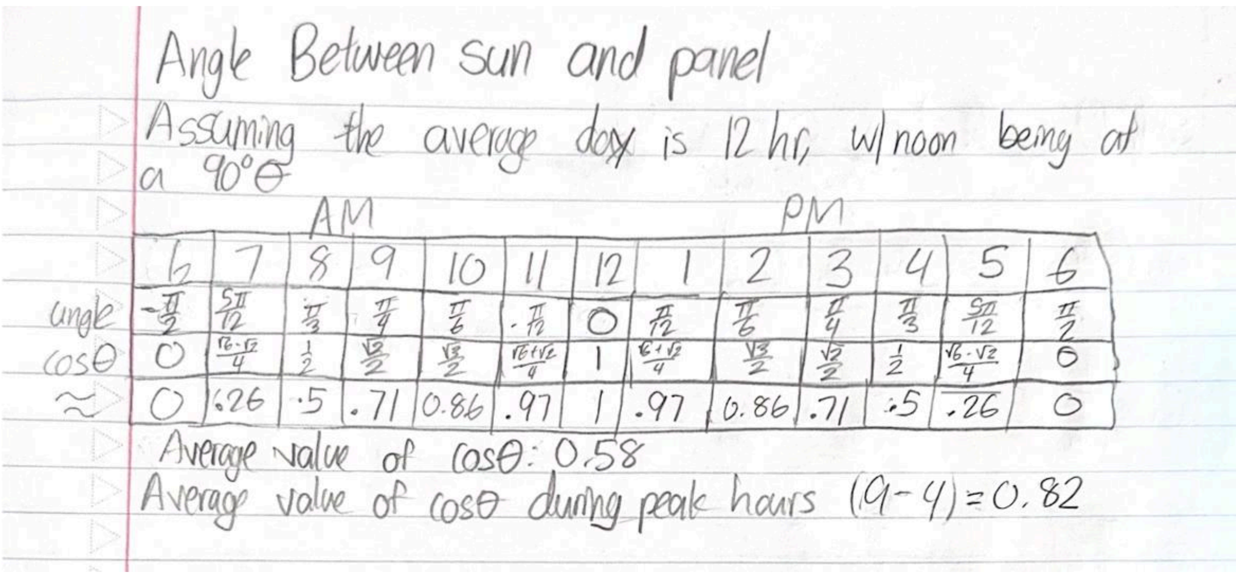
where b is the charge efficiency and P is the total power used to charge the battery after considering inefficiencies. Rearranging the variables yields the equation

$$P = bP_s \qquad \textbf{Equation VI.2.10}$$

Plugging **Equation VI.2.8** into **Equation VI.2.10**, then plugging that into **Equation VI.2.5** yields

$$t = \frac{QV}{k\eta A(ab \cos \theta)} \qquad \textbf{Equation VI.2.11}$$

The next step is to find the many constants added to the equation. After some research with the team's mentor, the team found that the solar constant, k, adjusted for factors at the surface of the earth, is around 1000 W/m^2. The average charging efficiency of most batteries, b, is around 70%, or 0.7. Since k is adjusted to the surface of the earth, a could be assumed to be 100% under direct sunlight. The specification sheet provided the surface area, A, of the solar panel and the efficiency, η, of the solar panel, being 0.0031 m^2 and 0.239, respectively. The team created a table for the average angle of sunlight throughout the day and found an appropriate average for cos θ would be 0.58 throughout the whole day and 0.82 during peak hours of the day, when the solar panel is most likely to be used. Lastly, all the numbers were plugged into the formula, yielding the final estimate for the charge time.


Angle Between sun and panel

Assuming the average day is 12 hr, w/ noon being at a 90° θ

	AM							PM					
	6	7	8	9	10	11	12	1	2	3	4	5	6
angle	$-\frac{\pi}{2}$	$\frac{5\pi}{12}$	$\frac{\pi}{3}$	$\frac{\pi}{4}$	$\frac{\pi}{6}$	$\cdot\frac{\pi}{12}$	0	$\frac{\pi}{12}$	$\frac{\pi}{6}$	$\frac{\pi}{4}$	$\frac{\pi}{3}$	$\frac{5\pi}{12}$	$\frac{\pi}{2}$
$\cos\theta$	0	$\frac{\sqrt6-\sqrt2}{4}$	$\frac{1}{2}$	$\frac{\sqrt2}{2}$	$\frac{\sqrt3}{2}$	$\frac{\sqrt6+\sqrt2}{4}$	1	$\frac{\sqrt6+\sqrt2}{4}$	$\frac{\sqrt3}{2}$	$\frac{\sqrt2}{2}$	$\frac{1}{2}$	$\frac{\sqrt6-\sqrt2}{4}$	0
$\approx$	0	.26	.5	.71	0.86	.97	1	.97	0.86	.71	.5	.26	0

Average value of $\cos\theta$: 0.58

Average value of $\cos\theta$ during peak hours $(9-4) = 0.82$

Figure VI.2.4 shows how the team put many possible values of cos θ on a table and averaged them to get 0.82 as the estimated effect of the sun's angle.

Under peak hours on a sunny day

$k = 1000 \quad a = 1$ | P_s = Power generated

$\eta = 0.289 \quad b = 0.7 \quad P$ = Power used to charge

$A = 0.0031 \quad \cos\theta = 0.82$

$$P_s = 1000(0.289)(0.0031)(0.82)$$

$$P_s = 0.6 \qquad V = 5.5$$

$$P_s = IV$$

$$\frac{P_s}{V} = I \qquad \int \frac{P_s}{V}\,dt = \int I\,dt$$

$$\frac{P_s t}{V} = Q \qquad P_s = Pb \qquad \frac{Pbt}{V} = Q$$

$$Q = 15600$$

$$15600 = \frac{0.6b\,t}{5.5} \qquad t = 204\,285 \text{ or } 57\text{ hr}$$

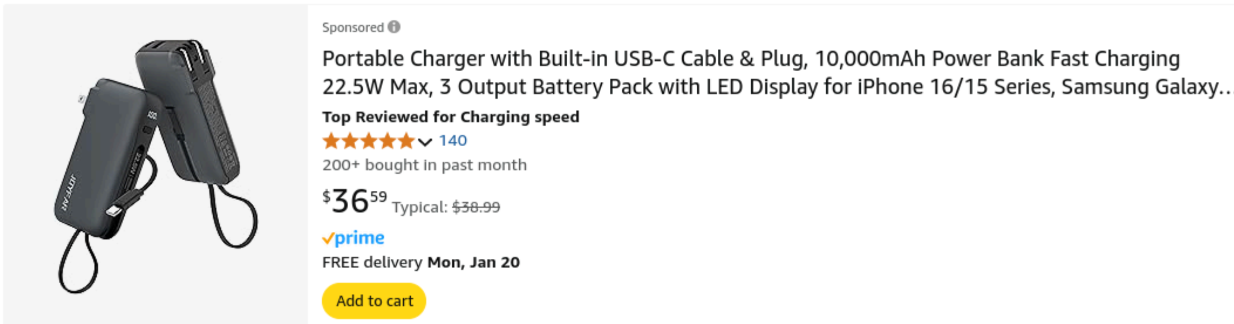
10 connected in parallel

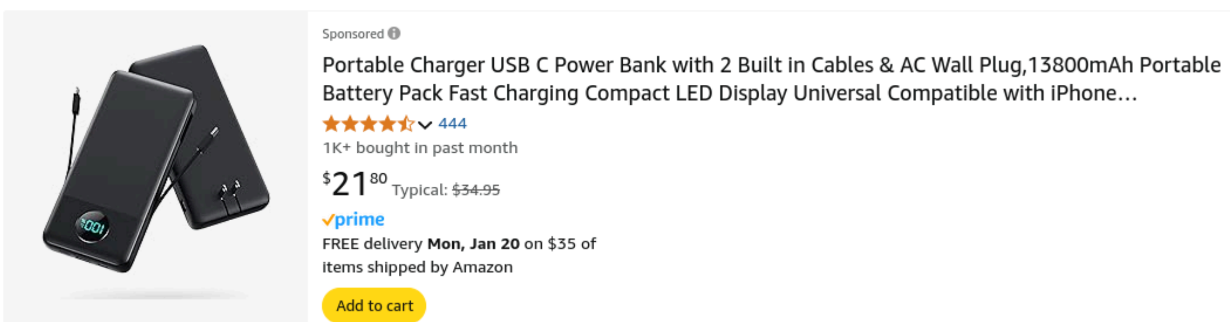
$$15600 = \frac{6bt}{5.5} \qquad t = 20\,429 \text{ or } 5.7\text{ hr}$$

Figure VI.2.5 outlines the calculations the team did to find the final estimated charging time of the solar panels to charge an iPhone 14 Pro Max.

The calculations showed the viability of adding solar panels on a portable charger, as the average charge time is estimated to be 5.7 hours. Current products on the market require several days to fully charge the battery, which in return, can fully charge the batteries of around 3-4 phones. This means it may take days before these batteries can harvest enough energy for one singular phone. However, this design, with its short charge time, will likely be able to charge more than 2 phones in one day during ideal conditions and at least 1 phone during normal conditions every day.

VII. Final Viability Analysis





Existing products in this category demonstrate strong performance and high sales figures, indicating consistent demand and a robust market. However, there is clear potential for improvement and differentiation within this space. Our proposed product introduces an innovative solution to a common challenge: ensuring access to power regardless of location or circumstances. For individuals who may forget to charge both their phone and portable battery, our device provides a reliable alternative by utilizing solar energy. Designed to be placed outdoors, it efficiently converts sunlight into power, offering a sustainable and convenient charging option. Many existing solar chargers perform well and are popular among consumers, but they still have limitations—especially when users forget to charge their devices or backup batteries. This new solar panel offers a reliable solution by using sunlight as a consistent power source, making it ideal for outdoor use or emergencies.

What sets this design apart is its **extendable flaps**, which increase the total surface area exposed to sunlight. This feature allows it to **capture more solar energy** and **charge devices faster** than most current models. By combining portability with improved efficiency, this solar panel provides a smarter and more dependable way to stay powered on the go.

VIII. Prototype Construction Plan

VIII.1 Identifying Subsystems

VIII.2 Subsystems: Form Factor

VIII.3 Subsystems: Solar Panels

VIII.4 Final Integration

Subsystems Testing:

Fully Body and Hinges

1. Hinge Testing:
    - Various CAD designs of hinges will be 3D-printed and evaluated for sturdiness and flexibility.
    - Stress testing will be performed on each hinge type to determine the most durable option.
2. Full Body Testing:
    - Once the best hinge design is chosen, the entire form factor will be 3D-printed.
    - Flaps will be attached and assessed for ease of movement and secure closure.
    - Wire channels and solar panel slots will be tested for proper alignment and accessibility.

Solar Panel Testing

1. Individual Panel Testing:
    - Each solar panel will be tested separately to confirm proper functionality.
    - A voltmeter will measure the output voltage of each panel under controlled lighting conditions.
    - Panels that produce insufficient voltage will be replaced or optimized with repositioning.
2. Voltage Regulation Testing:

- If voltage output is inconsistent or too low, a voltage booster will be introduced and tested for efficacy.
- The booster's performance will be evaluated using a voltmeter before integrating it into the full system.

3. Parallel Connection Testing:
   - Once all panels are verified, they will be connected in parallel to maintain a stable voltage output.
   - The output voltage of the parallel-connected panels will be measured using a voltmeter.
   - A voltage regulator will be introduced to ensure a consistent and safe output.
   - The final voltage will be tested again to confirm system viability.

Final Integration Testing

1. Panel Installation:
   - Solar panels will be mounted onto the designated slots on the flaps.
   - Wiring will be secured and tested for continuity.
2. Functional Testing with Portable Charger:
   - The solar panel system will be connected to a standard portable charger.
   - Charging efficiency will be monitored under different lighting conditions.
   - Potential overheating or inefficiencies will be documented and addressed.
3. Stress and Durability Testing:
   - The assembled prototype will undergo mechanical stress testing to evaluate hinge performance under repeated use.
   - Environmental exposure tests will be performed to assess durability.

IX. Prototype Development, Data Collection, and Analysis

IX.1 Form Factor Development

The first part of the prototyping process was to develop the form factor that can meet the criteria and constraints and fit all the necessary electronic components securely and safely. The flaps will need to be able to open and close easily but only when desired; otherwise, they should not be able to open or close at all. Ensuring a well-developed form factor will be key in the project's success.

IX1.1 Identifying Criteria, Constraints, and Needs

Basic criteria and constraints were listed out in **Section IV.2**, but more specific criteria and constraints would be needed before development started. According to the data sheet, the solar panels measured 66 x 66 ± 0.5 mm in area and 3.1 ± 0.5mm in thickness. Since the flaps were going to contain 2 solar panels, it meant the flaps would need to be larger than 132 x 66 ± 1 mm and thicker than 3.1 ± 0.5mm. Hoping to get a clearance fit, the team decided on allocating an area of 135 x 67 mm to allow the solar panels to fit in snugly. Each end was then extended outwards by 10mm, giving a total flap area of 155 x 87 mm, which is only marginally larger than many modern smartphones.

Determining the thickness of the flaps required another measurement: the gauge of the wires being used. Since the wires will be incorporated into the flaps, the thickness of the wires will be added with the thickness of the panels to yield a minimum thickness of the flaps. A simple dial calliper measurement yielded a gauge of 0.03 ± 0.005 in, or about 0.8 ± 0.13 mm, making the minimum thickness 3.9 ± 0.63 mm. Taking tolerance and stability into consideration, the team decided to set the thickness of the flaps to be 6 mm. Although this would mean the overall thickness will be slightly larger than the original constraint of 3 cm, it would allow for a more secure form factor.

Another criterion that required more details was the criterion requiring smoothed edges. It was decided that the corners not only be rounded out, but also chamfered to further remove risks of injury by the sharp corners. The flap was chamfered by 10 mm on all four corners (see **Figure IX.1.5**), then further rounded out by 1 mm to further minimize the risk of injury. The perimeter of the flaps were also rounded out by 2.5 mm, leaving no sharp edges exposed to the consumer.

Lastly, the clearance between pieces needed to be identified. Based on the team's experience, they decided the clearance between pieces would be 1 mm to allow easy clearance for the hinges. However, as the team started developing, they realized that although a 1 mm clearance was an appropriate choice for the hinges, it was wide to use as the clearance between flaps. If there was 1 mm of space between each gap, the final product would feel uneven, so the team decided to set the clearance between the flaps to be 0.5 mm.

IX.1.2 Developing the Hinges

The hinges were first developed based on a cylindrical hole with a concentric cylindrical rod in the middle. First mock-ups of this design were solely to ensure the flaps would open and close properly, so no considerations of stability or assembly were taken into account. Two concentric cylinders were extruded with the larger one having a concentric hole in the center to fit the smaller concentric cylinder. A total of 1 mm of tolerance was set between the two bodies. The inner cylinder connected to one of the flaps and the outer cylinder was extruded downwards to be connected to a second flap. Doing this ensured the flaps could open and close without getting in the way of each other.

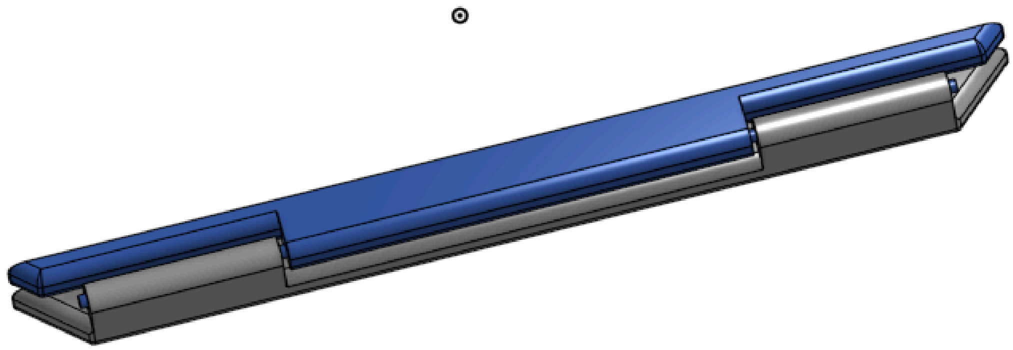


Figure IX.1.1 shows the very first mock up of the hinges. They were designed to solely work as hinges with ample tolerance.

The main issue with the first iteration is that the inner cylinder, or the rod, was too fragile and could easily snap under all the potential force, which gets converted into torque, the flaps or outer cylinder, could impart on the rod. To address this problem, the team added support to the ends of the rods that were secured to the flaps, greatly reducing the torque that would be imparted by any force.

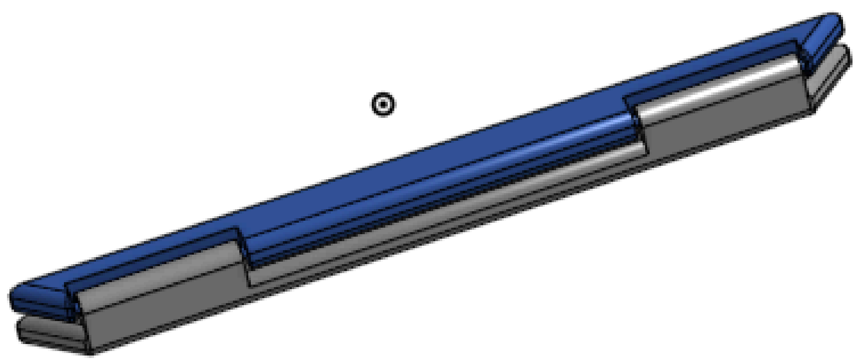


Figure IX.1.2 shows the new supports added to the ends of the rod to strengthen the rod and prevent it from snapping.

Another issue the team met was the assembly of the hinges. The current design did not allow for the assembly of the hinges without spitting each component of the hinge into multiple different assemblies, which would require adhesives or fasteners to keep together. This in turn would also compromise the sturdiness of the flaps. The team took inspiration from a clip system designed by Lego to solve this problem. Lego already had rods and clips that could be connected and disconnected freely, yet rotate smoothly and rarely disconnected unintentionally. By developing a clip system, albeit a tighter clip system, the hinges could be assembled together easily while maintaining its sturdiness.

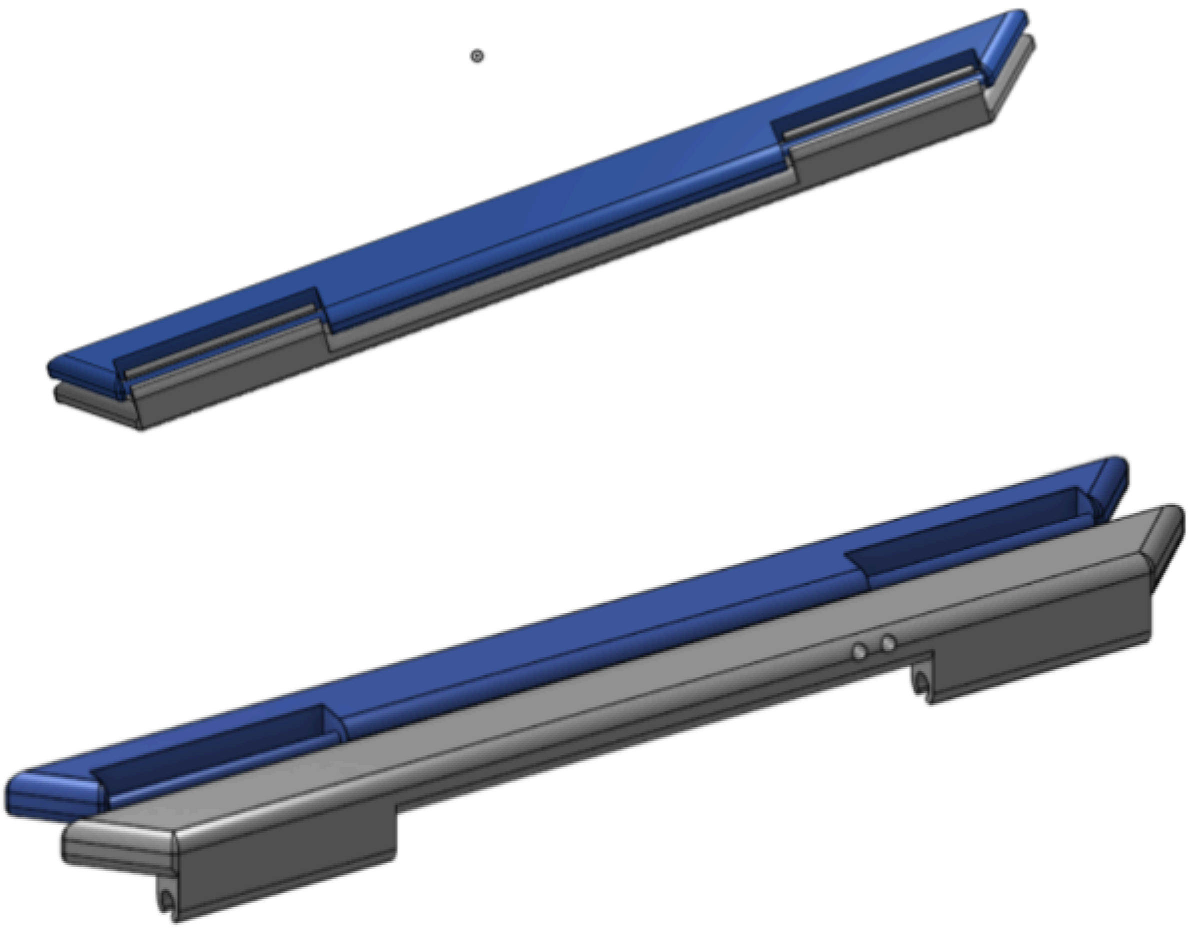


Figure IX.1.3 shows the hinges with the clip system. The clips were designed by simply extrude-cutting part of the top of the outer cylinder to allow space to assemble the hinges. The holes were for the wire pathways, covered in **Section IX.1.3**.

The last iteration of the hinges came when the team printed and assembled entire flaps together. The team realized that since one of the sides of the hinges was secured to a flap, there was a limit on how far the hinges could rotate. The design was very susceptible to damage due to overextension. As a result, the rod design was implemented on both sides of the hinges with a clip in the middle to serve as a connector. This not only allowed full 360-degree rotation freedom but also decreased the needed stress on the wires connecting the panels on different flaps.

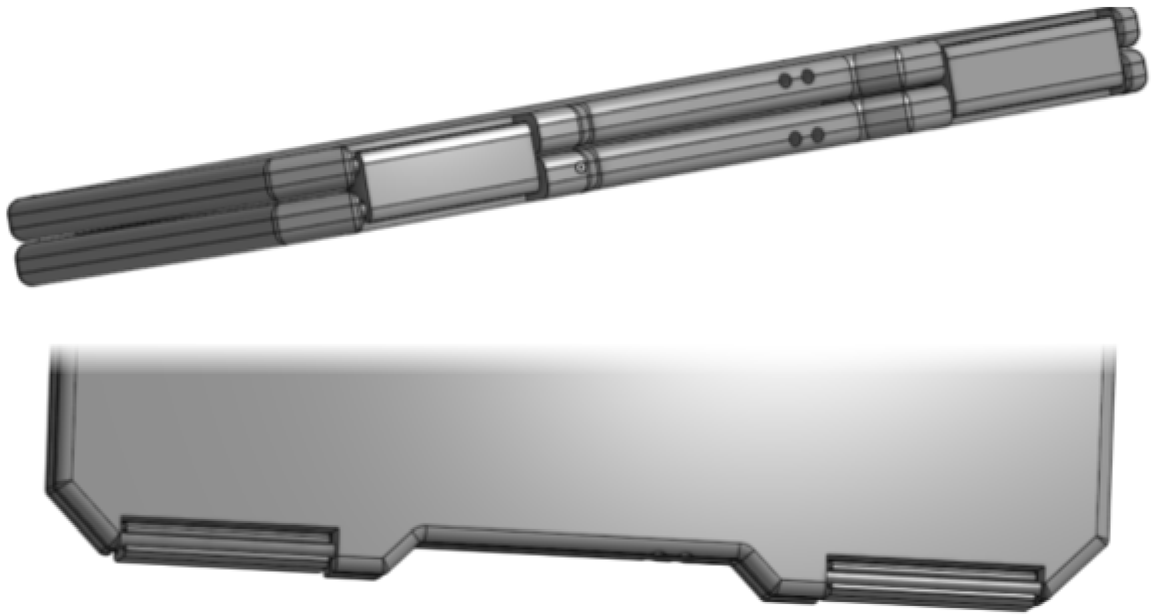


Figure IX.1.4 shows the final design of the hinges incorporated into the flaps. There are rods incorporated into the flaps and a clip piece that connected the two together, which prevented the issues of overextension of previous designs.

IX.1.3 Developing the Flaps

Once the hinges were completed the next step was to develop the flaps. The flaps were created by creating a rectangular prism with the dimensions 155 x 87 x 6 mm. Corners were chamfered in by 10mm and further filleted with a radius of 1 mm. The perimeter was also filleted with a 2.5 mm radius, leaving no exposed sharp edges on the body. Rods and clips were added on appropriate sides of the flaps depending on the needs of each flap.

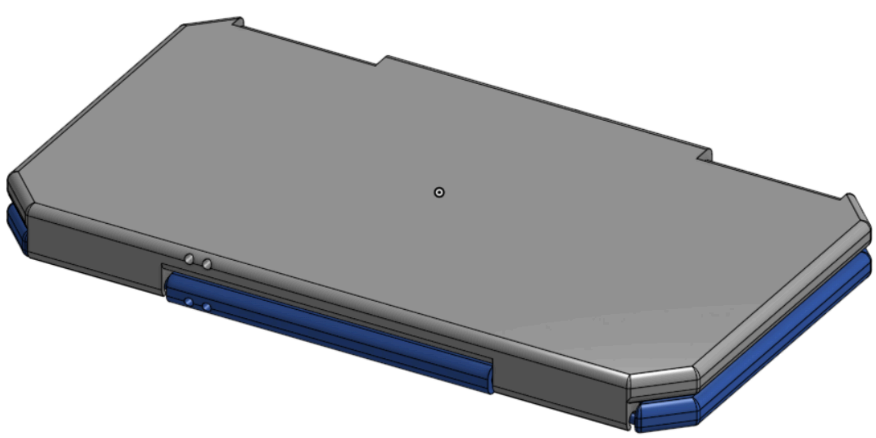


Figure IX.1.5 shows the first iteration of the flaps from the outside.

On the inside of the flaps, holes were cut in to allow the solar panels room to fit inside the flaps. Inside those holes, additional holes were cut out to allow space for the wires to run from panel to panel and flap to flap. The wire paths ensured every panel could be connected in parallel and guided the wires from both end flaps to the central battery.

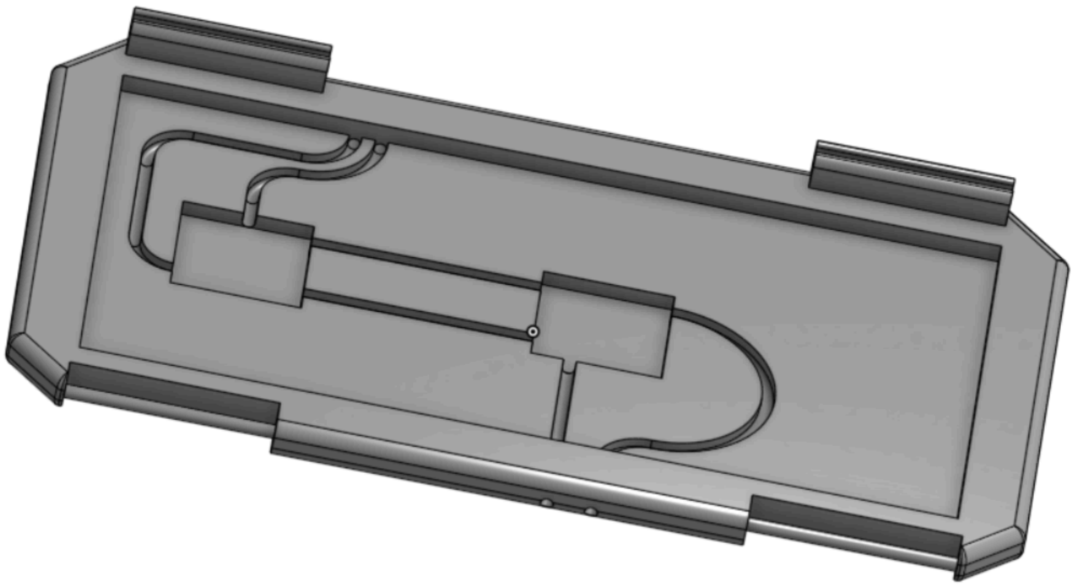


Figure IX.1.6 shows the holes cut out for the solar panels and the wiring pathways.

Figure IX.1.7 shows the part of the flaps that were printed out. The section selected to be printed included some hinges and the exit holes of the wire pathways, which would be where wires connected the panels of different flaps together.

The team printed a small part of the flap containing the hinges to test the hinges' viability, which revealed some issues with the current design the team had. As laid out earlier, the fixed clips on the flaps posed weak points in the hinges and the clips were modified to not be fixed to any flap. Another issue that arose was the amount of space between flaps for the wires. Upon attempting to open the flaps, the wires would prevent the hinges from opening. The first solution the team brainstormed was to cut the material between the two hinges holding the flaps together, giving more space for the wires to bend and allowing the flaps to open. However, upon testing that concept, the team realized substantial stress was being applied to the wires, which could potentially damage them.

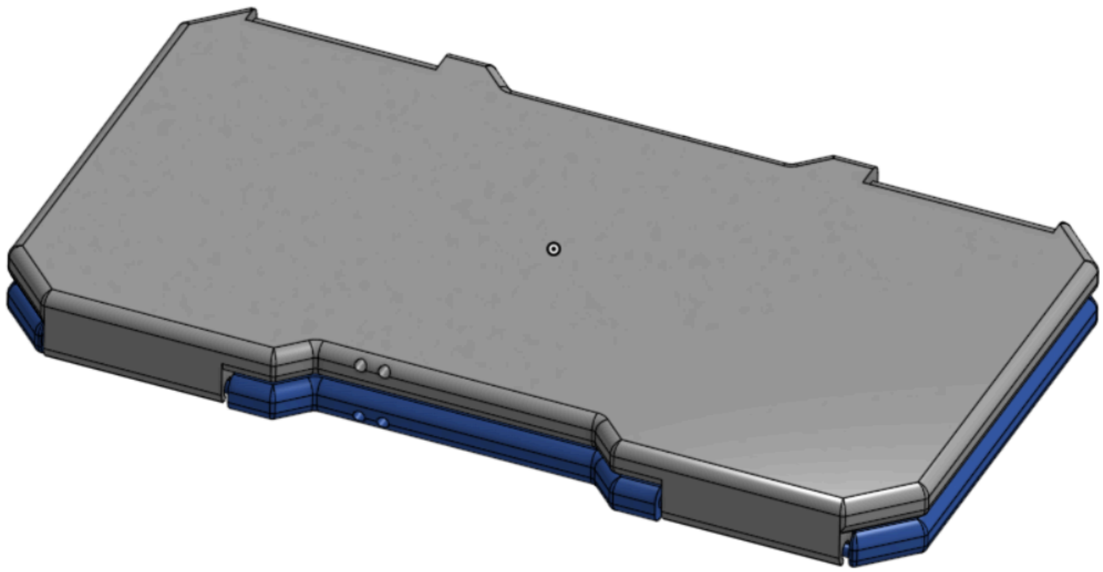


Figure IX.1.8 shows the first idea to solve the issue with the wires preventing hinges from opening. Although this provided a solution, it was not the best solution as parts could be easily damaged from overuse.

The team then realized the issue would be solved by a combination of two concepts introduced: the new hinge design and the cut material between the hinges. The new hinge design gave more rotational freedom to the flaps, which allows them to open without inducing as much stress on the wires as the old hinge design. These last additions solved most of the problems faced with the flaps and came together to make the finalized design.

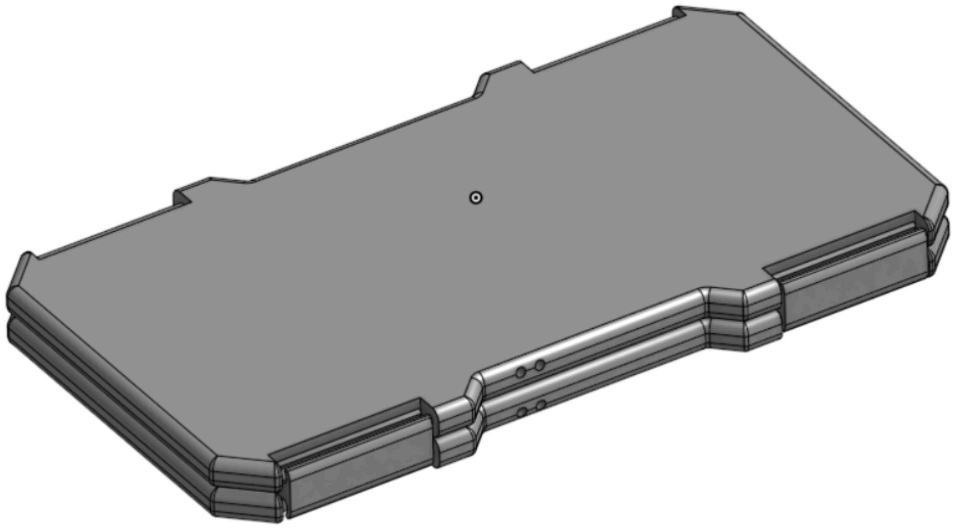
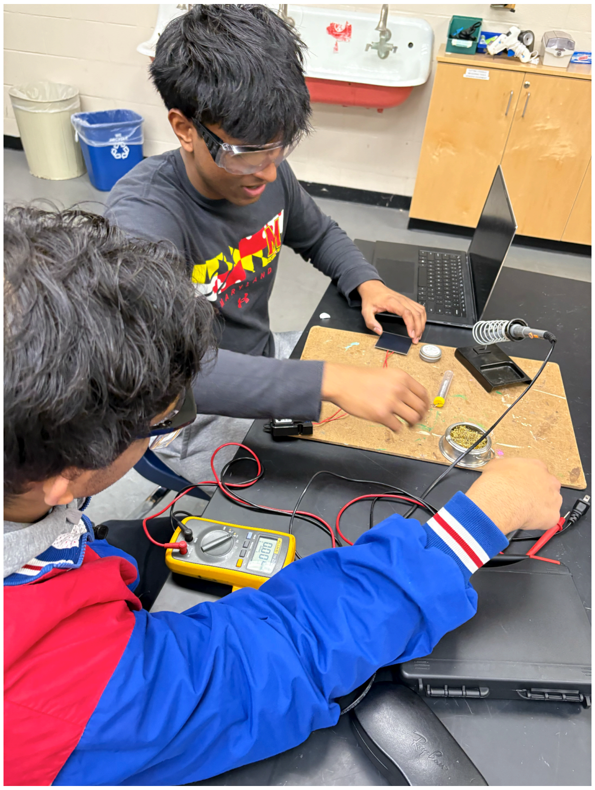
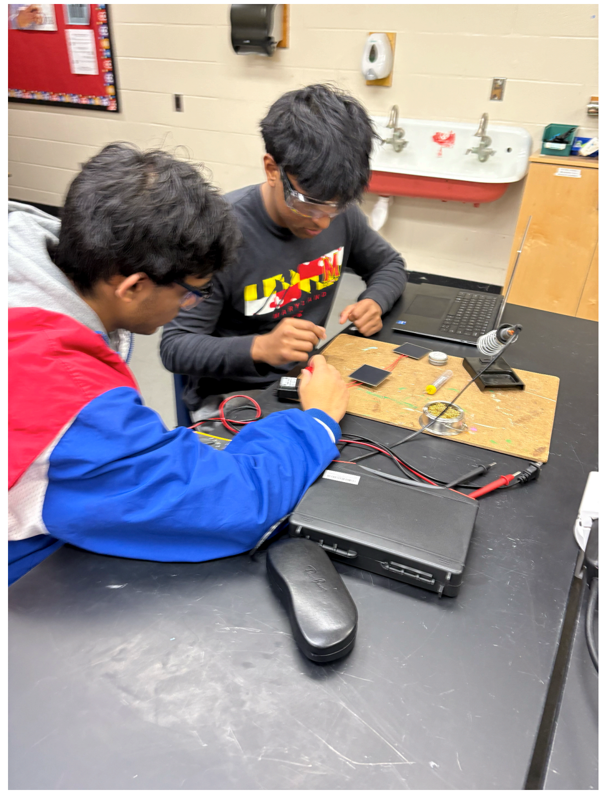


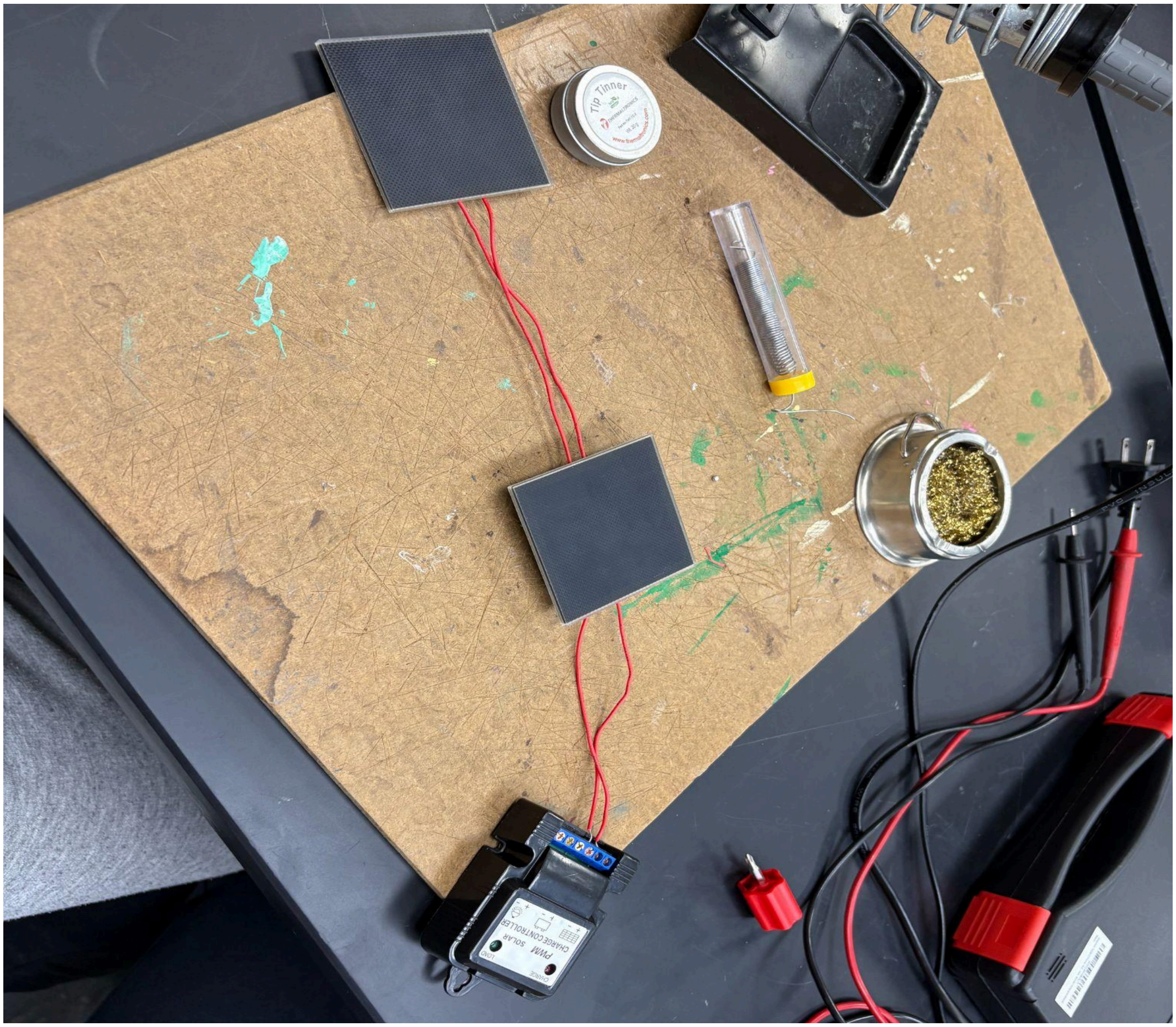
Figure IX.1.9 shows the finalized flap design. Although only 2 flaps are shown, a total of 4 flaps will be needed in addition to the main body.

IX.2 Electrical Component Development

Once the main body of our prototype was created, we moved on to the solar panel themselves. In order to maximize the voltage of our prototype, we needed to connect our solar panels in a parallel configuration. Below are the images of the soldering that we did to carry out this process.



The solar panels have a wire that is coming out at the end because this will be attached to the regulator. Below is an image of the finalized connections. We are currently working on finalizing the connections for the rest of our panels, and we will connect them all in a parallel fashion.



Now that we have finalized the creation of all our subsystems, we are currently working on integrating them all together into the final prototype.